CHAPTER – 3

ELECTRICAL PROTECTION SYSTEM

3.1 DESIGN CONSIDERATION

Protection system adopted for securing protection and the protection scheme i.e. the coordinated arrangement of relays and accessories is discussed for the following elements of power system.

i) Hydro Generators
ii) Generator Transformers
iii) H. V. Bus bars
iv) Line Protection and Islanding

Primary function of the protective system is to detect and isolate all failed or faulted components as quickly as possible, thereby minimizing the disruption to the remainder of the electric system. Accordingly the protection system should be dependable (operate when required), secure (not operate unnecessarily), selective (only the minimum number of devices should operate) and as fast as required. Without this primary requirement protection system would be largely ineffective and may even become liability.

3.1.1 Reliability of Protection

Factors affecting reliability are as follows;

i) Quality of relays
ii) Component and circuits involved in fault clearance e.g. circuit breaker trip and control circuits, instrument transformers
iii) Maintenance of protection equipment
iv) Quality of maintenance operating staff

Failure records indicate the following order of likelihood of relays failure, breaker, wiring, current transformers, voltage transformers and D C. battery. Accordingly local and remote back up arrangement are required to be provided.

3.1.2 Selectivity

Selectivity is required to prevent unnecessary loss of plant and circuits. Protection should be provided in overlapping zones so that no part of the power system remains unprotected and faulty zone is disconnected and isolated.

3.1.3 Speed

Factors affecting fault clearance time and speed of relay is as follows:

i) Economic consideration
ii) Selectivity
iii) System stability
iv) Equipment damage

3.1.4 Sensitivity

Protection must be sufficiently sensitive to operate reliably under minimum fault conditions for a fault within its own zone while remaining stable under maximum load or through fault condition.

3.1.5 Protection Zones

Overlapping zones of protection are provided so that no part of power system remains unprotected. The point of connection of the protection with the power system normally defines the zone boundary and generally corresponds to the position of the current transformers. Current transformers if provided on both sides of circuit breaker overlap Figure 3.1 (a). If they are provided on one side blind spots occur Figure 3.1 (b). Fault between CT and the circuit breaker will not trip the feeder CB and fault current will continue to flow until cleared by back up protection.

3.1.6 Primary and back up Protection

The design of a protective system should include backup protection to allow for failures and for periodic maintenance of the interrupting devices, sensing devices, and protective relays. Backup protection may be either remote or local or it may be a combination of both schemes. Remote backup protection consists of relays that are set to respond to faults in the next zone of protection. This type of protection is relatively slow as it should allow time for the primary relaying in that zone to operate. It also may cause interruption to large portions of the electric supply system.

In some cases, local backup protection is justified. Local backup consists of two sets of independent primary protection and breaker-failure relaying. Ideally, this should include two independent sets of current transformers, voltage transformers, protective relays, and breaker trip coils, but only one breaker-failure relaying system is required. Each protective relay system should be isolated so that a failure in one will not affect the other. Among other things, this requires that the control power for each system be supplied from separate low-voltage circuit breakers or fuses.

Two forms of back up protection are provided. These are protection failure or circuit breaker failure. Best form of back up protection for any system is one in which both ac and dc supplies are completely separate from main protection. Economic consideration determines the extent to which back up protection is provided.

3.1.7 Fault Data

Protective relay systems measure the current, voltage, or a combination of current and voltage during fault conditions. Fault current magnitude, and the associated change in voltage, varies with the type of fault and with the location of the fault with respect to the sensing devices.

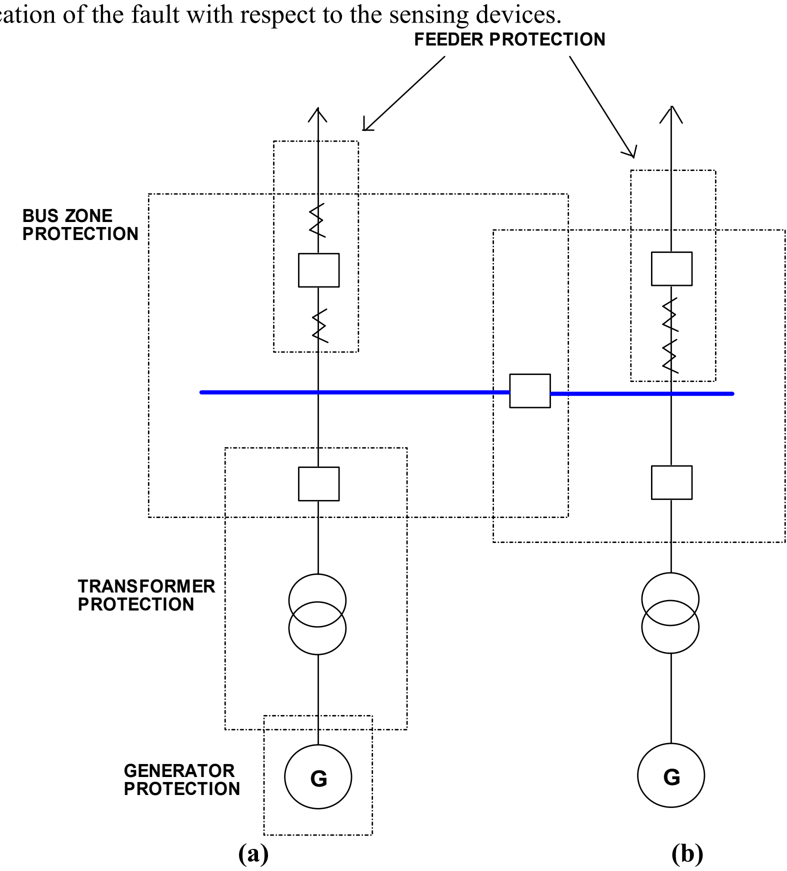


Figure 3.1

Therefore, a study of the types of faults that can occur is important to ensure that the selected protection system can detect and isolate all faulted portions of the electric system. The types of faults that should be considered are three-phase, phase-to-phase, double-phase-to-ground, and single-phase-to-ground.

3.1.8 Fault Current Versus Load Current

In most cases, fault exceeds normal load current by a factor of 2 or more. However, special consideration should be given to situations where load current is greater than fault current. For example, on systems that are grounded through a neutral impedance, the ground fault current is lower than the normal load current magnitude. For this situation, the use of separate ground fault relaying is required.

High-voltage phase over-current devices should not respond to maximum load current because these devices are applied to provide protection for short-circuits but not for maximum loads. Conductors, transformers, and other current-carrying devices should be rated to carry the maximum expected load, taking into account load profiles, diversity, and short time equipment ratings. Occasionally, special overload protection is provided for high-voltage equipment, but this should generally be avoided because of the difficulty of coordinating these schemes while maintaining reliable operation of the power system. However, overload protection is required for low-voltage equipment.

3.1.9 Circuit-Interrupting Devices

Fuses are single phase protective devices that combine sensing and interrupting functions into a single unit. Fuse operation is based on the magnitude and duration of current flowing in each phase of the circuit. The primary application considerations include maximum load, minimum and maximum fault current available, interrupting rating, operating time of the fuse relative to the operating time of protective devices on both the consumer and utility systems, and the effects of single-phase supply due to the operation of one fuse. Miniature circuit breakers are replacing fuses.

A circuit breaker is an interrupting device designed for normal switching functions as well as for fault interruption. Circuit breakers offer considerable flexibility and are available in variety of voltage, current, and fault current interrupting ratings. High-voltage circuit breakers are equipped with separate electrically operated close and trip coils that can be controlled by any required protection and control package. Low-voltage circuit breakers can be equipped with shunt trip devices but are usually self-contained with integral thermal magnetic or solid-state trip units.

A considerations in the application of interrupting devices is the source of control power for the close and trip coils. A station battery is considered the most reliable source of dc control power, because battery output voltage is not affected by the ac voltage drop that can occur during short-circuit conditions. A capacitive trip device will store energy for a short period of time that is sufficient to trip a breaker. This device may be used under circumstances when it is not practical to use a battery. When capacitive trip is used, the power to both the trip and close circuits is AC. The location of the ac source must be on the utility side of the main beaker to ensure power is available to close the main breaker.

3.1.10 Sensing Devices

Protective relay must be isolated from the high-voltage system but require current and voltage quantities proportional to those on the electric supply system. The standard ratings for protective relays are normally 5 A and 110 V, 50 Hz. Current and voltage transformers produce these relay input quantities and discussed in chapter 3.2.

3.1.11 Type of Protective Relays

There are many types of protective relays and protection schemes available. The types of protective relays that are usually used for various elements of hydro station are discussed in the respective sections of this chapter.

The relays discussed apply the relay function. The specific relays used can be either of electro-mechanical, solid-state, or microprocessor-based design (Refer 1.6).

3.1.12 System Studies

3.1.12.1 Types of Studies

Studies of an electric system should be conducted to provide the generation authority and the consumer with information regarding normal and abnormal conditions on the system. Studies performed to determine requirements for design of the protection system include load flows under maximum and minimum conditions, short-circuit and stability studies. These studies provide fault current magnitude; required clearing time data; data needed for proper selection of equipment such as CTs, interrupting devices, and protective relays; and data required for calculating the settings of protective devices.

Most of the hydro generators are grid interconnected. Fault current data is required to apply protective devices and to determine the required ratings of interrupting devices. The generation authority should provide the consumer with the minimum and maximum three-phase and phase-to-ground short-circuit duty (and associated X/R ratios) at the grid interconnection point for initial conditions (and any future conditions). Short-circuit contributions should be obtained from the state/grid substation owners. This information should be expressed in a form such that it is possible to determine the grid contribution alone.

Load flow studies are essential prior to performing stability studies; they are also important if there are multiple connections between the powerhouse and the grid. Stability studies that take into account system dynamic characteristics are typically performed by utilities when specific major changes occur in generation levels or transmission system configuration. The installation of a consumer facility with significant generation or load may justify a stability study of the new electric system configuration. Adding generation may need to perform a separate stability study to examine the dynamic response of this equipment to disturbances within the plant.

Power plant owners may perform load flow studies in order to determine the best method of supply, and to identify changes to their facilities or operating practices that may be required due to a large consumer installation. In some cases, a transient analysis study may be required to determine impact of a change in the switching sequence for energizing or reclosing a transmission line or transformer, or because of the installation of capacitors or reactors. The application of under frequency relays may require a special study to determine the frequency variation and decay rate associated with particular system disturbances. Even if special studies are performed at the time of each hydro generator interconnection, the database used for planning and operating studies should be updated as new facilities are installed, so that the cumulative effect of numerous interconnections will be considered in future studies.

Studies may be required to determine if any transmission line overvoltage problems will occur under certain switching conditions. Ungrounded high-voltage transformer connections (e.g., delta-connected windings) in combination with consumer low-voltage synchronous motor loads and/or generation can introduce severe transient over voltage if the power plant end of the transmission circuit trip with the consumer's transformer still connected. These transient overvoltages can be considerably higher than the times line to neutral voltage normally expected for unfaulted phases on a delta system when there is a single-line-to-ground fault. In extreme cases, tripping at the grid and terminal of the transmission line must be delayed to ensure that the remote consumer end is tripped first by direct transfer trip facilities.

3.1.13 Required Data

The basic data required for all electric studies is the positive. Negative, and zero-sequence impedance values of each system element, including generators, transformers, motors, cables and lines. For generators and synchronous motors, the transient and subtransient reactances are also required. The most common method of presenting this required data is in per unit or percent. The required data are often shown on a one line diagram covering all associated facilities.

3.1.14 Performance of Studies

Essentially, all system studies are computer based using generalized application software. The type and complexity of studies to be performed will generally determine who will conduct the study. Regardless of who performs the study, any results that impact on the design or operation of the interconnection should be communicated to the concerned parties.

Multi function protective relays may be cost effective for generator and line protection when many individual relays are required. When multifunctional relays are selected limited back up conventional relays be provided based upon safety, cost of equipment lost or damaged, repairs. Back up protective relays with different designs and instrument transformers should be provided for reliably and security and avoid blind spots.

3.2 INSTRUMENT TRANSFORMER

3.2.1 Introduction

Instruments transformers – i.e. current transformer and voltage transformers insulate secondary circuits from Primary (power) circuit and provide quantities which are proportional to those in primary. These quantities are used for metering and relaying circuits. Current and voltage transformers are regarded as constituting part of the protection system and must be carefully matched with the protective relay. Measuring current transformers for metering are required to accurately perform its function over normal range of load currents, whereas protective current transformers is required to provide sufficiently accurate secondary current to provide satisfactory protection over a wide range of fault current from a fraction of full load to many times of full load. Therefore separate type of current transformers are used for measuring and protection. In case of voltage transformers same transformers can serve both the purposes.

Protective relays in a. c. power systems are connected in the secondary circuits of current transformers and potential transformers. In current transformers, primary current is not controlled by condition of the secondary circuit. Hence primary current is dominant in the operation of current transformers. Instrument transformers are further classified into two groups:

1. Protective instrument transformers used in association with relays, trip coils, pilot wires etc.
2. Measuring instrument transformers – used in conjunction with ammeter, wattmeter etc.

As a result, the ratio error is very important in protective current transformers, and phase angle error may be less important. Voltage transformer is used for transforming voltage from one value to another (generally lower) value. Both current transformers and voltage transformers come under the title Instrument transformers. Discussions in this book are based on Indian Standards Mentioned here in under.

Latest version of following Standards may be referred for complete information.

A. Current Transformer

i) IS: 2705 (4 parts) – Current Transformer
ii) IEC 185 Current Transformer – International Electro-technical Commission
iii) IS 4201 – Application Guide for current transformers
iv) IEC-60044-1 - Current transformers

B. Voltage Transformer

i) IS 3156 (Part III) – Protective voltage transformer
ii) IS 3156 (Part I) – Measuring voltage transformer
iii) IS 4146 – Application guide fore voltage transformer
iv) IEC Pah 186 – Voltage transformer – International Electro-technical Commission
v) IEC-60044-2 - Voltage Transformers

3.2.2 Current Transformer

Primary requirement is that current ratio must be constant. Primary winding is connected in series with load and carries load current to be measured. The winding is connected to the relay or metering unit. Secondary current for relay together with load resistance and winding impedance constitute the burden of the transformer. Primary current contains two components.

a) Secondary current which is transformed and is in inverse ratio of the turns ratio.
b) Exciting current to magnetise the core and supply eddy and hysteresis losses and is not transformed. Amount of exciting current depends upon core material and burden requirement.

The ratio error is given by the following expression.

$$\% \text{ error } = \frac{K_a I_s - I_p \times 100}{I_p}$$

K_a = Rated transformation ratio
I_s = Actual secondary current
I_p = Actual primary current

As the relay time has reduced to the order of a few mili-seconds in modern protective relays, the transient behavior of current transformers and voltage transformers needs more attention. In order to prevent saturation of current transformer cores during sub-transient currents, larger cores and air gaps are introduced in CT's for fast protective relays.

The standard specifications given by IEC, IEEE and IS cover several aspects about current transformers such as general requirements, specifications, testing, applications, terms and definitions.

The major criterion of the selection of the current transformer ratio almost invariably is maximum load current. In other words, the current transformer secondary current at maximum load currents, should not exceed the continuous current rating of the applied relay. This is particularly applicable to phase type relays where load current flows through the relays. This criterion applies indirectly to the ground relays even though they do not receive current because they are generally connected to the same set of current transformers as the phase relays. Since the ratio has been set on the basis of load current of the phase relays, this ratio would then apply to the ground relay. The current transformer ratio is selected to provide around 5 amperes or 1 amp. (in switchyard) secondary for the maximum load current. Where delta-connected CT's are used, the √3 factors should not be overlooked.

3.2.3 Terminology of Current Transformer (IS: 2705)

Composite Error:- Under steady state conditions, the rms value of the difference, integrated over one cycle, between:

a) the instantaneous value of the primary current and
b) the product of the rated transformation ratio an the instantaneous values of the actual secondary current. (This includes the affects of phase difference, of any turns correction and of distortion of water waveform).

This is generally expressed as a percentage of the rms value of the primary current according to the expression given below:

Composite error = $\frac{100}{I_P}\sqrt{\frac{1}{T}\int_0^T (K_n i_s - i_P)^2 dt}$

Where
I_P = primary current (rms value)
T = duration of one cycle in seconds,
K_n = rated transformation ratio,
i_s = instantaneous value of the secondary current, and
i_p = instantaneous value of the primary current

Accuracy Limit Factor: The ratio of the rated accuracy limits primary current to the rated primary current. Standard accuracy limit factors are 5, 10, 15, 20 and 30. Rated Accuracy Limit Primary Currents

The value of the highest primary current up to which the transformer will comply with the specified limits of composite error. It is the product of rated primary current and rated accuracy limit factor.

Excitation Current: The rms value of the current taken by the secondary winding of a current transformer when sinusoidal voltage of rated frequency is applied to the secondary terminals; the primary and any other windings being open-circuited.

Standard Accuracy Classes: For protective current transformer, the accuracy class is designated by the highest permissible percentage composite error at the rated accuracy limit primary current prescribed for the accuracy class concerned, followed by the letter 'P' (meaning protection). The standard accuracy classes for protective current transformers are 5P, 10P and 15P.

Standard accuracy class for measuring current transformers are 0.1, 0.2, 0.5, 1, 3and 5.

Knee-Point Voltage: That sinusoidal voltage of rated frequency applied to the secondary terminals of the transformer, all other windings being open-circuited, which when increased by 10%, causes the exciting current to increase by 50%.

As per IS: 2705 Minimum knee point voltage (V_k) is specified in accordance with a formula of the type:

$$V_k = K.\ I_s\ (R_{ct} + R_b)$$

Where,

V_k is the minimum knee point voltage in volts,

K is a parameter to be specified by the purchaser which depends on the system fault level and the characteristics of the relay intended to be used.

I_s is the rated secondary current of the current transformer (or the secondary current as derived from a specified turns ratio and primary current)

R_{ct} is the resistance of the secondary winding corrected to 75^0C (generally left to manufacturer)

R_b is the impedance of the secondary circuit as specified by the purchaser

Phase Displacement: The difference in phase between the primary and secondary current vectors, the direction of the vectors being so chosen that the angle is zero for a perfect transformer. The phase displacement is said to be positive when the secondary current vector leads the primary current vector. It is usually expressed in minutes.

3.2.4 Application of Protective Current Transformers

General shape of exciting characteristics for cold rolled silicon steel material (cross) generally used for protection CTs is shown in figure 3.2.

Working range of a protective transformer extends from ankle point to knee point and beyond (full range). Metering current transformer normally operates in the region of ankle point about 10% to 120% full load. High permeability with low saturation level material is used for metering CTs. CT saturates above this range and protects the meters. Ratio and phase angle errors are shown in tables 3.1 & 3.2 for standard accuracy class and special accuracy class Ct for metering as per IS: 2705. Table 3.3 shows limits of error for protective current transformers.

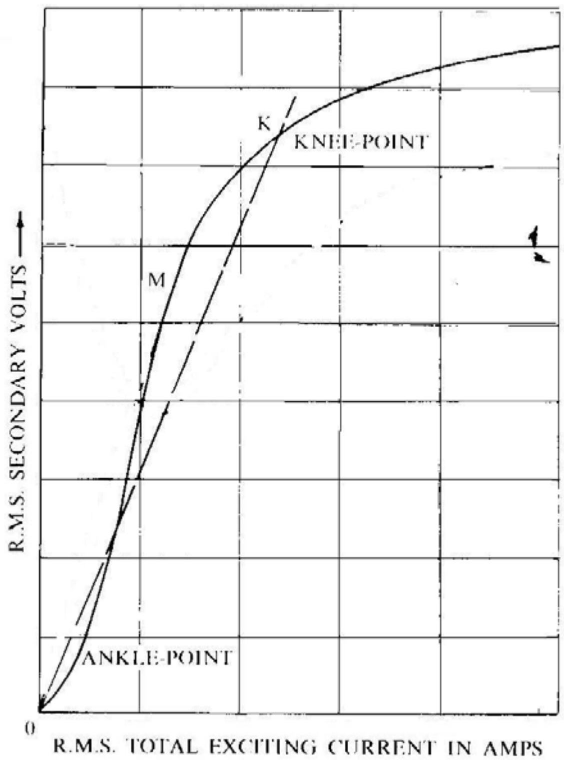


Figure 3.2: Exciting Curve for Current Transfer (Typical)

The determination of the rating of a protective CT is dependant on its application and consequently the following parameters are worked out: rated burden, rated accuracy limit factor and accuracy class.

For balanced protection system and distance protection special class current transformers designated class PS are used and needs in addition following parameters to be specified.

a) Rated knee point voltage
b) Secondary winding resistance
c) Maximum exciting current at rated knee point voltage

Table 3.1: Limits of Error for Standard Accuracy Classes 0.1, 0.2, 0.5 and 1

Accuracy Class	Percentage current (Ratio) Error at Percentage of Rated Current				Phase displacement in minutes at percentage of rated current			
	5	20	100	120	5	20	100	120
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0.1	0.4	0.2	0.1	0.1	15	8	5	5
0.2	0.75	0.35	0.2	0.2	30	15	10	10
0.5	1.5	0.75	0.5	0.5	90	45	30	30
1.0	3.0	1.5	1.0	1.0	180	90	60	60

Table 3.2: Limits for error for Special Application Accuracy Class 0.2S and 0.5S

Accuracy Class	Percentage current (Ratio) Error at Percentage of Rated Current					Phase displacement in minutes at percentage of rated current				
	1	5	20	100	120	1	5	20	100	120
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
0.2S	0.75	0.35	0.2	0.2	0.2	30	15	10	10	10
0.5S	1.5	1.5	0.5	0.5	0.5	90	45	30	30	30

Table 3.3: Limits of Errors

Accuracy Class	Current Error at Rated Primary Current (percent)	Phase Displacement at Rated Primary Current (minutes)	Composite Error at Rated Accuracy Limit Primary Current (percent)
(1)	(2)	(3)	(4)
5P	± 1	± 60	5
10P	± 3	-	10
15P	± 5	-	15

Rated Burden: The burden on a protective CT is composed of the individual burdens of the associated relays or trip coils, instruments (if used) and the connecting leads.

Normally, the standard VA rating nearest to the burden computed should be used,. But attention is drawn to the fact that a device may have different impedance under different operating conditions. The VA burden which is effectively imposed on the CT at rated secondary current is given by the following formulas:

$$Pe = Pr \left(\frac{I_s}{I_r}\right)^2$$

Where
Pe = affective VA burden on the CT
Pr = VA burden of the device at current setting
Is = rated secondary current of the current transformer,
Ir = current setting of the device

In selecting the most suitable standard rated output it is undesirable to specify a value which substantially exceeds the burden as computed above; to do so might result in a transformer uneconomic in cost or of unduly large dimensions. When the nearest standard VA rating is less than the total computed burden, it is usually satisfactory to adopt the former.

Rated Accuracy Limit Factor: In determining the appropriate accuracy limit factor for a given application, the important point to consider is the maximum value of primary current up to which maintenance of ratio is required, other factors however, are also involved. The capabilities of a protective current transformer are determined by the primary ampere-turns, the core dimension and material, and they are roughly proportional to the product of the rated burden and the rated accuracy limit factor. With present day material and normal dimensions, this product has a maximum value of about 150.

Correlation of Burden and Accuracy Limit Factor: Accuracy limit factor higher than 10 and rated burdens higher than 15 VA are not recommended for general purposes. It is possible, however to combine a higher rated accuracy limit factor with a lower burden rating and vice versa; but when the product of these two exceeds the resulting current transformer may be uneconomical and/or of unusually large dimensions. Moreover, it might not be possible to attain a product of 150 if the current transformers are of the wound-primary type with low ratio and high rated short-time thermal current.

Accuracy Class: The required accuracy class of protection current transformer is dependent upon the particular application and examples of its selection with particular regard to associated values of rated accuracy limit and rated burden is in the examples.

3.2.5 Special Application (PS class CTs)

When the operation of the protective equipment is more precisely dependant upon the magnitude and phase relationship of voltage and current as, for example, upon the balance of current in differential protection, the current transformers may require characteristics other than those prescribed above. These characteristics cannot conveniently be expressed in the terms used for accuracy classes 5P and 10P.

For such applications, the current transformers characteristic are normally specified in the following terms:

a) Knee-point voltage,
b) The exciting current at the knee-point voltage or at a percentage there of for both
c) Resistance of the secondary winding

The values of the above terms are dependent on the protection gear involved. In such cases, the designer of the protective system should specify the additional requirement that may be necessary in consultation with relay manufacturer.

3.2.6 Protective Voltage transformers

3.2.6.1 Terminology

Protective Voltage Transformers: - A voltage transformer intended to provide a supply to protective devices (relay or trip coils). These transformers are required to have sufficient accuracy to operate protective system at voltages that occur under fault condition.

Accuracy Class Designation: - The accuracy class for protective voltage transformer is designated by the highest permissible percentage voltage error for the accuracy class concerned from 5 percent of rated voltage to a voltage corresponding to the rated voltage factor. This expression is followed by letter P for protective. Voltage transformer and PR for 3 phase residual voltage transformer.

Standard Accuracy Classes: - this is designated by the highest permissible percentage voltage error at rated voltages prescribed for the frequency class concerned.

The standard accuracy classes for protective voltage transformer are ‘3P’ and ‘6P’.

Rated Burden: - The rated burden of a voltage transformer is usually expressed as the apparent power in volt amperes absorbed at rated secondary voltage. The burden is composed of the individual burdens of the associated voltage coils of the instruments, relays, trip coils to which the voltage transformer is connected. The total burden is computed by adding them together after referring the individual value to a common base i.e. rated secondary voltage.

Normally the standard VA rating nearest to be burden computed should be used. It is undesirable to specify VA rating much higher than the computed value, as to do so might result in inaccuracies and the transformer uneconomical in cost or of unduly large dimensions. When the value of the nearest standard VA rating is less than the computed value, the use of such VA rating should be made in consultation with the manufacturers.

Accuracy of a voltage transformer is guaranteed for burden variation between 25% to 100% of rated burden.

3.2.6.2 Limits of Voltage Error & Phase Displacement

The rated residual voltage of a 3 phase residual voltage transformer is as follows:

a. For effectively earthed neutral transformers — 1 x rated residual voltage
b. For isolated neutral voltage transformers — 3 x rated residual voltage

Acc. Class	Percentage Voltage Error	Phase Displacement
3 P	± 3.0 %	± 120 minutes
6 P	± 6.0 %	± 300 minutes

3.2.6.3 Voltage Transformer Intended to Produce Residual Voltage

a) Rated secondary voltage of winding connected in broken delta to produce a residual voltage is 110 volts, $110/\sqrt{3}$ or 110/3 for single phase voltage transformers intended to produce a residual voltage.

The rated residual voltage of a 3 phase residual voltage transformer is as follows:

i)	For effectively earthed neutral transformers	1 x rated residual voltage
ii)	For isolated neutral voltage transformers	3 x rated residual voltage

Rated Secondary Voltage

Preferred Value	**Volts**
100	110
$\frac{100}{\sqrt{3}}$	$\frac{100}{\sqrt{3}}$
$\frac{100}{3}$	$\frac{100}{3}$

If preferred value of rated secondary voltage produces a too low residual voltage, non-preferred values may be used.

Rated Output: - should be as per IS: 3150 and preferred values are 25, 50 and 100 VA.

Accuracy Class: - as per IS accuracy class for a residual voltage transformer i.e. 6 P.

3.2.6.4 Special Application

When using a 3-phase voltage transformer with a generator, whether for metering or protection, it should have a closed- tertiary – delta winding to provide path for the third harmonic component of the excitation current in the core.

3.2.6.5 Application of Measuring Voltage Transformers

A measuring voltage transformer needs to maintain its accuracy from 80 to 120 % of rated voltage. It is not required to maintain its accuracy within specified limit during the fault conditions.

3.2.6.6 Accuracy Class

It is undesirable that a higher class of accuracy should be called for, than is necessary for the duty required. To do so is uneconomical and may result in voltage transformer of excessive dimensions which may involve modification to the switchgear without serving any useful purpose.

3.2.7 Application of Protective Voltage Transformers

Altitude: voltage transformer bushing/weather casing between high voltage point and nearest earth point of voltage transformer is increased in accordance with IS: 4146.

Atmospheric Pollution: minimum creepage distance under varying degrees of pollution of the voltage transformer bushing/weather casing as recommended by IS: 4146 is as follows:

For heavily polluted conditions	23 mm per kV of highest equipment voltage
For normally and lightly polluted conditions	16 mm per kV of highest equipment voltage

Resistance to Earthquake: Porcelain insulators and bushings of voltage transformer 66 kV and above are made suitable to withstand the stresses likely to be caused by earthquakes as per IS: 1983 and vibration tests are specified.

Selection of the accuracy class for a particular application should be made in consultation with the manufacturer.
A protective device is called upon to operate under system fault conditions. As the faults are generally associated with voltage dips, a protective voltage transformer is required to maintain its accuracy within specified limit from 5 to the voltage factor of rated voltage.

For applications with protective devices whose operation does not depend on the phase relationship between the voltage and the current, for example, under voltage, overvoltage and over current relay of limit importance and accuracy class of 6 P is considered to be quite adequate.

For applications with protective devices whose operation depends on the phase relationship between voltage and current, for example, directional over current, reverse power and directional distance protection, voltage transformers of class 3.0 is used.

The selection of accuracy class for any particular application depends on the sensitiveness of the protection scheme required, and is decided by the purchaser in consultation with the manufacturer.

3.2.8 Choice of Connection (phase to Phase) (V)

In this type of connection, 2 single-phase voltage transformers are connected in 'V', both on the primary and secondary sides. As there is no neutral on the primary winding, the zero sequence voltage cannot be obtained. Hence, such a voltage transformer cannot be used where it is required to have zero sequence voltage for protection or indication.

3.2.9 Star- Star

This is the most common connection used in metering and relaying schemes. When 3 phase 3 limb voltage transmission are used the zero sequence voltage will not be transformed.

3.2.10 Star – Broken Delta

This connection is used for directional relay or when zero sequence voltage is required for earth fault relaying scheme. With this connection a bank of 3 single-phase voltage transformers is used, the primary star point being solidly earthed regardless of system earthing conditions. The voltage appearing across the broken delta is three times the zero sequence voltage.

3.2.11 Voltage and insulation level and overvoltage withstand etc.

Voltage and insulation level is the same as for other equipment in the powerhouse.

3.2.12 Typical Example

A typical example of CTs and PTs characteristics fixed for 2 x 10 MW. Mukerian project for protection and metering is shown in figure 3.4. Protection and metering single line is shown in figure 3.3.

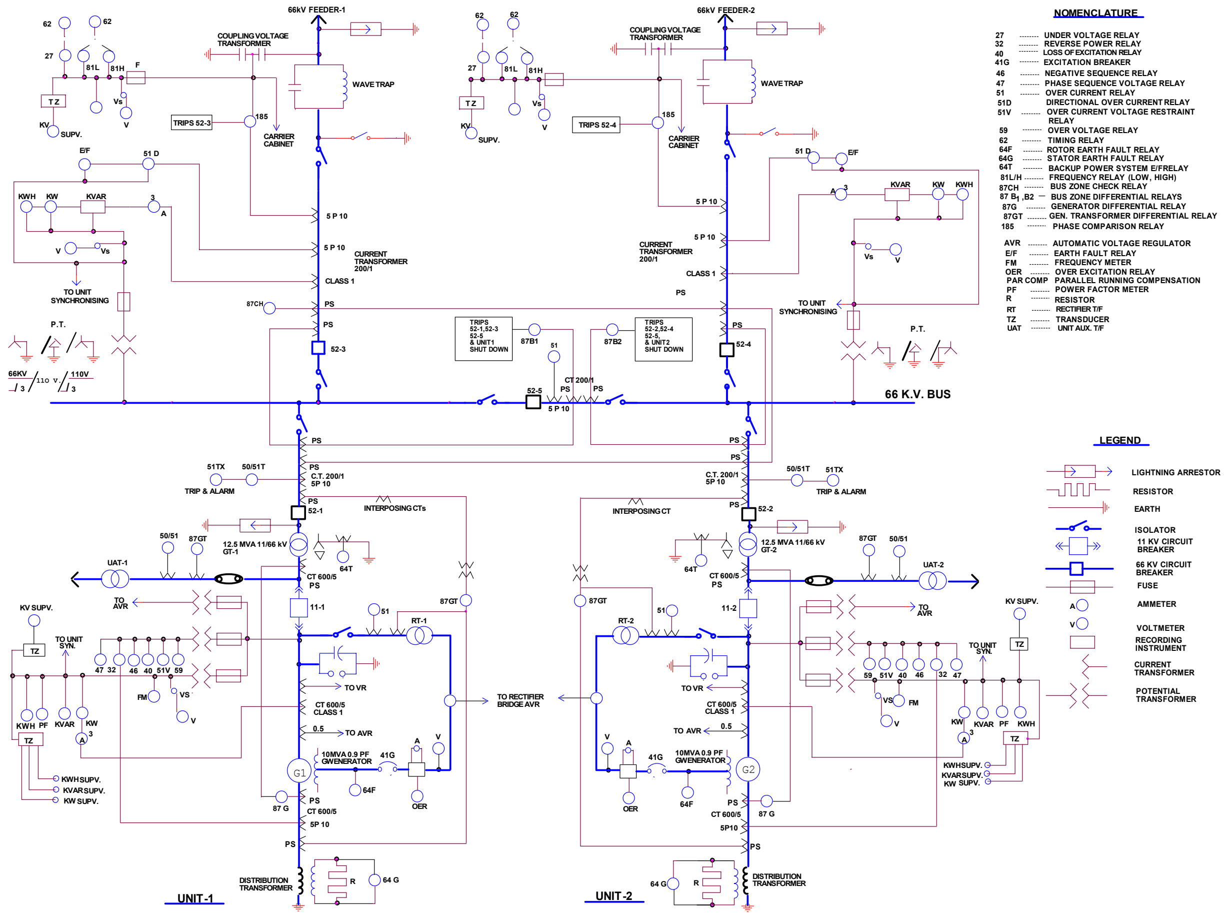
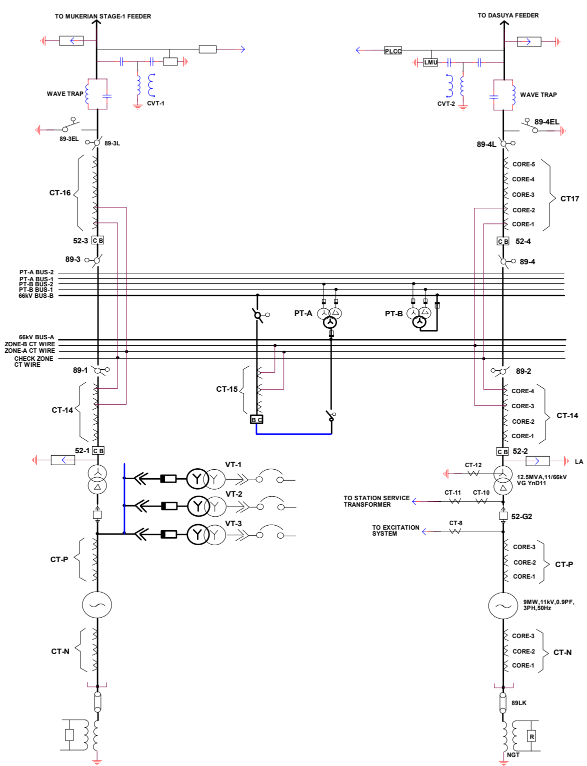


Figure 3.3: Protection and metering single line diagram (Mukerian Stage 2) (Specification)



CTs DETAILS

NO.	VOLTAGE	CORE	CIRCUIT	QUANTITY	RATED	ACC. CLASS	BURDEN VA
CT-N	11kV	1	OVERALL DIFFERENTIAL PROTECTION	6	600/5A	PS	--
---	11kV	2	PROTECTION	--	600/5A	5P10	60
---	11kV	3	GEN. DIFF. PROTECTION	--	600/5A	PS	--
CT-P	11kV	1	DIGITAL VOLTAGE REGULATOR (DVR)	6	600/5A	0.5	60
---	11kV	2	GEN. METERING & EHG	--	600/5A	0.2	60
---	11kV	3	GEN. DIFF. PROTECTION	--	600/5A	PS	--
CT-8	11kV	1	PROTECTION	--	30/5A	5P10	30
CT-10	11kV	1	PROTECTION	6	30/5A	5P10	30
CT-11	11kV	1	OVERALL DIFF. PROTECTION	6	30/5A	PS	--
CT-12	66kV	1	PROTECTION	2	200/1A	PS	--
CT-14	66kV	1	OVERALL DIFF. PROTECTION	6	200/1A	PS	--
---	66kV	2	BREAKER BACK-UP PROTECTION	--	200/1A	5P10	45
---	66kV	3	BUS DIFFE. PROTECTION MAIN	--	200/1A	PS	--
---	66kV	4	BUS DIFFE. PROTECTION CHECK	--	200/1A	PS	--
CT-15	66kV	1	BUS DIFFE. PROTECTION ZONE A	3	200/1A	PS	--
---	66kV	2	BUS DIFFE. PROTECTION ZONE B	--	200/1A	PS	--
---	66kV	3	BREAKER BACK-UP PROTECTION	--	200/1A	5P10	60
CT-16	66kV	1	BUS DIFFE. CHECK	3	400-200/1A	PS	--
---	66kV	2	BUS DIFFE. MAIN	--	400-200/1A	PS	--
---	66kV	3	METERING	--	400-200/1A	0.5	60
---	66kV	4	PROTECITON	--	400-200/1A	PS	--
---	66kV	5	DIRECTIONAL O/C & E/F PROTECTION	--	400-200/1A	5P10	60
CT-17	66kV	1	BUS DIFFE. CHECK	3	400-200/1A	PS	--
---	66kV	2	BUS DIFFE. MAIN	--	400-200/1A	PS	--
---	66kV	3	METREING	--	400-200/1A	0.5	60
---	66kV	4	PROTECITON	--	400-200/1A	PS	--
---	66kV	5	DIRECTIONAL O/C & E/F PROTECTION	--	400-200/1A	5P10	60

PTs DETAILS

NO.	CIRCUIT	QUANTITY	RATIO V/V	ACC. CLASS	BURDEN VA	PHASE
VT1	DIGITAL VOLTAGE REGUALTOR (DVR)	6	$\frac{11000}{\sqrt{3}} / \frac{110}{\sqrt{3}}$ V	0.5	50	1PH
VT2	METERING SYN. & EHG	6	$\frac{11000}{\sqrt{3}} / \frac{110}{\sqrt{3}}$ V	0.2	200	1PH
VT3	PROTECITON	6	$\frac{11000}{\sqrt{3}} / \frac{110}{\sqrt{3}}$ V	3P	100	1PH
BPT A & B	METREING,RELAYING,PROTECTION & SYNCHRONIZATION	6	$\frac{66000}{\sqrt{3}} / \frac{110}{\sqrt{3}} / \frac{110}{\sqrt{3}}$ V	0.5/3P	100-60	1PH
CVT 1,2	METREING,RELAYING,PROTECTION & SYNCHRONIZATION	6	$\frac{66000}{\sqrt{3}} / \frac{110}{\sqrt{3}}$ V	0.5/3P	50-50	1PH

REFRENCES DRAWINGS

FIGURE 3.2.12.2: 2x9MW MUKERIAN PROJECT METERING AND RELAYING SINGLE LINE DIAGRAM

Figure 3.4: Protection and Metering CTs & PTs (AHEC Project)

3.3 GENERATOR PROTECTION

3.3.1 Introduction

Size of individual hydro generating units has risen to over 500 MW. In India 250MW generators are installed at Nathpa Jhakri on River Satluj and at Tehri Hydro Power Project on river Bhagirthi. 6 x 165 MW units were installed at Dehar hydro power plant of Beas Link Project. Large sized electric generators running in parallel and connected to long distance transmission lines requires proper protection as the loss of even a single unit can jeopardize the operation of the power system to which it is connected.

The collective function of all forms of protection applied to large generators is, therefore, to reduce the clearance time of all fault conditions associated with it. It is of prime importance that the protective devices should disconnect the machines automatically if the fault is internal or if the external conditions are so abnormal that the continued operation would result in damage. With the advent of higher transmission voltages transmitting large blocks of powers at long distances, stability problems have increased and very low operating times have been provided, a review of hazards is desirable, because these should be understood when considering the advisability or otherwise of applying specific protective features.

Small hydro power projects from micro hydro range (5 kW-100 kW) and up to 25 MW capacity are being installed mostly for energy. Desired protection is determined by the interconnected power system and economic considerations.

3.3.2 Generator, Excitation Systems and Generating Station Arrangements

Stator winding of a three phase synchronous hydro generator consists of a number of single turn or multi turn coils that are connected in series to form a single phase circuit. The phase windings are normally star connected with neutral grounded through an external impedance. Most common arrangements are shown in figures 3.5 (a) and (b).

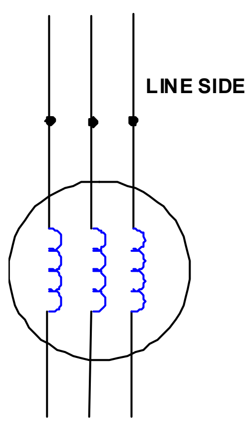


figure 3.5 (a)

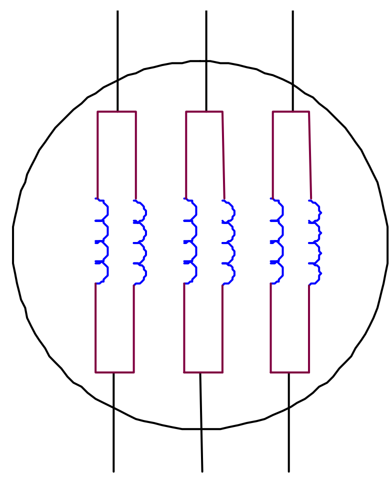


figure 3.5 (b) Split Phase Winding

Generator neutral grounding practice is discussed in Para 3.6 alongwith stator earth fault protection.

Shaft mounted DC excitation systems are not being used. Excitation systems are discussed in Chapter 10 Volume 1. Static excitation system for large generators (Figure 10.2, Vol. 1) and brushless excitation system (Figure 10.1, vol. 1) for small generators is being mostly used.

Generating station grid interconnection arrangements are discussed in Chapter 9 Para 9.2.1 & 9.2.2. Generally unit generator transformer connection (Figure 9.2.1) for large generators and providing generator breakers and generator bus sharing a transformer for multi unit (Figure9.2.2) for small sized generators are used.

Induction Generators feeding into the grid up to about 3000 kW unit size have also been used.

3.3.3 Possible Faults

There are number and variety of failures to which a generator may be subjected. Several protective systems are employed, both of the discriminative and non discriminative type. Great care must be exercised in co-ordinating the systems used and the settings adopted.

Classification of faults

All faults associated with the unit may be classified as either insulation failure or abnormal running conditions.

An insulation failure will result in either an inter-turn fault, a phase to phase or an earth fault, but most commonly the latter since most insulation failures eventually bring the winding into direct contact with the core.

Abnormal Running

The abnormal running conditions in hydro generators to be protected against comprise:-

a. Overloading
b. Loss of excitation
c. Unbalanced loading
d. Lubrication oil failure
e. Failure of prime mover
f. Over/under speed
g. Rotor displacement
h. Excessive vibration

Stator Faults

Break down of winding insulation may result in any of the following types of faults:
(a) Earth faults, (b) Phase faults (c) Inter-turn faults
Other faults originating from defective joints or inadequate or defective end turns or terminals will if undetected, reach a stage where there is a breakdown of insulation.

A fault to earth is liable to cause arcing to the core which may not only damage the conductor but also burning and welding of the laminations. To limit this damage it is almost universal practice to connect an impedance or an earthing resistance between the generator winding neutral and the earth. Practice varies on the method adopted for earthing and the impedance used. Phase to phase or three phase short circuit are not limited by the earthing impedance.

Stator core of large hydro generators at Dehar Power Plant (6 x 165MW) of Beas Satluj Link Project became loose at core joints a few years after commissioning. Stator punching at the location started vibrating and shifted by 2 to 10 mm resulting in following.

i) Stator earth faults
ii) Excessive rise of stator temperature (hot spots)
iii) Rotor earth fault and excess temperature

Localized hot spots in the stator core can also be produced by improper operation e.g. excessive leading power factor operation or core fluxing. Hot spots are the result of high eddy current produced from core flux that finds conducting path across insulation between laminations.

Special Protection required in large size hydro generators is as follows:

i) Rigidity and strength of stator frame is needed to resist deformation under fault conditions and system disturbances.

ii) Varying air gap is critical and can result in very large forces radial to the rotating element which would be transferred to the stator frame and guide bearings with their supports with possible consequential damage. Vibration measurements or direct dynamic measurements of air gap are required.

Rotor faults

The field system is not normally connected to earth, so an earth fault does not give rise to any fault current and is thus not in itself a danger. If a second earth fault develops then, however, a portion of the field winding may be short circuited, resulting in an unbalanced magnetic pull on the bearing causing rotor vibration and consequent failure of bearing surface or even displacement of the rotor sufficient to bend the shaft. In addition to this mechanical trouble, there is a possibility of overheating of field winding due to the automatic voltage regulator action which may try to maintain the rotor flux in spite of the loss of turns that have been short circuited by the double earth fault.

Loss of Excitation

Failure of DC excitation causes the machine to run as an induction generator, the stator drawing magnetizing currents from the Ac system. Due to saliency, normal hydro generators may carry 20-25% of normal load without field and not lose synchronism. Loss of field when a hydro generator is carrying full load may cause over loading of the stator by operating at low power factor, and of over heating the rotor owing to induced currents in the rotor body and damper windings. The unit will impose VAR drain on the system.

Unbalanced Loading

Unbalanced stator currents can be caused by external faults or unbalanced loading. An unbalanced load can be resolved into positive, negative and zero sequence components. The positive sequence component is similar to the normal balanced load, the negative sequence component is similar except that the resultant reaction field rotates counter to the D C field system and produces a flux which cuts the rotor at twice the rotational velocity. The double frequency eddy currents thus induced in the rotor are liable to cause heating of the rotor. Water wheel generators have a low rotational velocity and thus the heating in the rotor caused by small eddy currents is generally of less practical significance. It is provided as a two stages back up protection – a definite time alarm stage and trip stage in SHP.

Over Voltage

Water wheel generators have a high over speed factor and the provision of over voltage protection is most desirable so that insulation is not damaged. This protection also serves to avoid damage if the voltage regulator system fails to operate correctly. The potential danger of such failure cannot be ignored with the high speed and high range of modern regulators, designed to meet long distance transmission stability requirements.

System Frequency Swing

Large hydro generator connected to EHV power system sometimes leads to severe system frequency swings because of the complexity of modern EHV power system. This may cause generator to go out of step.

Other Abnormal Conditions

IEEE 242 – 2000 mentions following additional abnormal conditions. Protection for these abnormalities may be considered especially for large and mega size generators.

i) Sub synchronous oscillations
ii) Inadvertent energization
iii) Non synchronous connection

3.3.4 Thermal Protection

Stator Overheating

Overheating of the generator stator core and winding may result from:

1. Overloading
2. A number of the stator laminations becoming short circuited.
3. Failure of the machine's cooling system

Resistance temperature detectors (RTD) of PT100 type are used for detecting this condition in stator winding. These temperature sensors are embedded at various points in the stator winding and arranged to provide an indication of the temperature conditions which exist over the whole of the stator winding, thus ensuring that even localized overheating, such as would occur due to short circuited laminations, is detected.

Temperature sensors for protection of generator stator winding continuously monitor temperature of the stator winding. The sensors are normally connected to data acquisition system for scanning, recording and alarm and tripping for abnormal temperature rise.

Failure of Cooler System

Large hydro generators are provided close circuit air cooling system with air/water cooler on the stator frame. Failure of the cooling system can result in rapid deterioration of the stator core lamination insulation and or stator winding conductor and insulation. Cooling air temperature, cooling water supply pressure and temperature for each cooler is monitored for alarm and trip of the machine for abnormal conditions.

Hot Spots

Localized hot spots in the stator core can be produced by lamination insulation failure due to abnormal running conditions such as leading power factor operation or over fluxing or by vibration due to looseness.

Insulation failure of a number of large machines occurred. It is therefore common practice to specify conservative temperature rise for the generators e.g. specifying class B temperature rise for class F insulation is recommended for small hydro generators in IEC-1116.

Rotor (Field) Overheating

Monitoring temperature of main field winding and main rotor body for thermal protection by temperature sensors is not practical. Generator with static excitation system employing main field collector rings, the average approximate temperature of the field winding is determined by calculating hot field resistance using field current and voltage and comparing with known cold resistance. Hot spots cannot be determined. Filed currents are monitored through shunt and over current indicates overheating and is used for alarm and tripping of the unit.

Field Over Excitation

Over excitation protection is provided on large generators. This protection is provided by monitoring current (through shunt) or voltage of the main field or the exciter field. A device is set to pick up when field current exceeds full load value and is set to a) sound and alarm, b) adjust filed excitation corresponding to rated full load level or less and c) trip the unit after short time interval (expected system disturbance time).

3.3.5 Generator Stator Fault Protections

General Considerations

Generator stator faults can cause severe and costly damage to insulation, windings and the core and can produce torsional shocks to shaft and coupling. The fault current does not cease to flow when the generator CBs is tripped from the system and field is disconnected. Accordingly high speed protection is required to trip and shut down the machine as quickly as possible to minimize damage. High speed differential relaying is used for phase fault protection of generator stator windings. It acts by comparing the current magnitude at the two ends of a phase winding in its most common form.

The method of grounding the generator neutral affects the protection afforded by differential relays. For example if sufficient grounding impedance is used so that a ground fault at the generator terminal draws full load current, then for a fault at the midpoint of the winding, the fault current will be approximately one half of the full load current as only half the phase voltage is available to cause a flow of current. This way a point can be found at which a fault must be placed so as to pass minimum current to operate the relay. The winding above this point is the percentage winding protected against the earth fault. Practically the whole of the winding is protected against phase to phase faults since there is no limiting impedance included in the fault circuit. With a 10% setting about 90% of the winding is protected against earth fault for the case referred to above. The unprotected remainder of the winding is at a relatively low potential above earth and is, therefore, less likely to become faulty than the protected part. With lower impedance grounding the differential relay protects closer to the neutral. With high impedance grounding, the limit of protection for ground faults is farther from neutral end and for ungrounded machines (including distribution transformer earthing) the differential protection is inoperative against earth faults.

High Impedance Type Differential Relay

A relay connection is shown in figure 3.6. A stabilizing resistor is fitted in series with the relay operating coil to ensure that the relay does not operate for faults external to the protected zone. On external faults the voltage across the relay will be low while for internal faults, the voltage across the relay is relatively high. The relay is set to operate for stator winding phase to phase or 3 phase faults current as low as 2%. The current transformers CTs for high impedance type generator differential protection should have identical characteristics and are not used for any other function likely to cause unequal secondary loading and negligible leakage reactance.

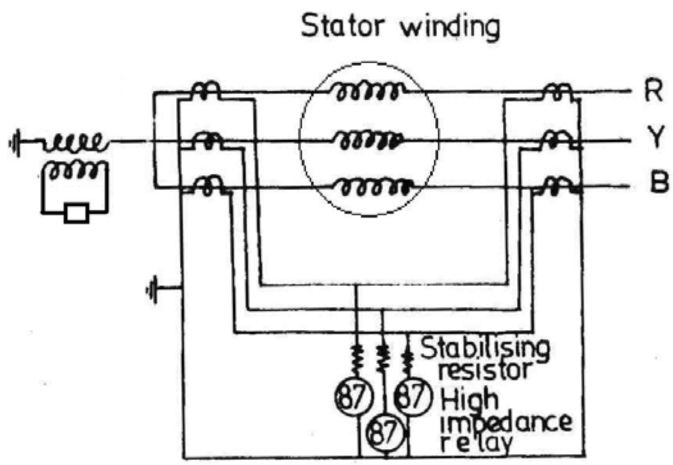


Figure 3.6 High Impedance Differential Protection

Percentage Differential Relay

Figure 3.7 shows the percentage or ratio differential protection around one phase and is most suitable for generator protection specially in cases where the performance of current transformers falls short of requirements due to practical limitations in design or excessive lead burdens and thus results in imperfect matching of the current transformers. The through fault secondary current circulates through the restraining windings which exerts a restraining force or bias on the movement caused by the operating winding which is energized by the difference in the two current transformer windings. Normally no current flows in the operating coil under through fault conditions, but owing to imperfect matching of the current transformers some spill current present due to ratio errors in the operating coil will not cause operation unless the operating restraining (bias) current ratio for which the relay is set is exceeded. The magnitude of the current to cause operation is not constant but automatically increases as the circulating current increases. This gives the relay the advantage of high sensitivity at light loads and decreased sensitivity for external short circuits.

The spill current level for the relay to just operate expressed as a percentage of the through fault current causing it is defined as the percentage bias of the relay; viz.

$$\%\text{age BIAS} = \frac{\text{Spill current for relay operation}}{\text{Through fault current}} \times 100$$

Operating characteristics, of this type of relay may be published as a curve, in which the differential current for operation is plotted against the through fault current. The former is

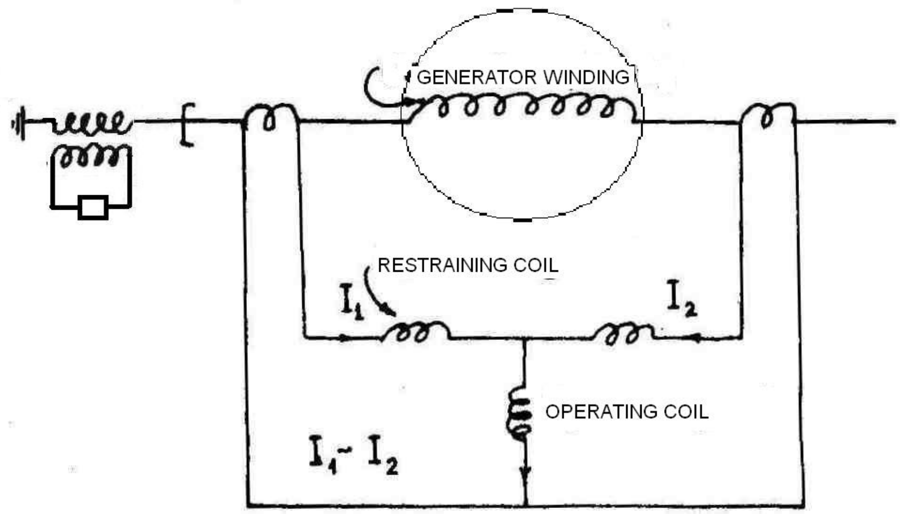


Figure 3.7: Percentage Biased Differential Protection

expressed as a percentage and the latter is multiple of full load current. The operating characteristic of a typical relay English Electric DDG 11 (now Alsthom) type of relay provided for Bhakra Left Bank 90 MW generators with 10% bias is plotted in Figure 3.8.

In Bhakra right bank generators high impedance type relays were provided. In Dehar power plant (6 x 165MW) and Pong (6 x 60 MW) generators of Beas project percentage biased differential relays were specified. General practice is to specify percentage biased differential relays with I.S. PS class accuracy CTs for hydro generators.

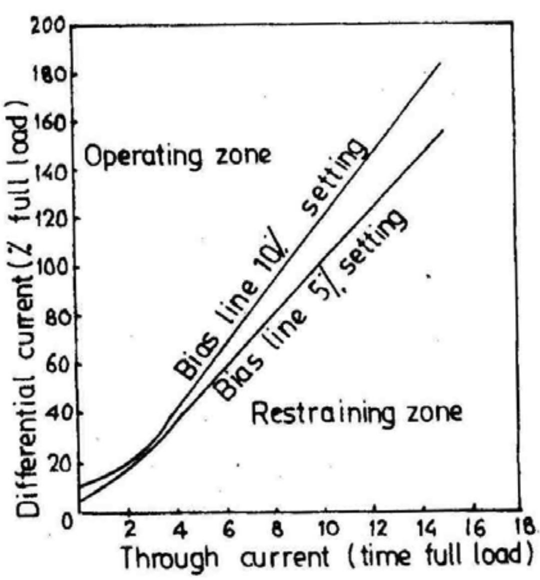


Figure 3.8 Generator Biased Differential Relay Type DDG Operating Characteristics for 10% Bias

Inter-turn Fault Protection of the Stator Winding

Most hydro generators have single turn stator windings. If generators have multiple turns coils with two or more circuits per phase the differential scheme shown in Figure 3.7 cannot detect inter-turn short circuits within the winding because the entering and leaving currents of a phase remain equal. Formerly, this protection was considered unnecessary because break down of insulation between points on the same phase winding contained in the same slot and between which potential difference exists, will very rapidly change into an earth fault and will be detected by either the stator differential protection or stator earth fault protection.

With size and voltage output of generator increasing interturn protection is becoming essential for all generators with inter-turn winding. There are several methods of providing inter turn protection Figure 3.9 shows split phase relaying and protection on generator having two or more circuits per phase. In this scheme the circuits in each phase of the stator winding are split into two equal groups and the currents of each group are provided separate differential relaying. A difference in these currents indicates an unbalance caused by turn fault. For more details on protection of split phase winding for large generators refer IEEE 37-102.

Application of protection for split phase and multi turn winding should be specified in design of generator so that CTs required can be economically provided.

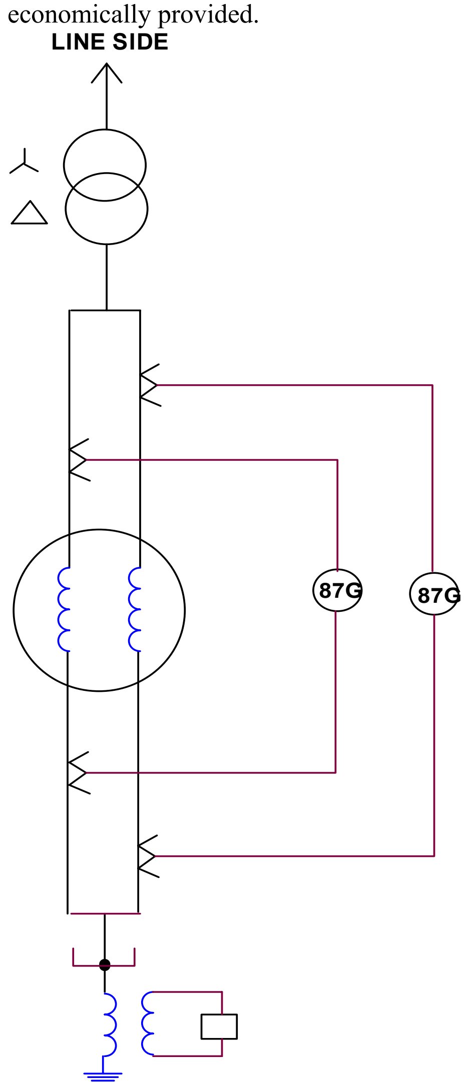


Fig: 3.9 Differential protection for two winding per phase 12 bushing generator (single phase shown)

Back up Overall Protection

Where generator and generator transformer are coupled together as one unit, an additional differential protection is provided to cover both generator and transformer as a backup protections for generator. A bias for restraining winding is essential so as to counteract the effect of dissimilar ratios and characteristics of the current transformers during through fault conditions as well as unbalance caused by power transformer magnetizing in rush current and a tap change of –10%. These coarser setting cause decrease in the percentage winding protected. Auxiliary CTs were used to compensate for phase shift (transformer star/delta connection) and for current differentials due to turn ratio in step up transformer (Figure 3.10). In some cases unit auxiliaries transformer may be excluded from the overall differential scheme if the size of unit auxiliary transformer is very small as compared to unit size. In Bhakra Right Bank power plant the size of auxiliary transformer was 500 kVA and unit size 120 MVA which is over 200 times the rating of the unit. Accordingly fault currents of over 200 times the CT rating will saturate the CTs resulting in a little or no current output to differential relays. The auxiliary transformer was not included in the overall differential scheme. This may induce a blind spot in the protection for unit. IEEE C 37 – 102 recommends elimination of this blind spot by providing a separate auxiliary transformer differential relay protection for unit auxiliary transformer. Overall scheme will detect severe faults, while auxiliary transformer differential will detect low level faults (Figure 3.11).

Where generators are bussed at generator voltages and generator breakers are used overall generation protection scheme is not applicable. In this case back up is provided by over current and negative sequence current relay as discussed subsequently.

In large hydro-electric generator where due to paucity of space the distance between switchyard and power plants is quite large, it may be worthwhile to provide independent differential protections-one for generators and the other overall for generator and transformer and third one for the inter-linking line including high tension circuit breaker in its zone. This arrangement will provide proper protection to transformer as well as the tee-off for unit auxiliary transformer as a lower setting. This protection was provided in Dehar Power Plant as shown in figure 3.11. One amp. CTs were providing to reduce voltage drop in extra long leads delta connected to compensate for phase shift in power transformer.

Tripping Schedule

Primary and backup protection envisages separate hand reset multi contact auxiliary relays which initiate following:

a) Trip main generator breaker

b) Trip field exciter breaker

c) Turbine shut down

d) Generator CO_2 (generator protection) for generator differential relays only

e) Operate alarm and annunciation

f) Transfer station service to standby source.

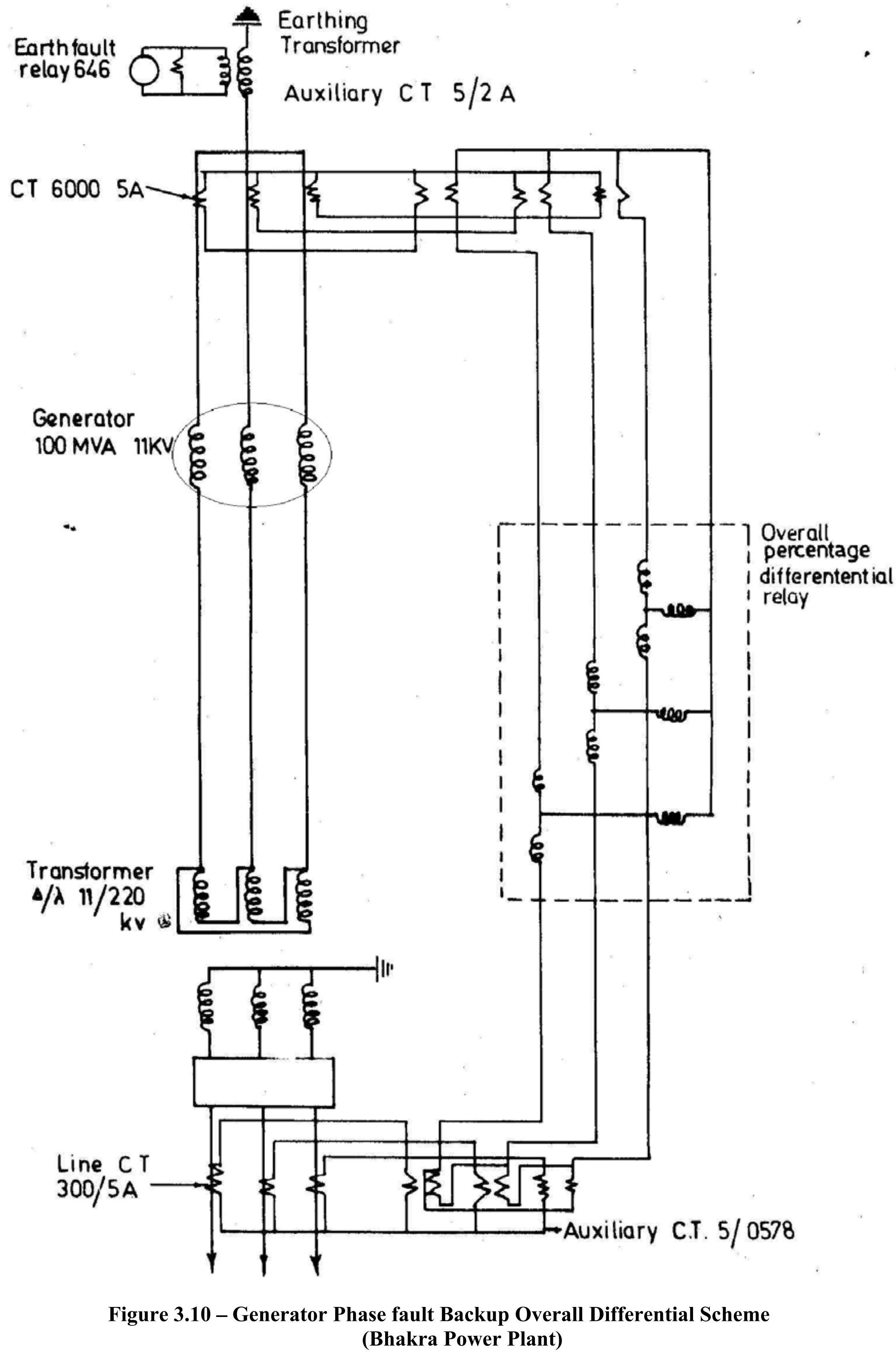


Figure 3.10 – Generator Phase fault Backup Overall Differential Scheme (Bhakra Power Plant)

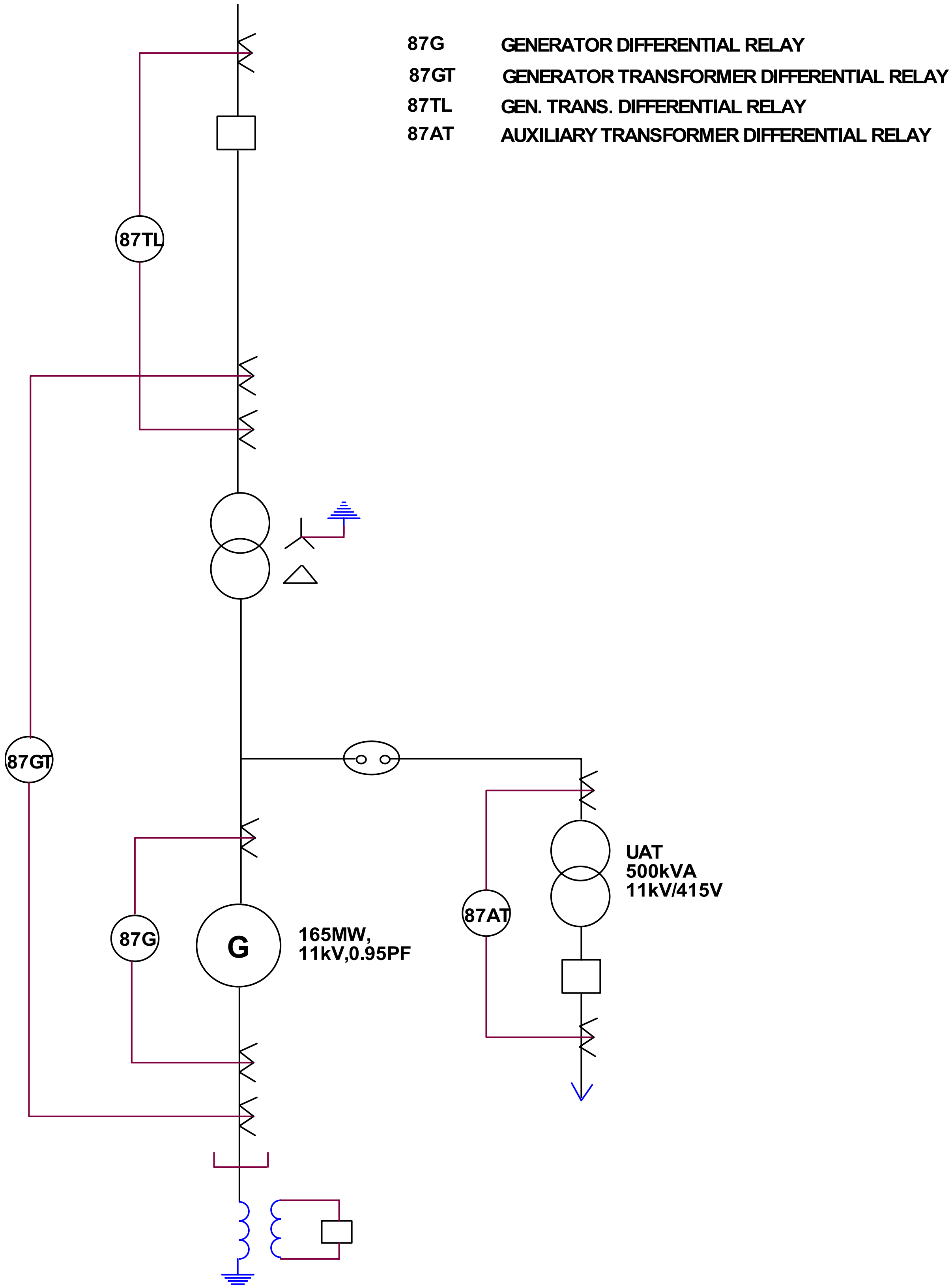


Figure 3.11 Dehar Power plant generator phase fault, back up overall differential; interlinking line differential and auxiliary transformer differential

3.3.6 Generator Grounding and Stator Earth Fault Protection

Protective schemes to be provided for stator ground fault protection is directly related to how the generator is grounded and therefore to the magnitude of the ground fault current available.

The aspects of the problem that must be taken into account in a consideration of the neutral earthing of unit connected generators and providing earth fault protection are:

(a) Operational advantages
(b) Damages at the point of fault
(c) Sustained or transient over-voltages
(d) Relaying
(e) Thermal rating
(f) Protection against over-voltages
(g) Cost

Generator and low phase winding of the power transformer (delta) is not directly connected to the system and as such is usually earthed through a much higher impedance than when the generator is connected direct to the system. Since the available ground fault may be small or limited to low values, it is common practice to provide separate sensitive ground fault protection for generators depending upon generator grounding method which may supplement whatever protection that may be provided by differential relaying.

Low Resistance Earthing

In this scheme the generator neutral is earthed through a suitable resistance of about 10 seconds rating. A setting of 5% or less of the rated current of the generator by means of a current operated relay with inverse time characteristics is generally employed. In this case risk of dangerous over-voltage is eliminated for all practical purposes but it becomes essential to trip the generator as quickly as possible after the occurrence of an earth fault. Fault current in this practice is limited to 200-300 amperes. In U. S. practice as per IEEE C 37 – 102 in low resistance grounding the grounding resistor is selected to limit the generators contribution to a single phase to ground at its terminals to value in the range of 200 A up to 150% of rated full load current. The method of grounding is recommended for generator directly connected to station bus.

When the stator neutral is earthed through a resistor, a C.T. is mounted in the generator neutral and connected to an inverse time relay as shown in figure 3.12. In this case the inverse time relay will require grading with other earth fault relays in the system. With resistor earthing it is impossible to protect 100% of the stator winding the percentage of winding protected being dependent on the value of the neutral earthing resistor and the relay setting. Reducing the fault setting or increasing the current passed through the neutral earthing resistor does not give proportionate improvements in the amount of winding protected. For example, with a 100% full load resistor and a 20% setting, 80% of the winding is protected. Doubling the resistor rating or halving the setting only increase the amount of winding protected by 10%.

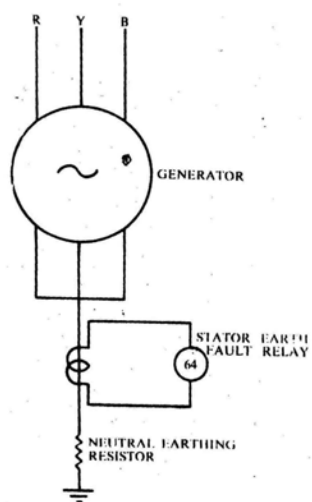


Figure 3.12 Stator Earth Fault Protection (Resistance earthed system)

In choosing a suitable setting for the protection the above facts should be considered. Further with large generator-transformer units care must be taken in the selection of settings to reduce the risk of mal-operation from earth faults in the H.V. system due to the effect of transformer inter winding capacitance. It is often advisable with such units to fit two earth fault relays, one instantaneous with a setting of 10-15% the other time delayed with a setting of 5% of the earth fault current.

Distribution Transformer (High Resistance) Earthing

This scheme consists of earthing the generator, connecting leads and low phase winding of the power transformer through a small distribution transformer loaded with a resistor on its secondary side. This method is a compromise between the V. T. and resistance method of earthing and it combines their advantages and disadvantages. The protection provided consists in connecting a voltage relay in parallel or a current relay in series with resistor (See figure 3.13) so as to sound an alarm or to trip. A combination of sensitive alarm and coarser setting of alarm and time delay trip are also used. The latter gives time to transfer the load to another machine at the hazard of operating with a fault on one phase. Generators of Bhakra left bank (5 x 90 MW), Dehar (6 x 165 MW) and Pong (6 x 60 MW) have been provided with this method of earthing and is common method of earthing for unit connected generators. The maximum earth fault current is determined by the size of the transformer and the loading resistor R. Optimum loading is when the power dissipated in the resistor equals the capacitive loss in the generator system. At this point the transient over voltages possible are at a practical minimum. Increasing the power dissipation in the resistor beyond this point increases the energy in the fault arc and therefore the degree of damage. Primary voltage rating of the distribution transformer is required to be equal to be generator to neutral voltage and the practice is to keep it rated generator phase to phase voltage. The secondary winding is 110/220 volts. The secondary resistor is selected so that for a single phase to ground fault at the generator terminal, the power dissipated in the resistor is equal to or greater than three time the zero sequence capacitive kVA to ground of the generator winding and all other equipment that may be connected to machine terminals. This method is considered high resistance grounding.

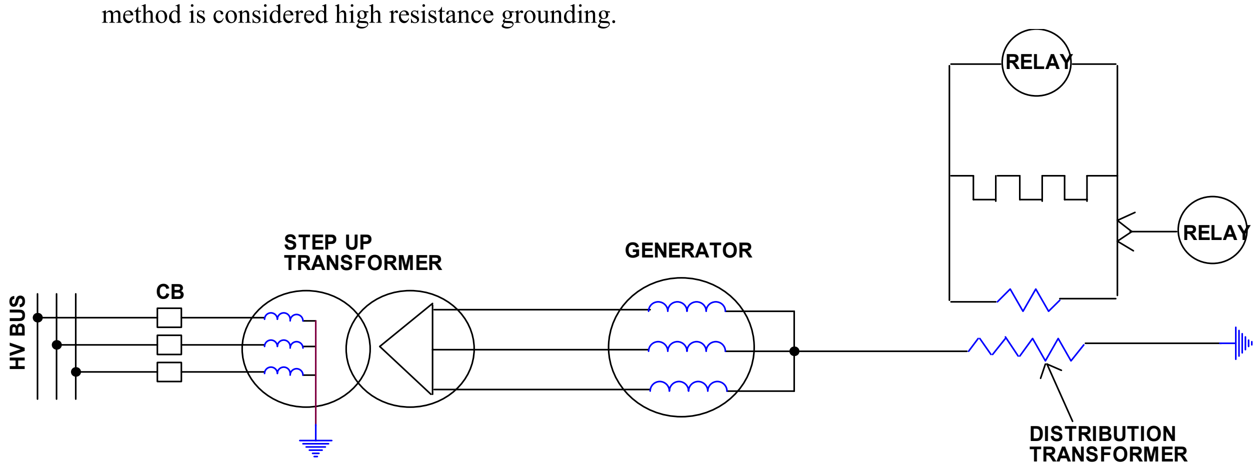


Figure 3.13 Distribution transformer grounding scheme for unit connected generator

Calculation carried out for Mukerian (2 x 9 MW) hydro project (single line diagram shown in Figure 3.13) illustrate the method of calculating the size of loading resistor and transformer.

Neutral Grounding Transformer Calculation

1.	Data for Calculations:		
a)	Generator capacitance to ground per phase (Cg)	=	micro farads (μF)
		=	0.535 μF
b)	Surge protection capacitance per phase (Cs)	=	micro farads
		=	0.25 μF
c)	Capacitance of transformer (LV winding), gen. bus cables to ground per phase ($C_{tl)}$	=	micro farads
		=	0.15 μF

Total capacitance (C) to ground per phase

C = Cg + Cs + Ctl (micro farads/phase)

= 0.535 + 0.25+0.15 = 0.935 μF/phase

2. Calculation of zero phase sequence current (Io) during a line – to- ground fault and the charging capacity (capacitive kVA)

The capacitaive reactance (Xc) and zero phase current (Io) are calculated by following formulas.

$$X_c = 1/(2*\pi*F*C)$$

$$= \frac{1}{2 \times \pi \times 50 \times 0.935 \times 10^{-6}}$$

= 3404.38 ohm ≈ 3400 ohm

$$I_o = 3*(1/X_c)*(V_{L\text{-}L}/\sqrt{3})$$

$$= \frac{3 \times 11000}{\sqrt{3 \times 3400}}$$

= 5.6A

Where,

$V_{L\text{-}L}$ = Generator line-to-line voltage (V) = 11000

F = Rated frequency (Hz) = 50

Therefore, the capacitance kVA is calculated by

Capacitance kVA = $(V_{L\text{-}L}/\sqrt{3}) * Io*10^{-3}$

= $(11000/\sqrt{3})*5.6*10^{-3}$

= 35.56 kVA

= 40 kVA (one minute rating)

3. Rating Neutral Grounding Transformer

The neutral grounding transformer was provided with the capacity equal to the capacitive kVA as calculated above and the capacity was applied on the basis of 1 – minute rating.

Transformer kVA (continuous) = capacitive kVA/K = 40/4.7

= 8.5 kVA

= 10 kVA (Nearest standard rating)

Where K = Ratio of the capacity of 1 – minute rating To that of continuous rating

= 4.7 as per standards

The rating of the neutral grounding transformer was as follows:

Capacity	:	10kVA continuous rating
Primary/Secondary voltages	:	11000/220 volts
Frequency	:	50Hz
Type	:	single phase, dry type

Neutral Grounding Resistor Calculation

Rating of secondary resistor

Secondary current (I_R) of neutral grounding transformer is given by

$$
\begin{aligned}
I_R &= N^* Io \\
&= 50 \times 5.6 \\
&= 280 \text{ Amp.}
\end{aligned}
$$

$$
\begin{aligned}
\text{Where } N &= \text{Grounding transformer turns ratio} \\
&= 11000/220 \\
&= 50
\end{aligned}
$$

The kW loss in the secondary resistor during the ground fault will be equal to the capacitive kVA

Therefore, the secondary resistance (R_S) is as follows:

$$R_S = \text{Capacitive kVA} * 10^3 / (I_R)^2 = \frac{35.54 \times 10^3}{(280)^2}$$

$$= 0.453 \text{ ohm}$$

The rating of the secondary resistor should be as follows:

Resistance	=	0.45 ohm
Rated Current	=	300 Amp.
Voltage	=	220 Volts

Since the protective relay is arranged to shut down the set completely upon the concurrence of a stator earth fault, the distribution transformer and loading resistor need not be continuously rated, a one minute or 30 seconds rating being adequate. For Dehar power plant 2 minutes rating was specified.

This is the most common method of large unit connected generator grounding.

Zero sequence voltage relay will detect faults to within 2-5% of the stator neutral. There are several schemes for detecting ground faults at or near the neutral. The schemes use third harmonic voltage at the neutral or at the generator terminals as a means to detect faults near the stator neutral. Reference may be made to IEEE std. C37 – 102-1995.

Grounding Fault Neutralizer

In this method the generator neutral is earthed through a choke coil the inductance of which neutralizes the capacitance to earth of the generator, connecting leads and low phase winding of power transformer. The non compensated capacity current is used for earth fault detection.

In Bhakra Right Bank the maximum capacitive currents worked out to 7.4A and out of which 6.1 amps are neutralized by a choke coil. A voltage relay connected to the secondary winding of the choke coil actuates an alarm and tripping. A volt meter connected across to choke approximately determines the point of earth fault.

With this arrangement over voltages were proposed to be obviated and unit could continue to operate for a period after an insulation failure with minimum danger of further internal damage and thus improve continuity of supply.

100% Stator Ground fault 3rd harmonic Method for Large Machines

This protection is now being offered in digital protection relays and may be provided in Mega/Large generators.

Third harmonic neutral under voltage protection covers the final 15% of the stator winding and, in conjunction with the other ground fault elements, provides 100% ground fault protection for the stator. This is supervised by a three phase under voltage element. Additional supervision using three phase active, reactive and apparent power can be enabled if required. A third harmonic neutral over voltage protection is also provided for applications where the measurement is available at the terminal end of the generator. The blocking features of the under voltage element are not required for this application.

3.3.7 Generator Rotor Earth Fault Protection

There are several methods to detect this type of fault in static excitation system. They are:

1. Potentiometer Method
2. AC Injection method
3. DC Injection method

Each scheme relies upon the rotor earth fault closing an electrical circuit, the protection relay forming one branch of the circuit.

3.3.7.1 Potentiometer method

The scheme for protection against earth is shown in figures 3.14. The earth fault protective gear consists of centre tapped resistor connected across the field winding and a sensitive relay connected between the centre tap and earth. These are equipotential point so long as there is no earth fault on the winding. The occurrence of an earth fault, however, upsets the balance and the relay respond to earth fault occurring over most of the rotor circuit and about 95% of field winding can be protected. If the tap on the resistor is varied then complete protection can be afforded. This scheme has been provided in Bhakra Left Bank Power Units.

The obvious disadvantage to this is that a relay blind spot exist for faults at the centre of the field winding. To prevent an earth fault in this operation remaining undetected, it is usual to displace the centre tap of the resistor by a push button or switch. When this type of rotor earth fault protection is employed, it is essential that station instructions are issued to ensure that the 'blind spot' is checked at least once a shift.

The main advantages of the scheme are its simplicity and the fact that it does not need any auxiliary supply.

3.3.7.2 AC Injection Method

The scheme is shown in figure 3.15. One point of the field circuit is earthed through a static condenser. The protective condenser is in series with the capacity of the complete exciter circuit. In case of an earth fault in the field circuit, the secondary circuit of the auxiliary transformer is closed through the voltage relay, condenser and part of the field circuit and earth fault causing the relay to operate. This scheme has been adopted in Bhakra Right Bank and provides complete coverage to rotor winding.

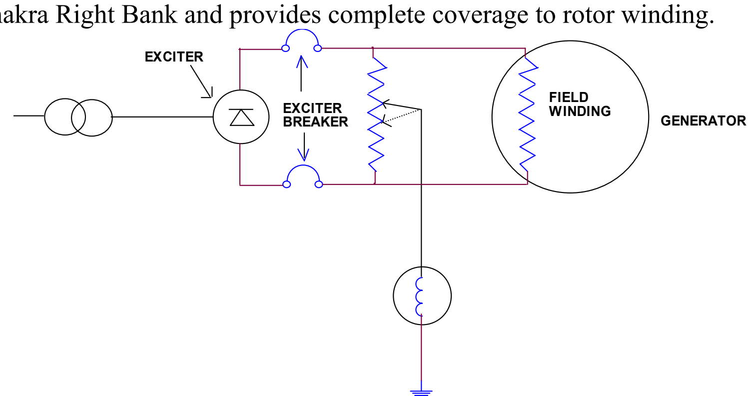


Figure 3.14 Generator earth fault protection using potentiometer

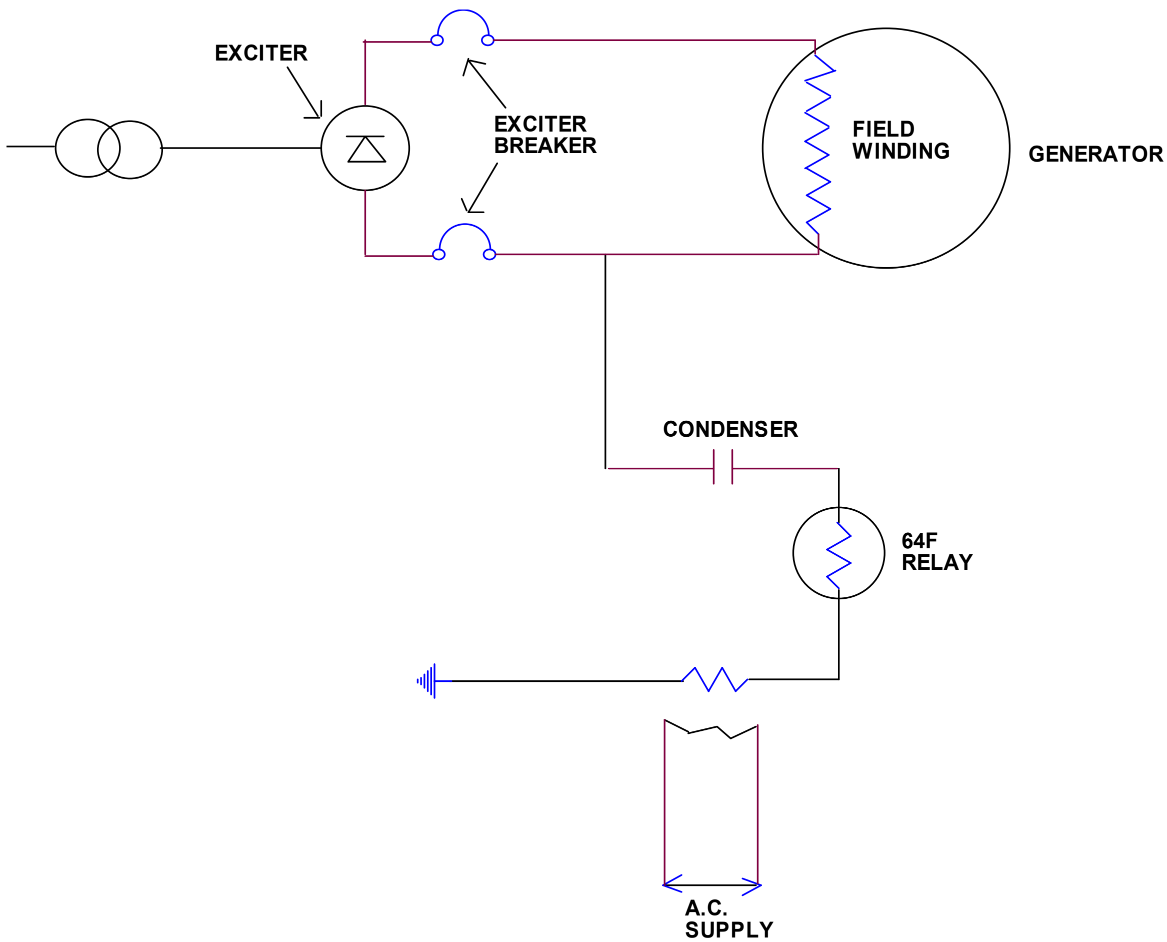


Figure 3.15 Generator earth fault protection using A. C. injection

This scheme is free from blind spots, it can have a high degree of sensitivity consistent with the withstand limitations of the relay and it is impervious to switching surges in the main field current. It has a disadvantage that there is always a small leakage current circulating due to the capacitance between the field and earth which has injurious effects on the bearings of the machine.

The relay is usually arranged to give alarm only and it is usually only necessary to disconnect the machines in un-attended stations.

3.3.7.3 DC Injection Method

The scheme is shown in Figure 3.16 the field circuit is biased relative to earth by means of a small transformer rectifier unit connected between the positive pole of the field system and the earth, a highly sensitive relay being included in this connection. A brush is used to ground the rotor shaft since bearing oil film may insert enough resistor in the circuit preventing relay operation on ground fault. One to three second time delay is normally used to prevent unnecessary operation of the relay for momentary transient unbalances of filed circuit to ground caused by fast response thyristor. The positive pole of the field system is biased about say 40 volts negative to earth and the remaining portion of the field circuit are proportionally more negative. A fault occurring at any point in the field system will apply to the relay which is sufficient to cause operation by the potential relay. This relay was specified for Dehar and Pong Power plants of Beas projects.

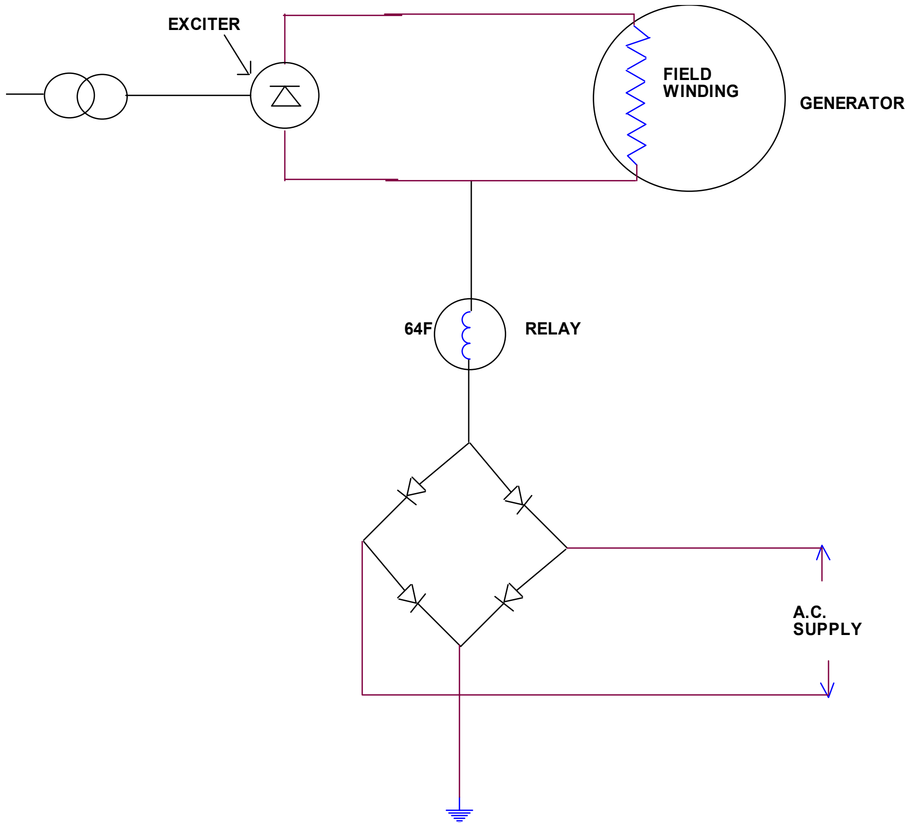


Figure 3.16 Rotor earth fault protection using DC injection

3.3.7.4 Rotor Earth fault Brushless Excitation System

Brushless excitation system field ground detection is not possible with conventional ground relay since the generator field connections are contained in the rotating element. It is not generally provided for this reason on the brushless generators. It is considered that this protection should be provided for brushless generators above 5 MW capacity unit size. Two methods for detection earth faults as per IEEE std. C 37 102 are outlined below.

In one method a collector ring is provided on the rotating shaft to a access the field along with a pilot brush periodically dropped to monitor the system. This method does not provide continuous monitoring.

Continuous monitoring of the field current on brushless machine is recommended by mounting a transmitter on generator filed diode wheel. Transmitter is powered by a.c. brushless excitation system. Ground detection is the obtained by connecting one lead of the transmitter to the negative bus of the field rectifier and the ground lead to the rotor shaft. Under normal conditions the transmitter emits light from light emitting diode which is stopped on field earth. A receiver on the exciter housing senses the light signal and is turned off when rotor fault occurs. This actuates an alarm or trip.

3.3.7.5 Back up Protection

Back up for rotor earth fault protection is provided by vibration detectors provided to trip the main and field breakers if vibration is above that associated with normal short circuit transients for faults external to the units. Shaft vibration detectors were specified for Mukerain Hydro project.

3.3.8 Filed Failure

Failure of the field system results in a generator operating at above synchronous speed as an induction generator, drawing magnetizing current from the system, provided the system is capable of supplying the additional reactive power for excitation, which can approach the full load exciter rating of the machine;

there is no risk of system instability. However, overloading of the stator and overheating of the rotor result from continued operation, therefore the machine should be disconnected and shut down if the field cannot be restored. The size of the machine relative to the system is significant, and where it is assessed that system instability would result from loss of field, the machine must be disconnected and shut down immediately.

Two schemes are available for protection against loss of field, one employs an undercurrent relay operating from a shunt in the main field current, the other comprises an offset mho distance relay connected in to the stator circuits. The under current method, illustrated in figure 3.17 is simple and cheap, but suffers from a number of fundamental disadvantages. Firstly, if the relay is to operate for complete loss of field alone it must have a setting which lies well below the minimum exciting current value, which can be 7 - 8% of the rated full load current.

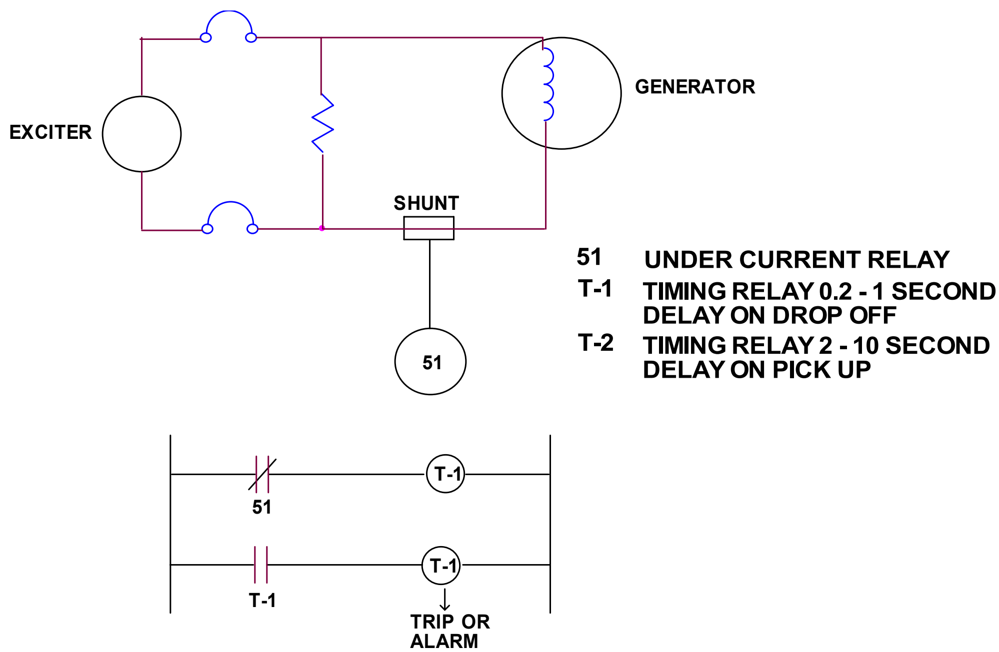


Figure 3.17 Loss of field by under current relay

Secondly, when loss of field is due to exciter failure, the field circuit remaining intact, slip frequency currents are induced into the field circuit. Thus the relay picks up and drops off at slip frequency. To overcome this problem the relay is applied with time relays as shown in Figure 3.18. Normally close contact of under current relay 51 is held open during normal operation. On loss of filed it closes to energizes timing relay T1 which energize timer with an adjustable time of 2 to 10 seconds. Relay 51 is time delayed on drop off to stabilize scheme against slip frequency effects. This scheme is recommended for small machines only.

Distance relays are most widely used for loss of filed protection. These relays sense the variation of impedance as viewed from generator terminals. This scheme is recommended for all large, important sets and allows for tripping the machine in the presence of swing conditions resulting from loss of field, and, initiates load shedding with subsequent tripping of the machine if the field is not restored within a prescribed time. The scheme comprises an offset mho relay and connections are given in figure 3.18.

In Bhakra Left and Right Bank Power Plant units a current relay in the rotor circuit has been provided to supervise the field system. Modern voltage regulators are liable to vary the field current over a wide range and under certain circumstances may swing down to about 20-25 percent of no-load excitation value. The relay should not respond to these transient offsets and a low setting with time delay feature is thus required. A relay to detect induction generation of the unit is also used for this detection. In Dehar Power House, a mho type relay has been used for this purpose because of negative excitation provision for line charing (see diagram 3.18).

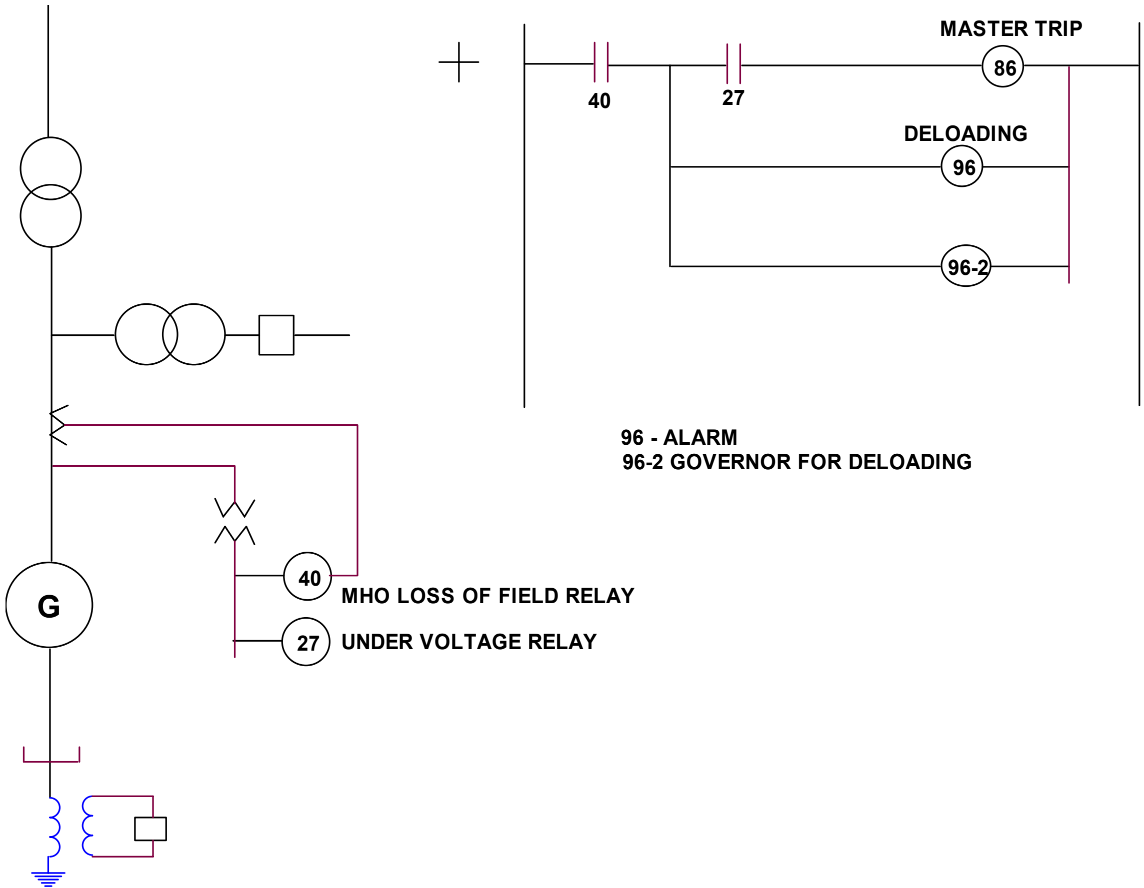


Figure 3.18 Loss of field protection using Mho relay

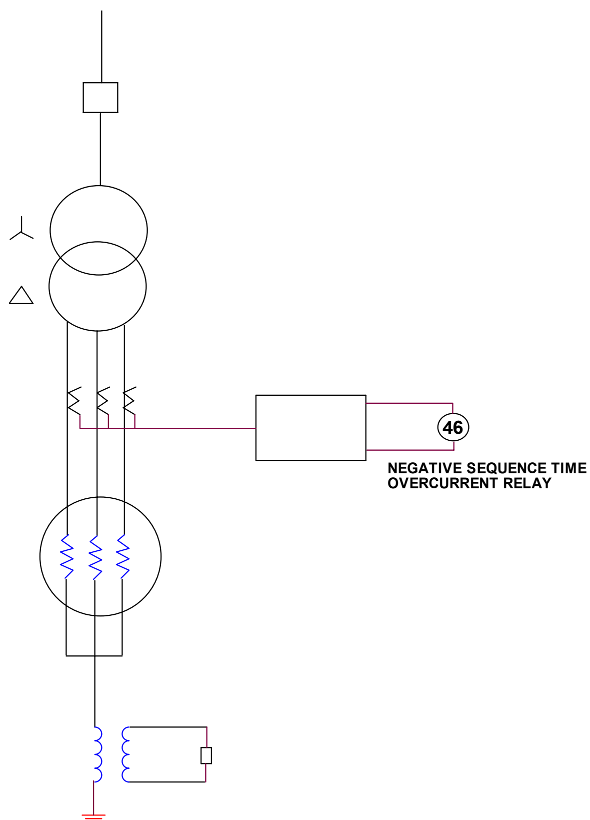


Figure 3.19 – Unbalanced Current – Protection

3.3.9 UNBALANCED STATOR LOADING PROTECTION

Negative sequence currents result in heating of the rotor, therefore, the amount of negative sequence current existing for any appreciable time must be strictly limited. This applies more to steam generators with cylindrical rotors rather than to hydro-generators of the salient pole type, since, in the latter case, the damper winding provide a path for the double frequency currents.

Internal stator faults are cleared instantaneously by the differential protection but external faults or unbalance resulting from an open circuit may remain undetected or persist for a significant period depending on the protection co-ordination of the system. It is therefore, necessary to install a negative phase sequence relay with a characteristics to match the withstand curve of the machine. A practices is to provide protection for the generator for external unbalanced condition that might damage the machine. The protection consist of a time over current relay which is responsive to negative sequence current as shown in Figure 3.19. The relay is arranged to trip the main generator circuit breaker and give an alarm.

Negative sequence protection for unbalanced loading has not been provided for Bhakra Left Bank Units. For Bhakra Right Bank Units and Dehar & pong Units of Beas negative sequence relay give alarm at a lower setting and trip the unit at a higher setting. This also acts as back-up for in zone faults to differential relays. In small hydro negative phase sequence protection for phase unbalance only is provided.

3.3.10 Loss of Synchronism

Large machines connected to EHV system having low inertia constant and increased generator per unit reactance result in reduced critical time to isolate faults near a generating plant before generator loses synchronism with power system resulting in low system voltage, machine excitation etc. The operation may cause winding stresses, mechanical stress and damage generator and turbine shaft. The generator should be tripped during first half cycle of a loss of synchronism. A separate out of step relaying should be provided on large machines.

Impedance relay are used and most cases generator can be separated before the completion of step cycle. For specific cases stability studies may be required for selection of an out-of-step relay or scheme. Tripping of main generator with its auxiliaries is adequate. This scheme was not provided at Dehar Power Plant unit connected to EHV system.

3.3.11 Failure of Prime Mover

The effect of prime mover failure is to cause the machine to ‘motor’ by taking power from the system. The seriousness of this condition depends on the type of drive used for the generator.

Hydro sets do not normally require electrical protection against motoring, since mechanical protections usually take action to disconnect the generator from the system should the water flow drop to a level insufficient to maintain the electrical output.

As there is a power reversal when the machine motors a power relay with a directional characteristics would detect this condition over the full p. f. range. This type of relay would also operate for power swing conditions and when the machine is being synchronized or during power swings caused by system disturbances.

Therefore, to prevent unwanted operations, it is usual in this application to introduce a time delay. About 30 second time delay to prevent operation during power swings caused by system disturbances or when synchronizing is normal. This is arranged by utilizing a separate timing relay, or by an inverse time reverse power relay, which combines the time and power direction characteristics delivered with the additional facility that heavy motoring loads are cleared promptly.

Reverse power relay is not provided on large hydro Bhakra Beas complex but provided on all small hydro.

3.3.12 Over Voltage Protection

Load rejection in hydro generators may cause voltage rise due to speed rise. In units connected to EHV lines a further proportional rise in voltage may occur if receiving end breaker of long interconnecting transmission line is tripped. The uncompensated capacitance of the line will further increase the voltage. At Dehar power palnt of Beas Satluj link project computer studies indicated that tripping of 420 kV line at receiving end result in 170% voltage rise.

Protection for generator overvoltage is provided by frequency insensitive overvoltage relay. It has both instantaneous and time delay units with inverse time characteristics. Instantaneous inverse time set up to about 150% while inverse time is set to pick up 110% of normal voltages. The protection is set to trip main generator breaker and field breaker.

3.3.13 Back up Over Current Protection

Back-up over current protection may be provided to generator either (i) as standby protection against faults in the network or (ii) as a safeguard against failure of the generator unit protection.

In connection with the first case, the question of setting must be carefully considered and the rapid decrement of fault current fed by the generator must be taken into account. It is important that the generator is not tripped as a result of system faults even through the generator is operating under its maximum excitation condition and the relay setting must be chosen to discriminate with the outgoing circuit protection. The main aim is to provide a back-up protection and the over current relays are set, not so much with the intension of tripping under through faults but rather to guard against fault currents fed back from the system upon the occurrence of an in zone fault. So it is most usually provided with a voltage restraint and inverse time delay features so that tripping occurs only in case there is a fall in the generator voltage.

Over current voltage restraint relay serves as a very useful standby system of protection for such periods as for example when the differential protection is being tested at which time the over current settings can be varied at discretion to suit the temporary condition.

Back-up over current voltage restraint protection has been provided for Bhakra Left , Bhakra Right and Beas project units. With the advent of modern static quick response type automatic voltage regulators controlling large reserves of excitation power, the generator circuit decrement in fault condition is delayed so that over-current/times settings can be chosen so as to give back up cover against through fault conditions as well.

In general the question whether or not back up over current protection is to be provided and what time and current settings should be used must be considered separately for such installation in the light of discussion as above.

IEEE std. C37.102 – 19925 also recommends alternately distance type of back up relay when over current relay is used for line protection.

3.3.14 Numerical Generator Protection relays

Multi function Digital Generator protection relays providing flexible, integration of protection, control, monitoring and measurement functions from small generators up to large generators are now available. Some of the multifunctional relays of some manufacturers as per available catalogues/data are discussed below for illustration. Latest catalogues of the manufacturers should be used in consultation with supplier/manufacturer. Limited back up protection by conventional relays is provided for card failure contingency.

3.3.14.1 Areva Multifunction Digital Generator Protection Relays

Functions available as per relays catalogue for MICOM relay for generator protection is shown in figure 3.20 and summarized in table 3.4.

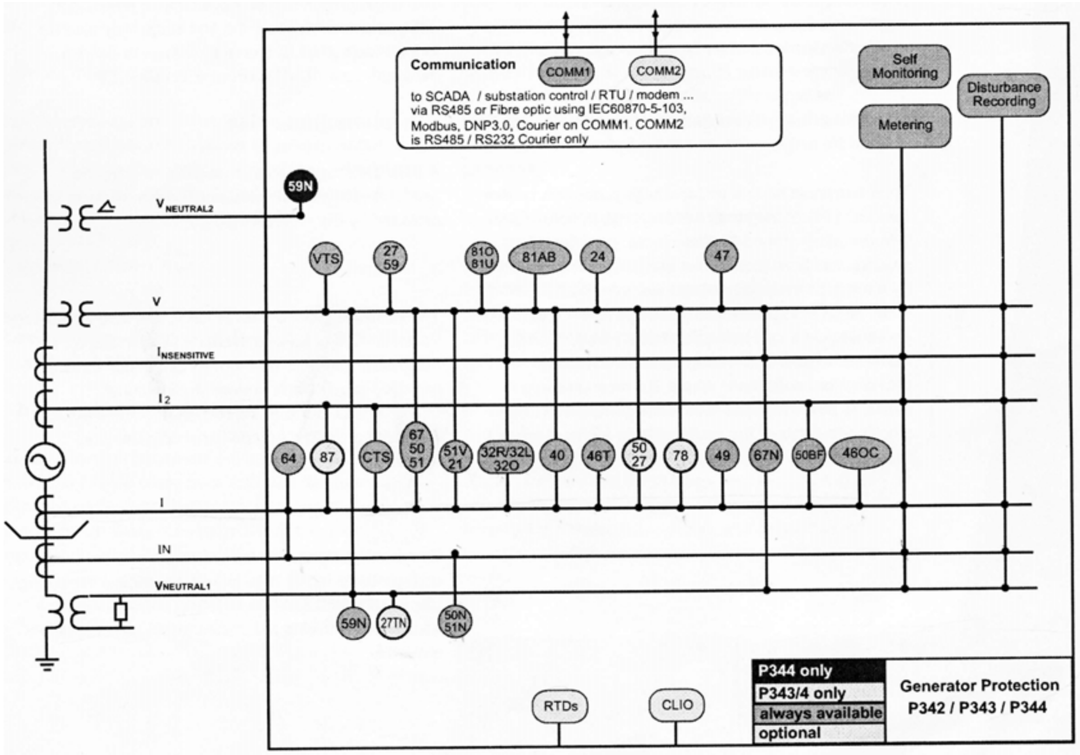


Figure 3.20: Functional Overview - Areva Numerical Generator Protection Relay

P342 may be used for small generators where differential protection is not required. P343 can be used for medium generators up to 50,000 kVA & P344 may be used for large/mega generators.

Table 3.4

Functions overview		P342	P343	P344
		Settings		
87	Differential Interturn (split phase)	- -	1 1	1 1
50/51/67	Directional/non directional, instantaneous/ time delayed phase over current	4	4	4
50N/51N	Non directional, instantaneous/ time delayed phase ground fault	2	2	2
67N/67W	Sensitive directional earth fault/wattmeteric ground fault	1	1	1
64	Restricted ground fault	1	1	1
51V	Voltage dependant over current	1	1	1
21	Under impedance	2	2	2
59N	Neutral voltage displacement/residual overvoltage, interturn – measured (M), derived (D)	2M/2D	2M/2D	2M/2M
27/59	Under/over voltage	2/2	2/2	2/2
81U/81O	Under/over frequency	2/4	2/4	2/4
81AB	Turbine abnormal frequency	6	6	6
32R/32L/32O	Reverse/Low Forward/Over power	2	2	2

40	Loss of field	2	2	2
46T	Negative phase sequence thermal	2	2	2
46OC	Directional/Non directional, negative phase sequence over current	4	4	4
47	Negative phase overvoltage	1	1	1
49	Stator thermal overload	2	2	2
24	Over fluxing	5	5	5
78	Ploe slipping	-	1	1
27TN/59TN	100% stator earth fault 3rd harmonic neutral under/over voltage)	-	1	1
50/27	Unintentional energisation at standstill	-	1	1
50BF	CB fail	2	2	2
	Current transformer supervision	1	1	1
	Voltage transformer supervision	1	1	1
	RTDS x 10 PT 100	Option	Option	Option

3.3.14.2 Woodward Multifunction Digital Generator Protection Relays

Woodward offers a series of industrial grade multifunction digital protection relays that offer multiple protective features in a single package e.g. MFR 13 model for generator protection unit is shown in figure 3.21. Functionality available are summarized in table 3.3.14.2.

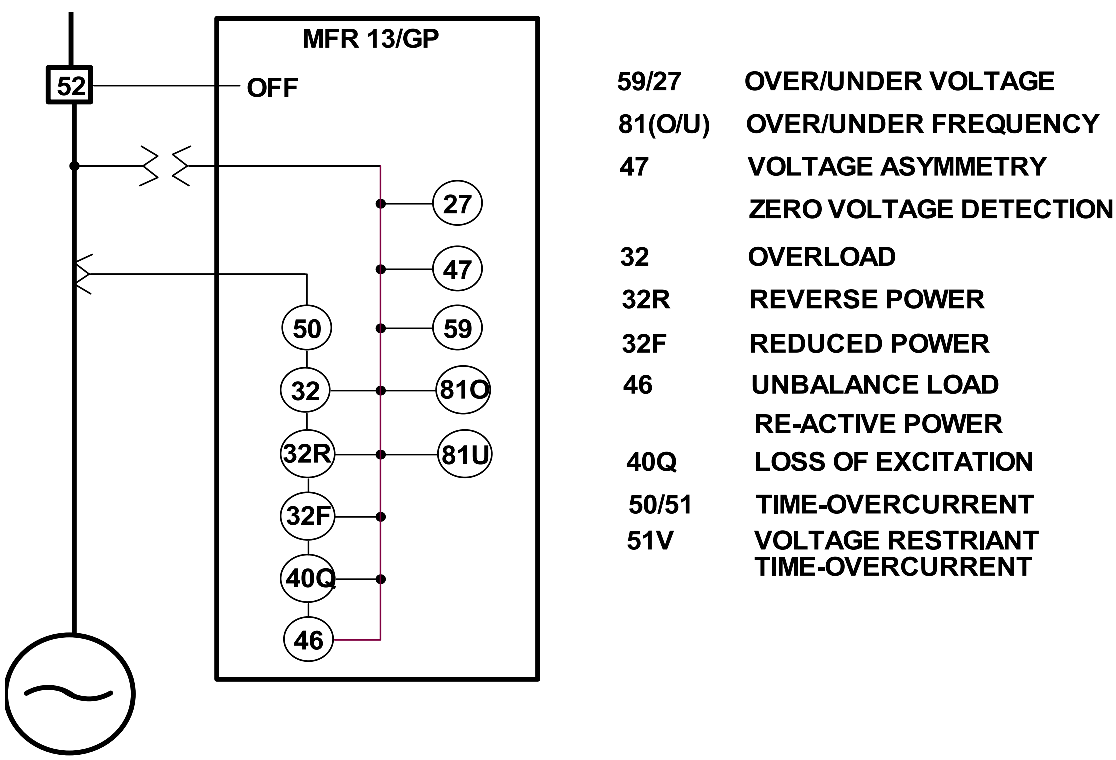


Figure 3.21: MFR 13 Protection Relay

Digital Protection relay ESDR4 is for Generator current differential and ESDR 4T is for generator transformer current differential protection.

3.3.14.3 Siemens Multifunction Digital Generator Protection Relays

Numerical generator protection relay functions available in Siemens (SIPROTEC) are given in table 3.5 for medium size generators. SJ relays in the table are recommended for small generators and SUM type for medium size generator up to 50 MW. Differential relays are available in 7 UM62 and above.

3.3.15 Tripping and Annunciation

Typical tripping annunciation block diagram for a medium/large generator is shown in figure 2.20.

Table 3.5

PROTECTION FUNCTION	ANSI	7SJ60	7SJ61	7SJ62	7SJ63/64	7UM61
Rotor overload protection	49	X	X	X	X	X
Earth fault protection directional/non directional	64G 50G 67G	X X X	 X 	X X X	X X X	X X X
Over current time protection	50 51	X	X	X	X	X
Negative sequence protection	46	X	X	X	X	X
Rotor earth fault protection	64R		X	X	X	X
Reverse power protection	32				X	X
Over current protection	59			X	X	X
Under excitation protection	40					X
Frequency protection	81			X	X	X
Temperature monitoring (by an external monitoring box called thermo box)	38	X		X	X	X
Breaker failure protection	50BF	X	X	X	X	X
Programmable logic			X	X	X	X
Control functions		X	X	X	X	X
Flexible serial interface		1	2	2	2/3	2

3.3.16 Protection Schemes

3.3.16.1 Small Hydro Generator Protection Scheme

Small hydro generator protection required to be provided for generator up to 5 MW is based upon recommendation by different agencies as given in table 3.6 and subsequent policy of the government to make provision for interconnection of all hydro electric plants with grid including micro hydro for economical consideration as well as continuity of power supply in remote area electrified by microhydro.

In actual modern practice generator electrical protection is now provided to take care of following aspects.

i) Interconnection of all hydro electric plants with grid including micro hydro from economical consideration as well as for continuity of power supply in remote area electrified by microhydro.

ii) Isolated operation for supply of power to local areas in case of grid failure. A large unbalance in 3 phases was observed in such cases. Commercial generators used in small hydro allow a maximum 30% variation in phase currents. Protection for phase unbalance is required.

Table 3.6: Generator Protection Schemes Recommendations for Small Hydro up to 5 MW

<table>
<tr><th rowspan="2">Sl. No.</th><th rowspan="2">Generator Rating</th><th rowspan="2">Central Board of Irrigation Power Pub. No. 175 SHP Standardization</th><th colspan="2">Micro Hydro Standards (AHEC) for generators up to 100 kW</th><th rowspan="2">IEC Standard 1116 SHP E & M Equipment up to 3 MW unit size generator</th><th rowspan="2">AHEC Guidelines for Control Automation, Protection & Metering of SHP up to 25 MW</th></tr>
<tr><th>Gen up to 10 kW</th><th>Gen. above 10 kW</th></tr>
<tr><td rowspan="2">1.</td><td rowspan="2">Gen. up to 1000 kW</td><td rowspan="2">i. Restricted earth fault protection (64 GT) single CT on the neutral side and three CTs on the phases.

ii. Voltage controlled over-current relay (51 VR) in case sustained fault current is less than the full load current. Otherwise

• Over-current/earth fault relay (51 & 64) if the generator and the step up transformer are connected in unit system.

• Over-current/earth fault relay may not be provided if generator circuit breaker with thermal overload and instantaneous magnetic short circuit release is provided on the line terminal.</td><td colspan="2">• MCB/MCCB with shunt trip coil and adjustable over-current protection

• Earth leakage circuit breaker (ELCB)/ Residual current operated circuit breaker</td><td rowspan="3">Over current (stator & rotor protection)

Earth fault stator and rotor

Over/under voltage

Over/under frequency

Power reversal

Differential protection for large units when justified.</td><td rowspan="3">a) Micro hydro generators – As per AHEC Micro Hydro Standards

b) Generator up to 5 MW as per IEC 1116 for synchronous and asynchronous

Digital Multifunction generators relay Category 1 corresponding to Areva P342 may be used where differential protection is not required.

Category 2 (P343) where differential protection is required

c) Generators 5 MW to 25 MW

Category 3 (P344) for generator above 5 MW

Suitable back up protection be provided</td></tr>
<tr><td></td><td>Over current

Over/under voltage

Over/under frequency

Reverse power

Stator temperature

Bearing temperature</td></tr>
<tr><td>2.</td><td>Gen. above 1000 kW and up to 5000 kW</td><td>i. Three pole differential relay (87 G) – 3

CTs on the neutral of the generator and

3 CTs on the phases.

ii. Voltage controlled over-current relay (51 VR)/over-current and earth fault relay (51 & 64) as mentioned as above.

iii. Rotor earth fault protection single phase (60 F)

iv. Stator earth fault protection (64 G)

v. Over voltage protection (59)

vi. Field failure protection (40) for synchronous generators

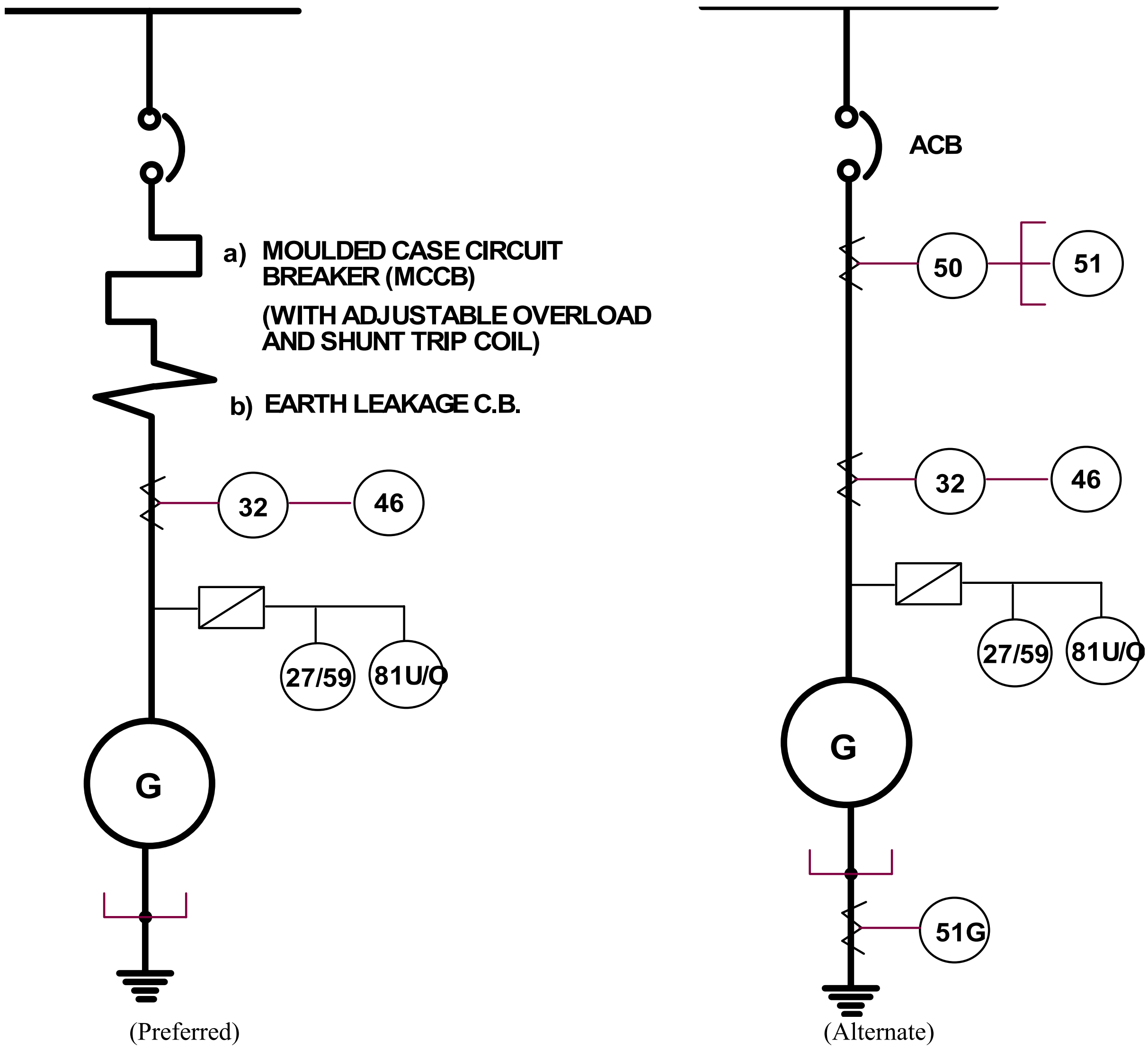
vii. Instantaneous over-current relay (50) and over-current relay (51) in the tapping for excitation transformer (static excitation system) if used.</td><td colspan="2"></td></tr>
</table>

3.3.16.2 Typical Protection scheme provided for small hydro by conventional relays

Figure 3.22 (a), (b) & (c) for micro hydro and Generators up to 300 kW unit size.

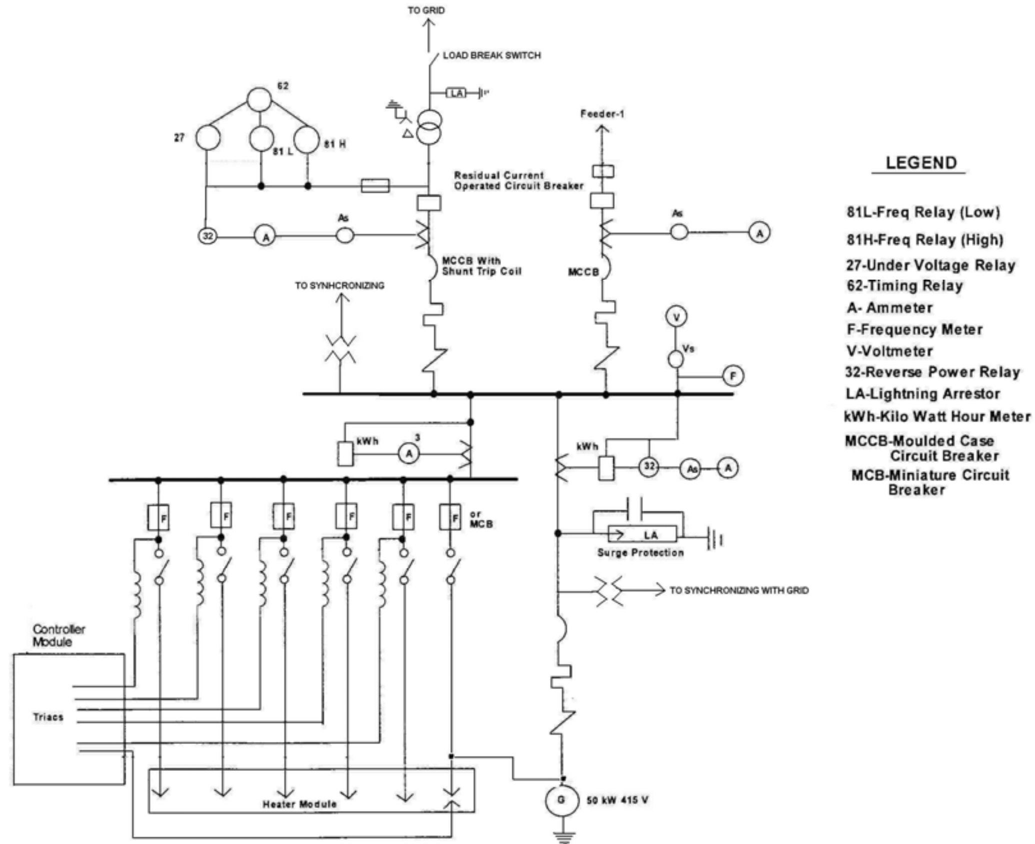
Figure 3.23 (a) & (b) for Generator above 300 kW.

Figure 3.24 (a) & (b) for Generators 301 kW to 5000 kW



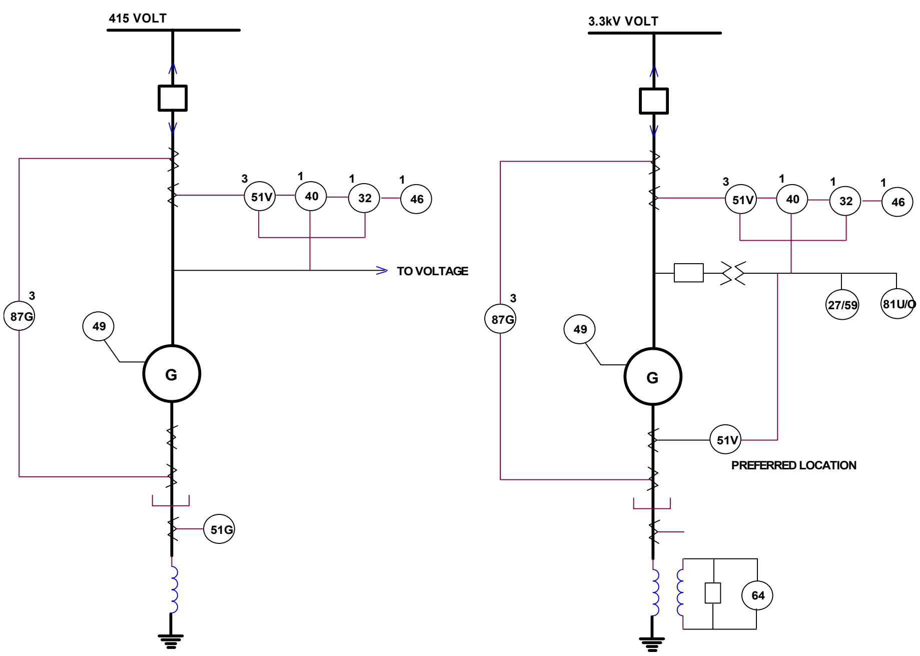
27/59	Under/over voltage
32	Reverse power relay
46	Phase unbalance (current)
50	Over current - 2 phases
51N	Ground time over current relay
81U/81O	Under over frequency

Figure 3.22 (a) & (b) Generator Protection - (Micro Hydro & SHP up to 300 kW) (AHEC Practice)



Generator Protection - (Micro Hydro)

Figure 3.22 (c): A Typical Metering, Relaying and Interconnection with Grid as per Micro Hydro Standards with Electronic Load Controller (ELC)



Low voltage (415 V) generator interconnected to sub transmission (11/33 kV) system

Medium voltage (3.3 to 11 kV) interconnected to sub transmission (11/33 kV) system

Figure 3.23 (a) & (b) Generator SHP 300 to 5000 kW with conventional relays

Protection for small hydro unit suitable for interconnection with grid as per practice is shown in figure 3.23 (a) & (b) and consist of following devices.

27/59	Under/over voltage
32	Reverse power relay
46	Phase unbalance (current)
49	Temperature relay to monitor winding temperature
50	Over current - 2 phases
51G	Ground time over current relay
51V	Voltage restraint/controlled over current
64F	Generator field ground relay
64G	Generator ground fault current
81U/81O	Under over frequency
87G	Generator Differential Relay (Impedance type)

Mechanical protections
Overspeed
Bearing temperature

3.3.16.3 Typical protection schemes with multifunction numerical generator protection relays

Protection scheme for Halaipani Project in North-East given in figure 3.24

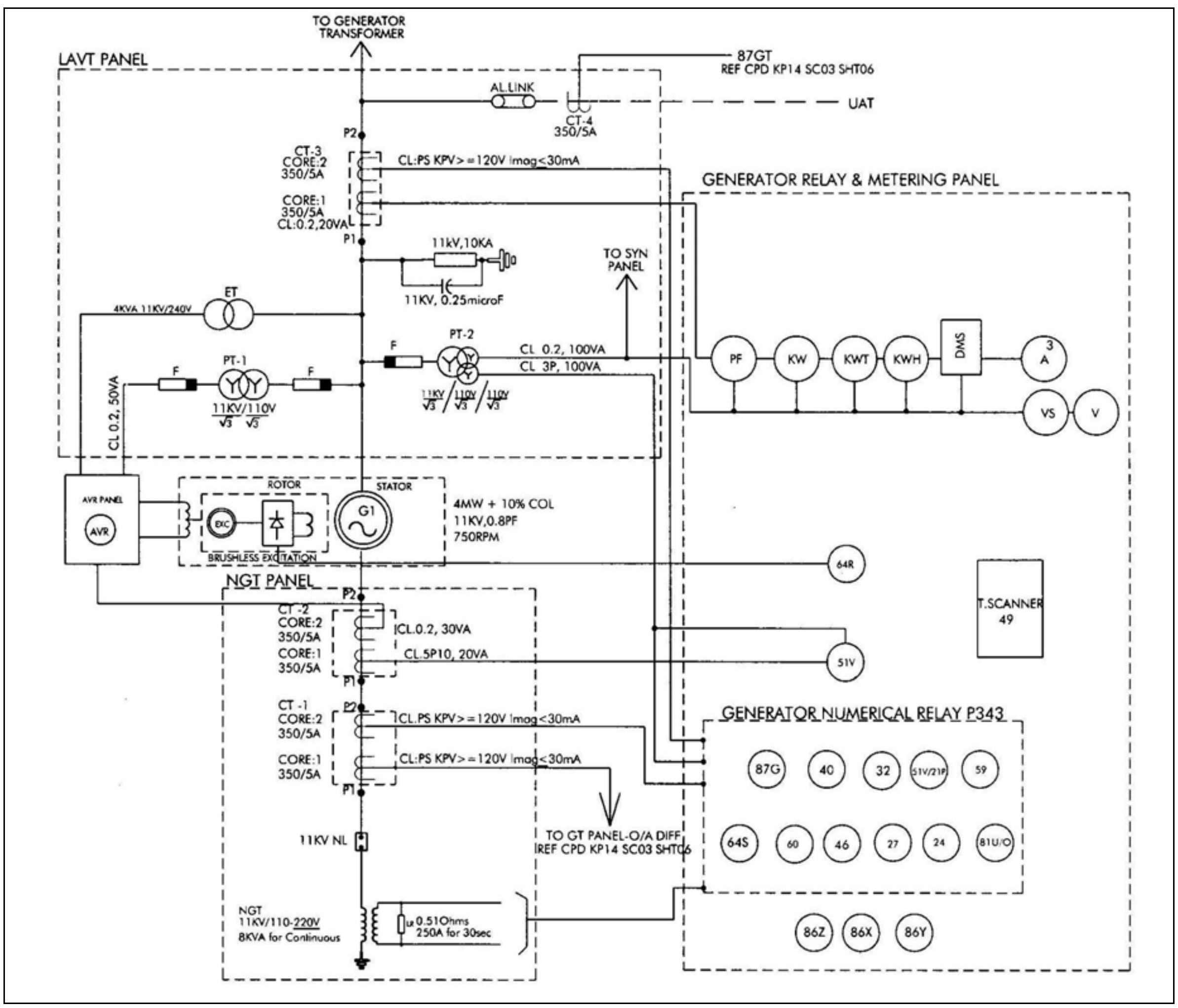
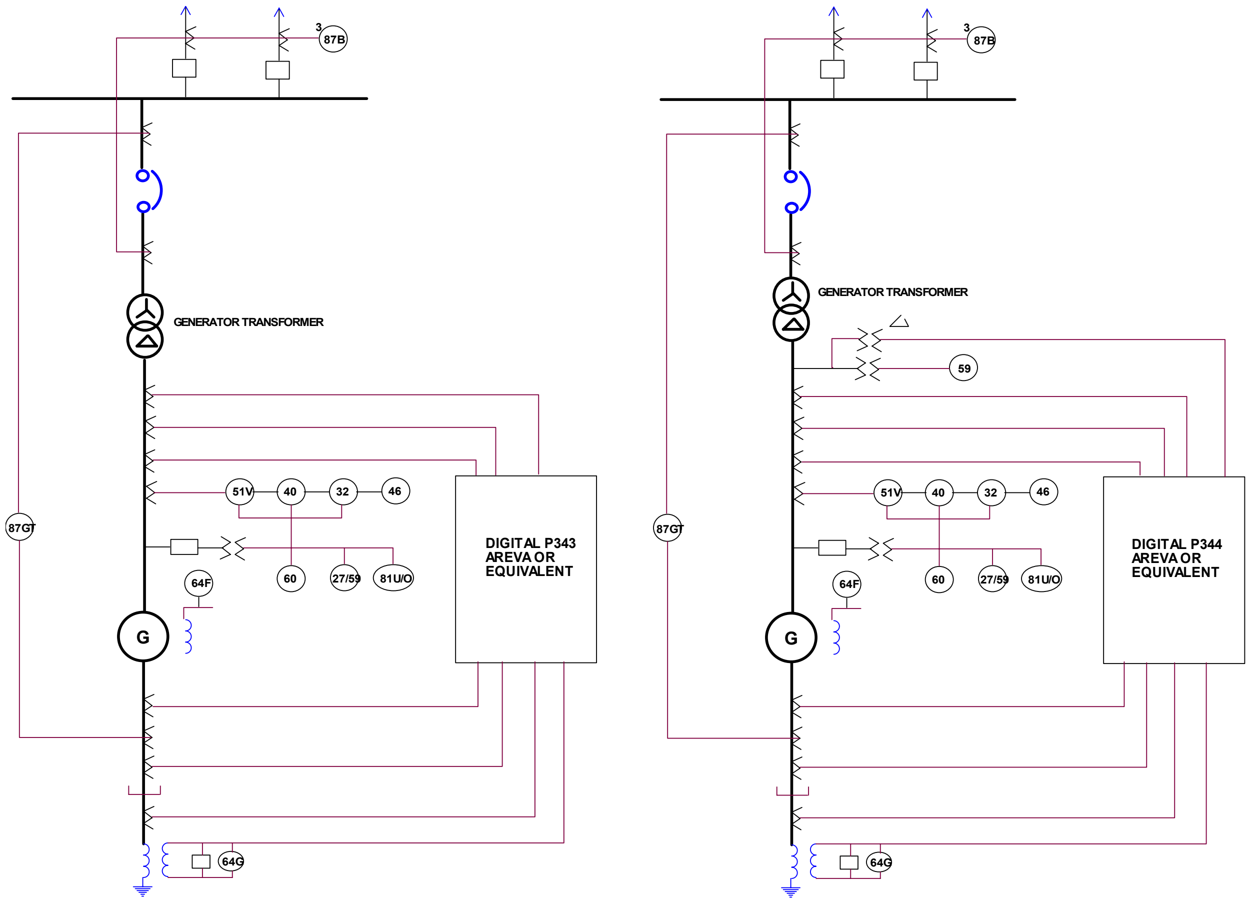


Figure 3.24 Multifunction Generator Relays ???

Notes:

1. Unit Metering & Relaying Single Line is as per Figure 2.51
2. Back up electromagnetic relays provided are i) voltage restraint over current relay (41V), ii) Rotor earth fault relay (64R), iii) Overall generator transformer differential is from transformer multifunction relay

Protection scheme for large generators may be provided as shown in figure 3.25 (a).



(a) **For Large Generator** (b) **For Mega generator**

Figure 3.25 :Generator connected to generator transformer without intervening breaker

Protection as per small hydro and in addition provide following.

i) Generator protection to be high speed percentage biased differential protection
ii) Backup generator transformer high speed differential protection from transformer numerical protection relay
iii) Separate PTs for metering & voltage regulation
iv) 64F – Generator field ground fault relay
v) 60 – Voltage balance relay for PT failure
vi) 87 B – High speed bus differential relay

Although (v) & (vi) they are not generator protection, they provide high speed clearing of bus fault and therefore generator back up over-current relays are not required to perform this primary function.

Large/Mega Generators (above 50,000 kVA)

Protection scheme for Mega generators may be provided as shown in figure 3.25 (b).??

Additional protection recommended for these generators are as follows:

- i) Thermal and over fluxing
- ii) Pole slipping
- iii) Unintentional unit energization at stand still
- iv) 100% ground fault
- v) Inter turn protection for split phase winding
- vi) Current transformer and voltage transformer supervision

References

1. English Electric – Protective Relay Application Guide (book)
2. O. D. THAPAR – Electrical Protection of Large Hydro-Electric Generators (Power Engineer, 1961, Vol. 11, No. 1, PP. 12-17
3. IEEE std. C37. 102 – 1995 – IEEE Guide for AC Generator Protection
4. www.areva-ted.com
5. IS: 4722 – 2001: Rotating Electrical Machine
6. Siemens PTDEA Application of SIPROTEC protection relay – 2005
7. Alternate Hydro Energy Centre "Micro Hydro Quality Standards" – 2005
8. Hydropower project reports and specifications
9. www.govconsys.com/woodwar_prtective-relays.htm
10. IEC 1116 – standard for E & M Equipment for small hydro up to 3 MW

3.4 POWER TRANSFORMER PROTECTION

3.4.1 Introduction

Power transformers associated with hydro-electric power station comprise of following special types.

i) Generator Transformers – Step up transformers for stepping up generator voltage to that required for transmission of power, to load centre/grid.
ii) Interlinking transformers to connect up two different step up voltage if provided e.g. in Dehar Power Plant (6 x 165 MW) power plant 2 unit are interconnected to 220 kV grid by 11/220 kV generator transformer and four units are stepped up to 420 kV by 11kV/420 kV generator transformers. 220 kV and 420 kV buses are interlinked by an interlinking 245/420 kV Auto transformers.
iii) Station transformers for auxiliary power supply, these transformers are generally about 500 kVA for unit auxiliaries and up to 1000 kVA or more for station auxiliaries.

Generator transformers and interlinking transformers are oil filled, normally placed in open switchyard/transformer deck. Auxiliary transformers are generally dry type.

Protective relays are required to be provided for transformers to achieve following.

a) Isolate the faulted equipment
b) Limit damage to the faulted equipment and personal.
c) Minimize fire hazard

Cost effective, technically, feasible, scheme of protection of required sensitivity, speed and selectivity is required for minimizing following.

a) Cost of replacing damage
b) Cost of lost power generation
c) Adverse effect on the balance system
d) Isolation of fault, minimize damage of adjacent equipment
e) Period of non availability of the damaged equipment

3.4.2 Possible Faults

Electrical winding and the magnetic core in a transformer are subject to different forces during operation including expansion and contraction due to thermal cycle, vibration, local heating due to magnetic excessive heating due to overloading and external short current or inadequate cooling.

According to statistics in USA (IEEE std. 242-2001) maximum failures (37%) occurred due to winding failures followed by 22% for tap changer failure. Core failures are rare.

External short circuits may only be limited by transformer reactance. Typical value of the transformer impedance values are given in IS: 2026 and short circuit withstand capability is also given in IS: 2026. Transformer faults may be caused by following conditions.

a) Winding break down due to insulation deterioration or defects in manufacturing, overheating, mechanical stress, vibration or voltage surges.
b) Overheating of transformer due to following.
    i) High ambient temperatures
    ii) Failure of cooling system
    iii) External faults not cleared
    iv) Overload
c) Electrical faults e.g. short circuit, ground faults and abusive operating conditions i.e. overloading, transient over voltages etc.
d) No – load tap changers, excessive vibrations, inadequate design or assembly.
e) Bushing failures due to contamination ageing or cracking

f) Miscellaneous causes – core insulation break down, bushing current transformer failure, transformer oil leakage due to poor welds or tank damage etc.
g) Over excitation on generator transformer see Para 3.4.4 (c).

3.4.3 Fault Detection System

a) Temperature monitors for winding or oil temperature
b) Gas detection in transformer oil and analysis of gas composition. Application can be caused by electro arcing and other gases by corona and thermal degradation of cellulose insulation.
c) Sudden gas and oil surge – pressure relays
d) Oil level monitors

3.4.3.1Gas Analysis

Many transformer faults in their early stages are incipient and deterioration is gradual. Combustible gases formed can be detected by gas detective relays (alarm) and periodical gas analysis by portable gas analyzer can be performed by manual or automatic methods to forestall serious outages. Key gases indicating location of fault are as follows:

a) Hydrogen – Corona or partial discharges
b) Ethylene (C_2H_4) – Thermal degradation of oil.
c) Carbon Mono-oxide and carbon di-oxide – Overheating of cellulose insulation
d) Acetylene (C_2H_2) – Arcing in oil

3.4.4 Factors Affecting Performance of Electrical Protection

Current operated relay application for detection of internal faults in transformers is constrained by following.

a) Magnetizing inrush current:- magnetizing inrush current when transformer is energized. The inrush currents lasting from a few cycles to many seconds can cause unbalance and false operation of differential relays. Magnetizing inrush currents contain harmonics especially second harmonics.
b) Unbalance by CT ratio:- very small change in magnitude of current when a limited number of turns are shorted. Approximately 10% or more of winding will have to be shorted for detection by overload relays.
c) Over Excitation:- Over excitation may be caused especially in hydro generation due to sudden load rejection and during normal starting and shut down sequence for maintaining nominal voltage while speed is below normal. This may over heat core and damage transformer. The distorted wave form has harmonic content. Field excitation application on unit connected generators at low speeds 15 – 35% of synchronous speed (during starting) excites step up transformer and unit station service transformer. Harmonic restraint relays and unit voltage per unit frequency (V/Hz) may be required.
d) Phase shifting Δ and Y connection provided on generator transformer create 30^0 phase shift. Compensation by auxiliary CTs increase the effective burden. The CTs may be connected to create the same phase shift as in primary transformer winding. This can be done by connecting CTs in Δ on the Y side of the transformer and in Y on Δ side of transformer. The relay will not see any phase shift.
e) Δ CT connection on the Y side will trap zero sequence current on ground fault on HV side and prevent mismatch formal-operation.

3.4.5 Protection System for Transformers

Protections system applied to power transformers are as follows:

i) Gas and oil surge (Buchholz)
ii) Oil and winding temperature
iii) Over current and earth fault
iv) Earth fault (restricted)
v) Current differential
vi) Over flux

Combination of protective system to be employed is dependent on the size, voltage class and importance of the transformer with respect to the grid. Protective system combination to be provided is discussed with specific reference to generator transformer, interlinking transformer and unit and station service transformer. Usual practice is to provide over current and instantaneous earth fault protection to small sized unit and station service transformers. For large and more important unit transformers restricted earth fault schemes are applied (Refer Figures 3.25 & 3.26). Differential protection is recommended for transformers of approximately 10 MVA three phase (self – cooled rating) and above (IEEE committee report B 49).

Practice in India is to generally provide protection schemes as per voltage class of transformers. Protection scheme recommended by Central Board of irrigation and Power (CBI & P Manual on transformer 1987) for transformers, interlinking transformers etc. is as follows.

A. Generator transformers for 145 class; 245 class and 420 kV class transformers.

i) Overall differential current relay covering generator zone also in addition to transformer differential protection.

ii) Restricted earth fault relay on HV side

iii) Over-flux relay

iv) Neutral over-current relay against sustained external system earth faults

v) Buchholz relay with alarm and trip contacts.

vi) Oil temperature indicator with alarm and trip contacts

vii) Winding temperature indicator with alarm and trip contact

viii) Magnetic oil gauge with low level alarm contacts

ix) Lightning arrestors on HV side (when located outdoors)

x) Pressure release device with trip contacts for transformers rated 100 MVA and above

xi) Oil flow indicator with one contact for alarm (if applicable)

xii) Water flow indicator with one contact for alarm (if applicable)

B. 145 kV and 245 kV class Interlinking Auto Transformers

i) High speed differential relay with harmonic restraint feature.

ii) Restricted earth fault relay

iii) Back up over current and earth relay on both primary and secondary sides.

iv) Restricted earth fault relay

v) Over flux relay

vi) Oil temperature indicator with alarm and trip contact.

vii) Buchholz relay with alarm and trip contact

viii) Winding temperature indicator with three sets of contacts for alarm, trip and control of fans (ONAN/ONAF) and four sets of contacts (ONAN/ONAF).

ix) Magnetic oil gauge with low level alarm contacts

x) Oil surge protection for OLTC diverter tank with trip contact

xi) Lightning arrestors on both primary and secondary sides when the transformer is located outdoors and is connected to overhead lines.

xii) Pressure release device with trip contact for transformer rated 100 MVA and above

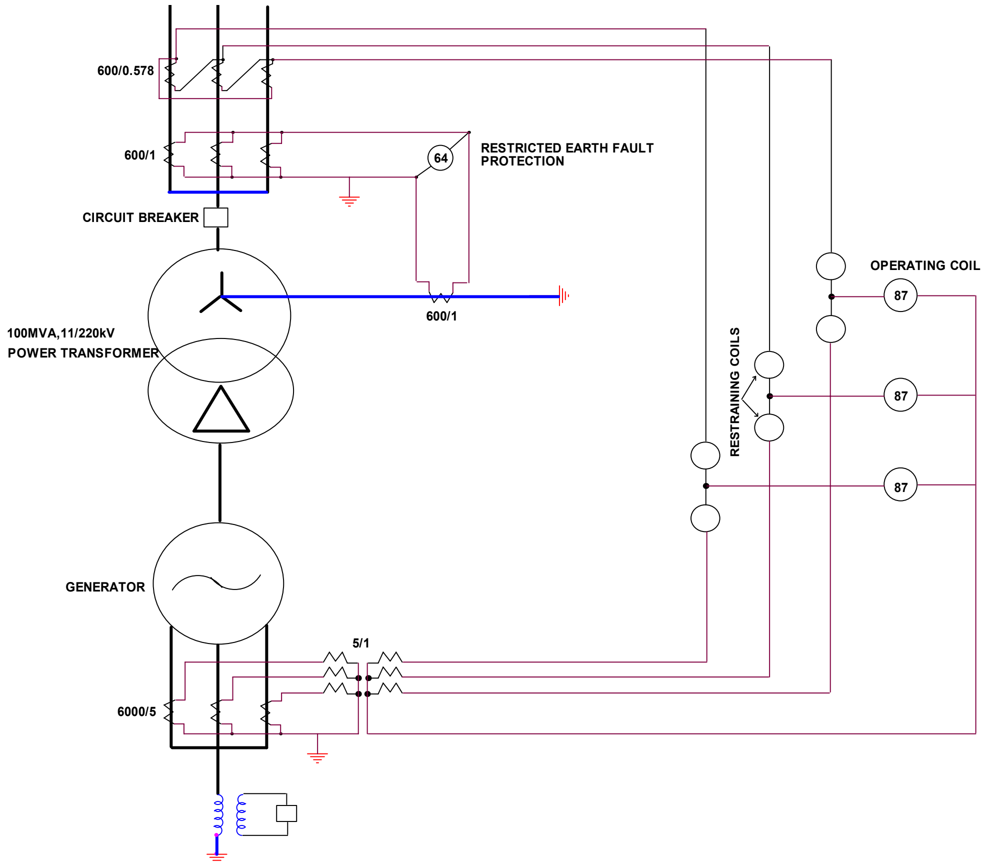


Figure 3.25: Separated Overall Differential and restricted Earth Fault Protection

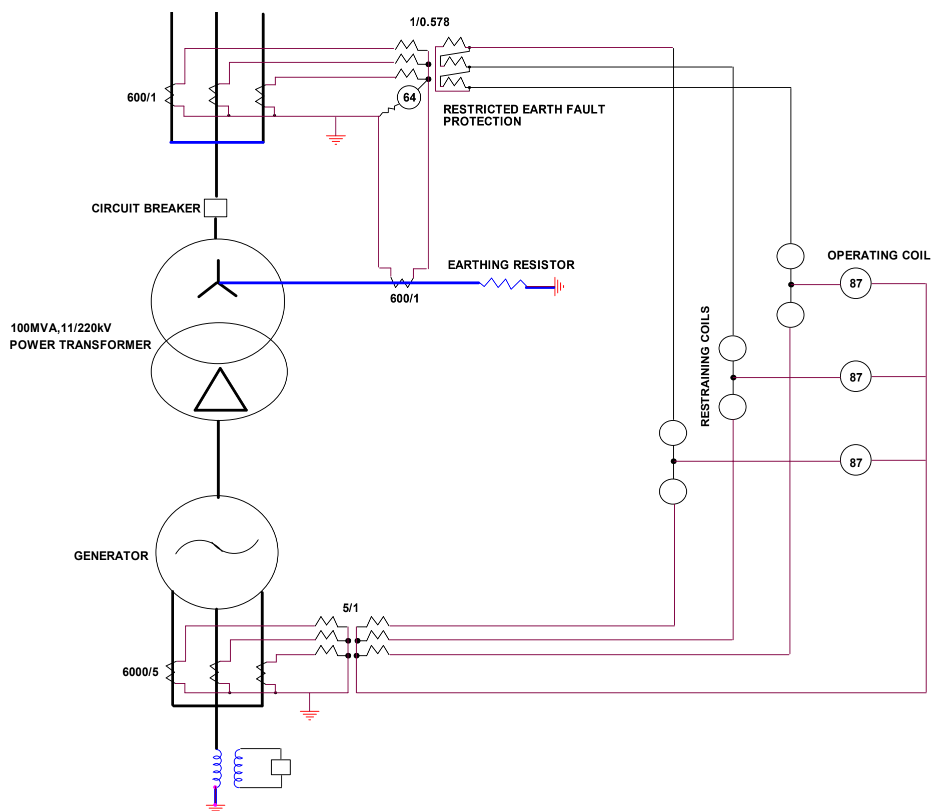


Figure 3.26: Combined Differential and Restricted Earth Fault Protection

C. 420 kV Class Interlinking Auto Transformer

i) High speed percentage biased differential relay with harmonic restraint.

ii) Restricted earth fault relay

iii) Neutral displacement relay or restricted earth fault relay for protection against faults in the tertiary winding/associated connections depending upon the tertiary earthing arrangements.

iv) IDMT or DMT (over current and earth fault) or impedance relays for back up protection.

v) Over flux relay

vi) Buchholz relay with alarm and trip contact.

vii) Oil temperature indicator with alarm and trip contact.

viii) Winding temperature indicator with alarm and trip contact.

ix) Magnetic oil gauge with low level alarm contact.

x) Lightning arrestors on both sides of the transformer.

xi) Pressure release device with trip contact.

D. 72.5 kV Class Power Transformers

i) Percentage biased differential relay (without harmonic restraint) for power transformer up to 100 MVA.

ii) High speed differential relay with harmonic restraint feature) for power transformer of capacities above 100 MVA

iii) Back up over current relay on primary side

iv) Back up over current and earth fault relay on the secondary side

v) Oil temperature indicator with alarm and trip contact.

vi) Buchholz relay with alarm and trip contact

vii) Winding temperature indicator with alarm and trip contact. (For transformer having capacity up to 10 MVA)

viii) Winding temeprtaure indicator with three contacts one each for alarm, trip and control of fans (for transformer having capacities above 10 MVA)

ix) Magnetic oil gauge with low level alarm contacts

x) Lightning arrestors on both primary and secondary sides when the transformer is located outdoors and is connected to overhead lines

xi) Oil surge protection for on load tap changer diverter tank with trip contact

xii) Pressure release device with trip contact for transformer rated 100 MVA and above

E. 36 kV Class Power Transformers

i) 36 kV class power transformer of capacities ranging from 3.15 MVA and above

ii) Percentage biased differential relay (without harmonic restraint) for power transformer up to 10 MVA.

iii) High speed differential relay with second harmonic restraint differential device for power transformer of capacities above 10 MVA

iv) IDMT type over current relay with high set elements on the primary side

v) IDMT type over current and earth fault relay on the secondary side

vi) Oil temperature indicator with alarm one electrical contact for alarm or trip contact.

vii) Buchholz relay with alarm and trip contact

viii) Winding temperature indicator with three electrical contacts for (a) alarm (b) trip & (c) Fan control for transformers above 10 MVA

ix) Lightning arrestors on both primary and secondary sides when the transformer is located outdoors and is connected to overhead lines

x) Oil surge protection for on load tap changers (OLTC) (if provided) diverter tank with trip contact

xi) Pressure release device with trip contact for transformer rated 100 MVA and above

F. 12 kV Class power transformers

i) IDMT over current relay on the 11 kV side

ii) Over current and earth fault relay on the secondary side

iii) Buchholz relay with alarm and trip contact

iv) Oil temperature indicator with alarm and trip contact.

v) Lightning arrestors on both primary and secondary sides when the transformer is located outdoors and is connected to overhead lines

Differential Protection System: Most commonly used protection for transformer is current differential relying. Relays of three general classes of current differential are as follows:

a) Time over current relay which may include an instantaneous trip unit having high current setting.
b) Percentage bias differential with restraint actuated by input and output currents
c) Percentage bias differential relay with restraint actuated by one or more harmonics in addition to the restraint actuated by the input and output currents.

CT connection and ratios must be such that the net current in the relay operating coil or elements for any type or location or location of external fault is effectively zero.

3.4.6 Overall Unit Differential – Special Relay Protection

Generator connected to unit transformer without intervening switchgear where the generator winding is star connected with high impedance grounding through transformer with secondary resistor, the unit transformer is delta LV side and star solidly grounded HV side, overall differential protection for large units is provided as discussed in Para 3.3.5 generators. Special consideration for application of overall unit differential relay covering generator and unit transformer are as follows:

a) Phase shift due to Δ/Y transformer
b) Magnetizing inrush surges due to restoration of voltage on fault clearance.
c) Tap changer varies the matching current
d) Modern high ceiling voltage static excitation system for hydro-generator may cause problem of over excitation.

Remote large hydro generator transformers connected to grid by large EHV lines are provided with high ceiling voltages static excitation systems from stability considerations. On sudden unit unloading due to system fault clearing when the unit may be at ceiling voltage, the unit transformer may be excited with voltage exceeding 130% of normal. Transformer iron core may saturate due to over excitation with exciting current exceeding 25 % of the unit current rating. Differential relay unless provided for over excitation restraint capability may mal-operate. This problem can be solved by special CT connections as explained in IEEE std. C37.91-2000 and shown in principle in figure 3.27.

3.4.7 Over Flux Protection

In over excitation condition saturation of laminated steel cores of the generator and transformer may occur. This combined with stray magnetic field may cause severe localized overheating in transformers in core assembly or winding insulation resulting in eventual break down.

Direct-connected generator, transformer are subjected to wide range of frequency during the acceleration and deceleration of the turbine. Under these connection the ratio of the actual generator terminal voltage to the actual frequency should not exceed 1.1 times the ratio of transformer rated voltage to the rated frequency on a sustained basis:

$$\frac{\text{Generator terminal voltage}}{\text{Actual frequency}} \leq 1.1 \text{ X } \frac{\text{transformer rated voltage}}{\text{transformer rated frequency}}$$

Over excitation relays with a definite time delay or inverse time over excitation characteristics are recommended for use on generator transformers as well as at receiving end transformer.

3.4.8 Differential Protection of Auto Transformers

High impedance relays may be used for star/star connected auto transformer. A typical connection are shown in figure 3.55 and discussed in Para 3.7.6. This protection is immune to the effect of magnetizing inrush current which is cancelled by the neutral CTs. Also, there is no imbalance current in the relay circuit due to the load tap changing equipment. Thus a high impedance differential relay can be applied without restraint, load bias, or time delay.

Unloaded tertiary winding is generally included in the differential protection zone and the relay would sense ground faults in the tertiary winding. This scheme does not provide protection for phase faults or turn-to-turn faults in the tertiary winding. Where the tertiary winding is used to supply load over current protection should be provided.

3.4.9 Transformer Differential Protection by Numerical Relays

Typical multifunction digital differential protection relay (MICOM P63X) with IEC protocol with functionalities available is shown in Figure 3.28 & functional extracts given in table 3.7 for two winding Small, Large and 3 winding interlinking transformers for complete details refer Areva T & D. Suitable back up conventional protection is provided.

Table 3.7 (Extracts from Areva MICOM P63)

Functions Overview			**Type**		
			P631	**P632**	**P633**
87	DIFF	Differential protection	2 wind.	2 wind.	3 wind.
87N	REF $_X$	Restricted earth fault protection	-	2	3
50	DTOC$_X$	Definite – time O/C protection	2	2	3
51	IDMT$_X$	Inverse – time O/C protection	2	2	3
49	THRM x	Thermal overload protection	1	1	2
27,59	V< >	Over/under voltage protection	-	1	1
81	f < >	Over/under frequency protection	-	-	1
24	V/f	Over excitation protection	-	-	1
	MCM x	Measuring circuit monitoring	2	2	3
	LOGIC	Programmable logic	1	1	1

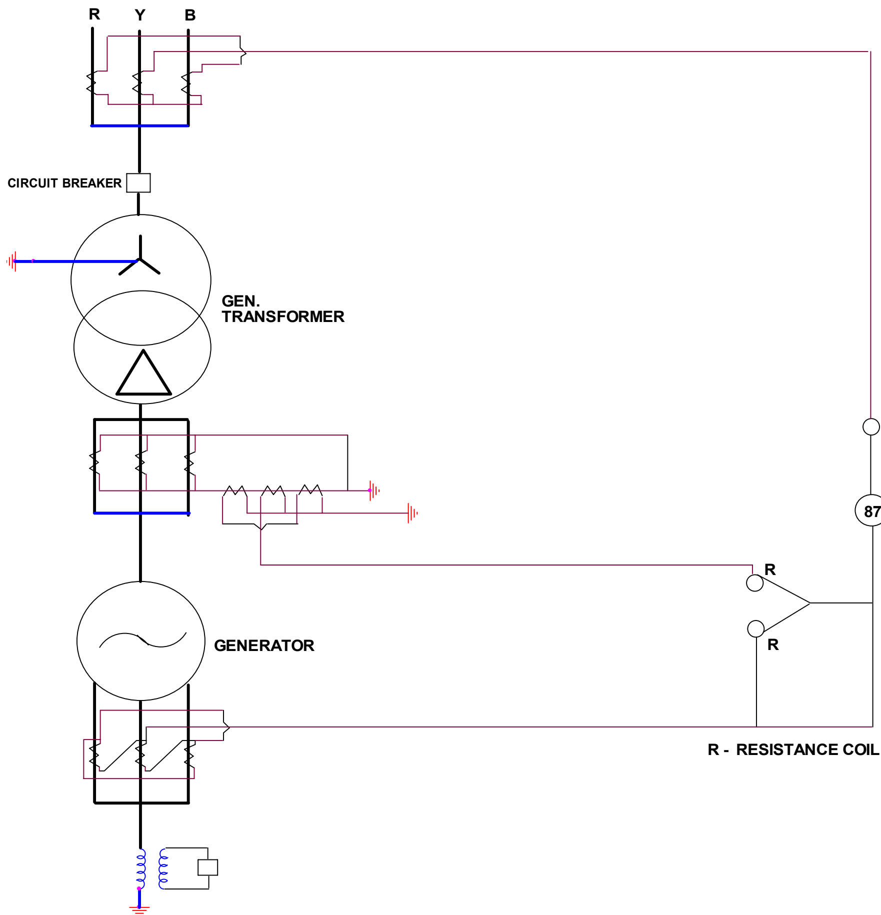


Figure 3.27: Special Percentage Differential Relay Connection for Overall Protection of Unit Generation Transformer with High Ceiling Voltage Excitation System

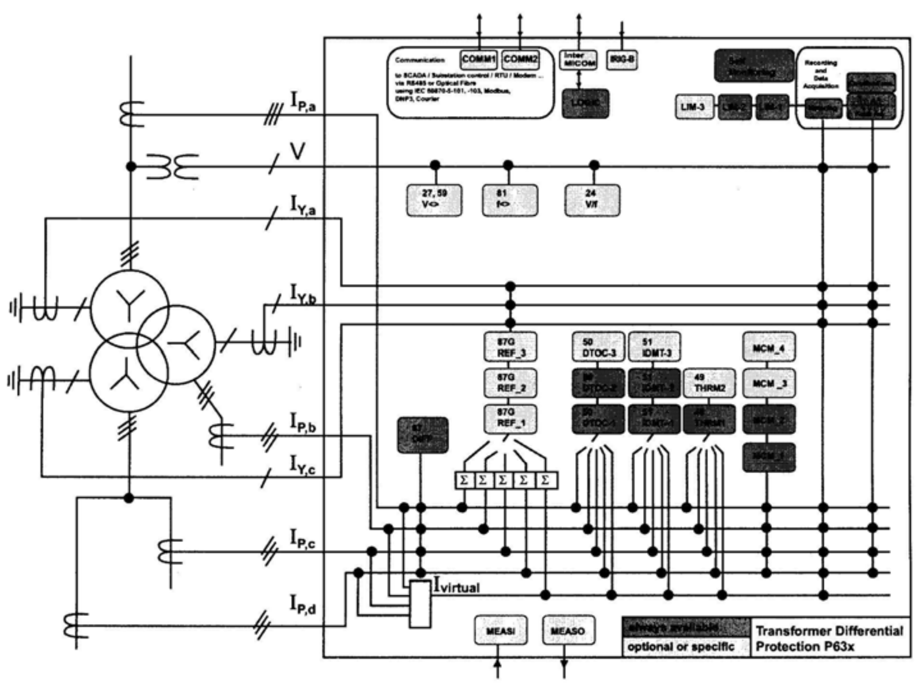


Figure 3.28: Functional Overview – Transformer Differential Protection (2 & 3 windings)

Type P631 is for use as small hydro generator transformer, P632 and P633 for Large hydro generators for Large and Mega generators transformers and interlinking transformers in consultation with Areva.

A typical unit connected transformer numerical relay protection for Halaipani Project Transformer is shown in figure 3.29. Generator transformer overall differential protection provided for unit connected transformers acts as back up for generator.

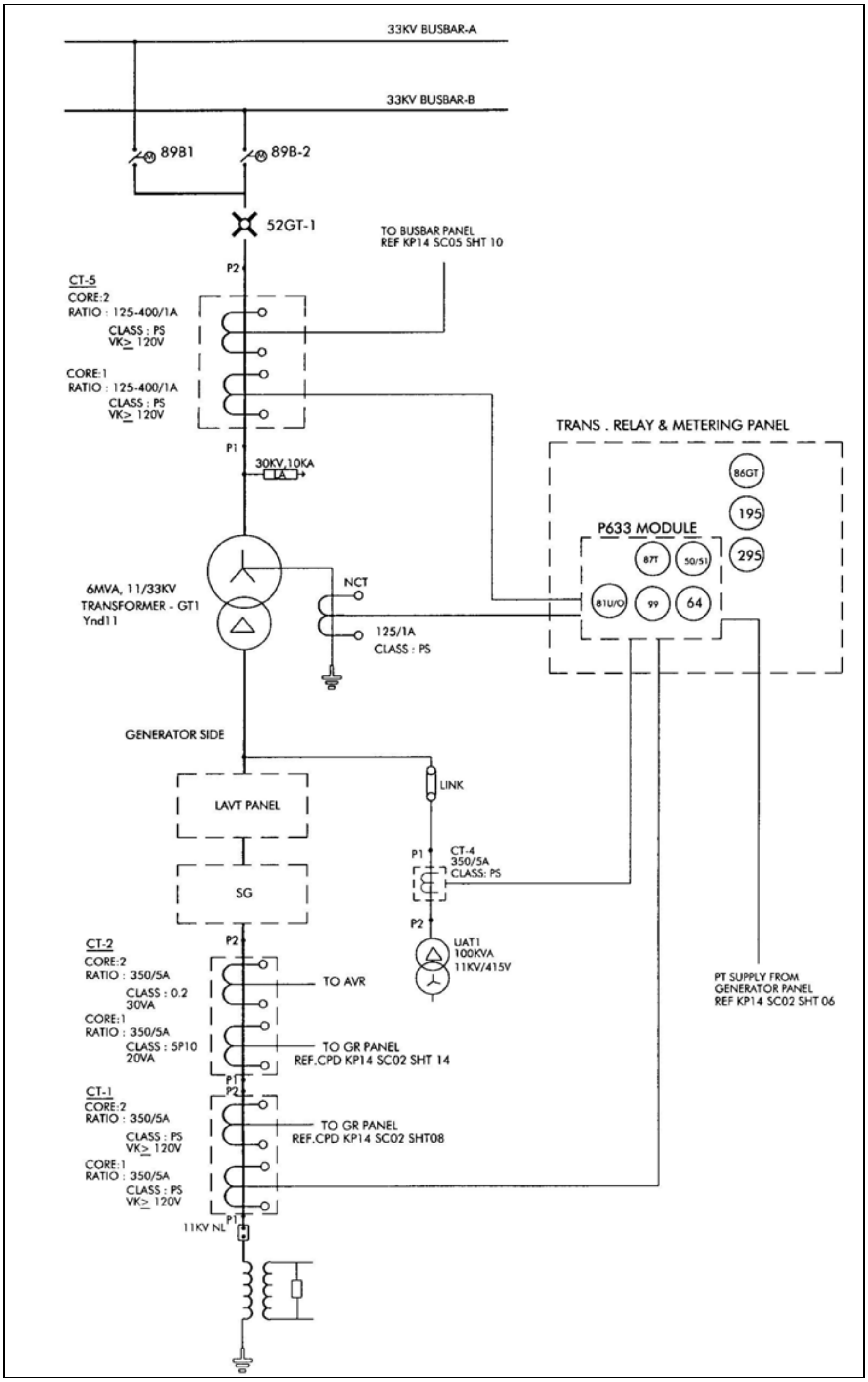


Figure 3.29: Schematic Drawing – 6 MVA, 11/33 kV Gen. Trans. Protection Single Line Diagram

3.5 BUS BAR PROTECTION

3.5.1 General

Bus bars and switchgear are the parts of the system which are used to direct the flow of power to various feeders. To isolate bus faults, all circuits connected to the bus are opened electrically. This disconnection shuts down all feeders supplied by the bus and may affect other parts of the system. Bus bars are sectionalized into bus zones to avoid complete shutdown.

Bus bar faults may be due to the followings.

i) Insulation failure due to material deterioration.
ii) Flashover caused by prolonged and excessive over voltage.
iii) Failure of a circuit breaker to clear under through fault conditions.
iv) Errors in the operation and maintenance of the switchgear.
v) Foreign objects accidentally falling across bus-bar.

Factor affecting clearance of bus-bar faults:

i) Concentration of fault MVA increases risk of considerable damage.
ii) Loss of installation would result in widespread supply interruption.

Performance requirements of bus-bar protection

i) High speed for prompt fault clearance, to minimize damage and maintain system stability.
ii) Must be absolutely stable for all faults external to the switchgear installation, since failure to stabilize would cause unnecessarily widespread interruption of supply.
iii) Must be capable of complete discrimination between zones to ensure that the minimum number of circuit breakers are tripped to isolate the fault.
iv) Freedom from incorrect operation preferably without using complicated interlocks.
v) Isolation of all circuits from a faulted bus zone regardless of whether they are capable of supplying fault current or not.
vi) Individual control of all circuit breakers through separate trip relays.

Clearance of Bus-bar Faults by Back up Protection

Over current protection and distance protections are used for providing back up protection to bus zone. High speed fault clearance or correct discrimination with such schemes is generally not possible.

Accordingly unit form of protection of important installations is recommended.

3.5.2 Metal Clad Bus Bar Installation

Switchgear and bus bars up to 11 kV used in small hydrohydro and for auxiliary power and station service system in large hydroelectric systems are generally metal clad. In auxiliary systems redundant bus section breakers operated by under voltage relays and fed from different sources are provided for dependable auxiliary power supply system (see Para 4.2 for more details). Separate unit form of differential protection is not provided.

3.5.3 High Voltage Bus Bars

Forrest Flashover Protection

This protective system, the principle of which is shown in Figure 3.30 is for earth faults only. Earth fault current itself is directly employed in operating the fault detecting or discriminating relay. The scheme is designed for application to open-type busbars and makes use of the fact that a flashover on a post or string insulator stack, or on a switch or transformer bushing can be interrupted by means of a separately earthed guard-ring, the earth connection of the latter being arranged to from the bar-primary winding of a current transformer feeding the discriminating relay. The several insulators associated with each bus bar section are all treated in this manner, the guard rings being earthed in groups rather than individually. A neutral current check features is employed.

The disadvantage of the scheme is that it provides no protection for faults other than insulator flashover but since such faults probably constitute at least 80% of the total number of busbar earth faults this is not such a draw back as might appear at first sight. The system has the compensating advantage that it is relatively cheap as well as being simple to apply and maintain. It is recommended especially for use up to 132 kV bus bar.

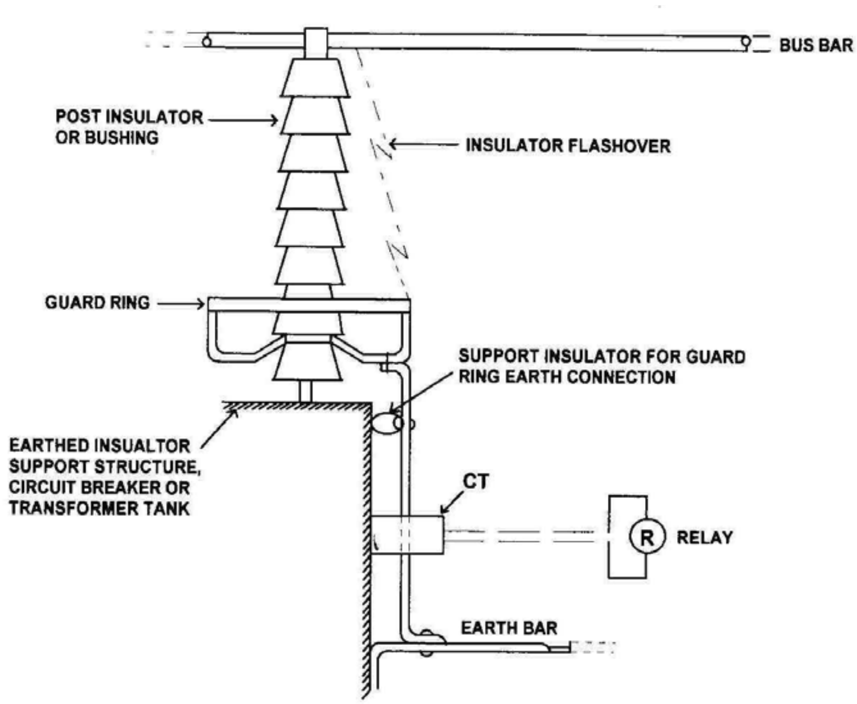


Figure 3.30: Forrest Flashover Protection

Differential Protection

Differential protection is the most sensitive and reliable method of protection for station bus bar zone. During normal load or external fault conditions the sum of the currents entering a bus, by Kirchoff's junction law, equals the sum of those leaving. This equality cannot exist during an internal fault, and this is the operating principle of circulating current protection. This protection is recommended for large schemes.

Circulating current schemes may be applied for phase and earth protection, the essential differences in the schemes being the method of connecting the current transformers.

The particular problem in these applications is the large number of circuits involved and hence, different energisation levels encountered in the various circuits for external faults. For example, with an external fault on one circuit of a four circuit bus zone, three of the CTs may supply varying amounts of fault current, but the fourth and the faulted circuit must balance out the total of all others. This is energized at a much higher level near saturation and may give rise to high false differential currents.

High impedance circulating current relays are generally applied for bus zone protection using a stabilizing resistor in series with a current operated relay. In calculating the value of the stabilizing resistor the following assumption are made:

i) One set of current transformers is completely saturated.
ii) The whole of the primary fault current is perfectly transformed by the remaining current transformers.
iii) The maximum loop load burden between the relay and current transformers is used.

3.5.4 Current Transformer Requirements

To obtain in the required steady state stability up to the rating of the switchgear and ensure positive operation of the protective relay, it is essential in high impedance schemes that the current transformers are designed so that the knee point voltage is not less than twice the relay voltage setting, i.e. the voltage across the relay circuits to causes setting current flow. Thus, the amount of iron in the core of the current transformer depends upon the stability level, load burden and the transformer's internal resistance.

3.5.5 Typical Schemes

Single Bus Arrangement: The application of the simple high impedance bus zone protection scheme to a sectionalized single bus installation is shown in figures 3.31. Here four generator transformers are supplying four outgoing feeders. Current transformers were arranged on one side of the bus section breaker for the two zones of protection for economic considerations. Each set of bus-wires is connected to a relay. It may be noted that sectionalizing breaker faults are not covered by zone 2 and over current relay was provided for isolation. This scheme was successfully provided for 220 kV bus system in Bhakra Right Bank and Dehar 220 kV single sectionalized bus system (figure 3.3). Similar arrangement for Mukerian Projects is shown in figure 3.3 and 3.4.

Double Bus Arrangement: Discrimination between the two zones of protection is obtained by means of the current transformers at the bus section breaker, which unbalance the faulty side and cause the appropriate protective relay to operate.

In the case of a double bus arrangement, discrimination of zones are selected through the bus bar isolator auxiliary switches, which connect all current transformer secondaries to the appropriate bus bars. The switchgear installation is provided with three over lapping zones of protection, two on the main bus and on the reserve bus. It should be noted that the secondaries, of the current transformers associated with the bus-section breaker and bus coupler are permanently connected to the appropriate zone bus service. Figure 3.54shows bus differential scheme as proposed for 420 kV bus bar system.

3.5.6 Check Features

The principle of two lines of defence is invariably applied to large high voltage stations using a circulating current scheme. This is obtained with a check feature, operating from separate current transformers, in addition to the discriminating feature already described. Both the main and check features are usually of the circulating current type. Check feature only supervises the incoming and outgoing circuits as shown in figure 3.31.

3.5.7 Circuit Supervision

On important installation it is usual to monitor the continuity of the current transformer secondaries by employing a sensitive alarm relay, which is normally connected across the buswires of each protected zone. Should an open circuit or a cross connection occur in the secondary wiring while load current is flowing the primary circuit, an unbalanced condition prevails and the relay operates to initiate an alarm and take protection of the affected zone out of service by shorting the appropriate buswires.

3.5.8 Location of Current Transformer

Depending on the type of switchgear used, current transformers for bus bar and circuit protection are either arranged to overlap or are installed on one side of the circuit breaker.

With overlapping zones of protection, any fault that may occur on the circuit side, between the current transformers and the breaker, would cause the immediate operation of both the circuit and busbar protection and thus completely isolate the fault since both ends of the line are tripped with current transformers accommodated on the circuit side only, a fault between the current transformers and the circuit breaker would be seen by the bus bar protection only since the circuit protection sees it as an external fault and does not operate. In order to isolate feeder faults, the remote end circuit breakers must also be tripped which can conveniently be carried out by d. c. interrupting or other means depending on the type of circuit protection on generator and transformer circuits, it is usual to fit an interlock over current relay which is controlled by the busbar protection and arranged to shut down the generator or trip the other side of the transformer if fault current continuous to flow after operation of the bus bar circuit breakers similarly when the current transformers are located on one side of the circuit breakers, a fault between the current transformers and the breaker can only be seen by the circuit protection. To isolate the fault in these circumstances, an over current relay is arranged to by-pass the bus-bar protection relays.

3.6 LINE PROTECTION (TRANSMISSION LINE)

3.6.1 Introduction

Protection and relaying system for outgoing lines for power evacuation from hydro stations is important because lines are the most exposed elements of the system. Majority of faults on high voltage lines begin with the flashover of the insulation at one point; that is, a L-G fault, due to lightning or extraneous objects on lines such as trees, kites etc. However, L-L-G faults are quite common due to lightning and occasionally a simultaneous L-L-L-G fault due to lightning will occur. The L-G and L-L-G faults will produce a residual current on a grounded neutral system but the L.L.L.G fault does not usually do so. Faults of the L.L and L.L-L type will occur in wind or sleet storms, due to conductors swinging together. These faults do not produce residual currents. Line protection must, therefore, cover phase-to-phase faults which are free of ground as well as phase-to-ground faults. Detailed system short circuit studies are required to be carried before deciding the protection for the transmission lines. EHV system requires special consideration and discussed in Para 3.7.

The general requirements for ideal line protection are as follows:

(a) The protection must operate instantaneously
(b) The relay scheme must be inherently selective
(c) The relays at both ends of the line must operate simultaneously for all line faults
(d) The relays must not respond to surging between generating sources as long as the generators do not fall out of step, in which case the relays should operate.
(e) The protection must cover all phase and ground faults.

3.6.2 General Considerations

Small hydro are generally interconnected with the grid by sub transmission lines at 11 kV and 33 kV. Large hydro generators are interconnected by transmission lines. All these transmission lines are generator transformer ended at sending end. The transformer neutrals are solidly earthed.

General considerations involved in designing suitable protection and relaying system for the outgoing transmission lines are as follows:

i) Operating voltage of the outgoing line
ii) Line Length and power to be transmitted
iii) Type of feeder – grid interconnection (two terminals line), parallel line and radial lines

3.6.2.1 Line Length and power to be transmitted

Operating voltage and Length of a two terminal line has a direct bearing on the protective relay system applied.

Transmission lines may be categorized as short, medium or long. The impedances Z_S and Z_L are the source and line impedances with respect to the relay location figure 3.32. Source impedance Z_S is a measure of fault MVA at the relaying point and for faults involving earth. Line impedance Z_L is a measure of the impedance of the protected section.

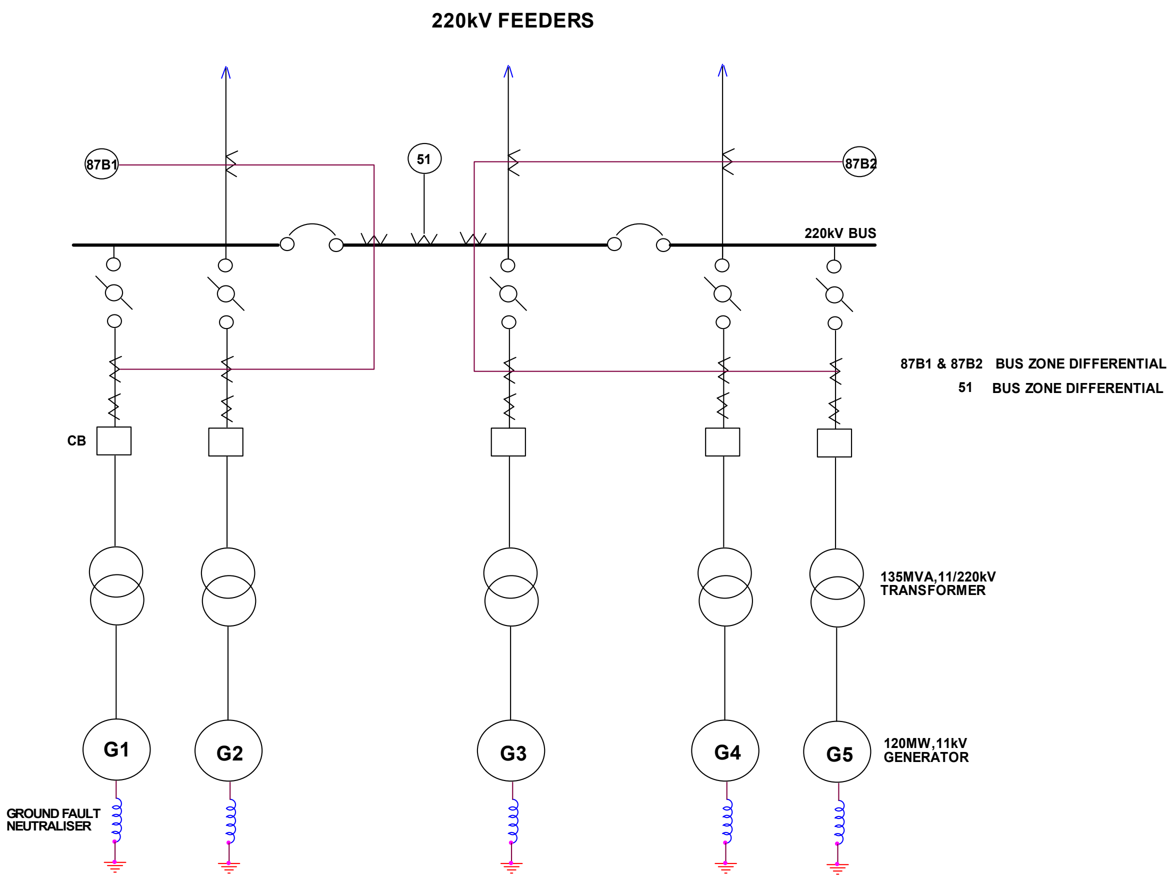


Figure 3.31: Bus Zone Differential Protection (Bhakra Right Bank - 5 x 120 MW And Mukerian Project Refer Drawing No. 3.3 & 4) (As Designed)

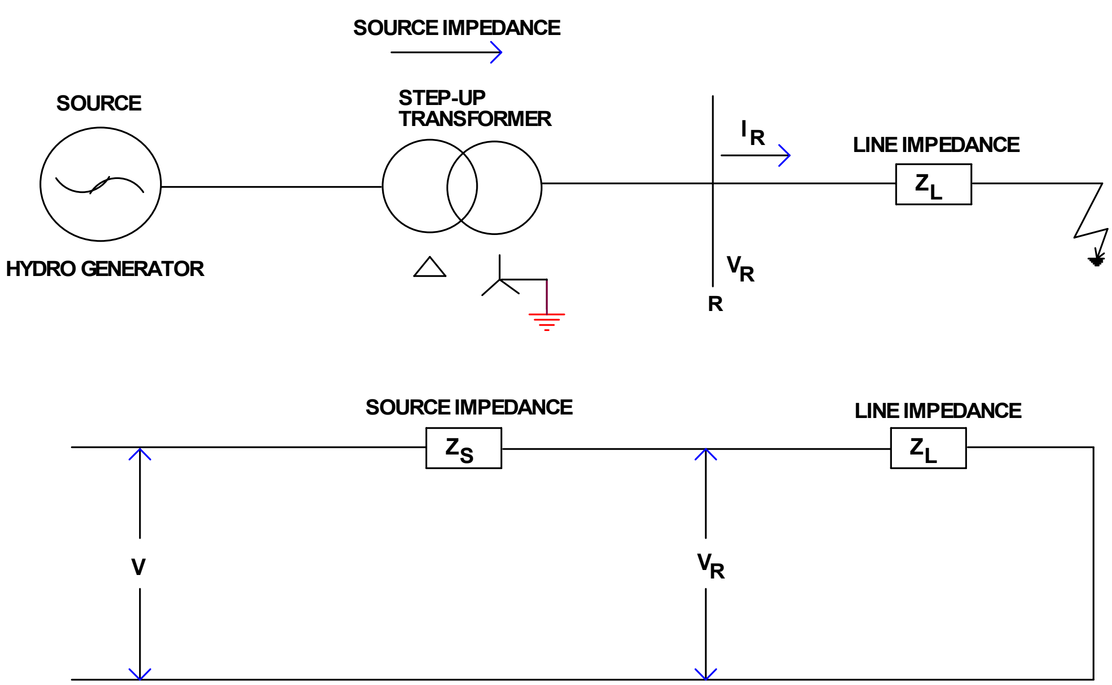


Figure 3.32 Source Impedance and Line Impedance

The ‘minimum fault voltage’ for a fault at the reach point to which the relay will remain accurate varies with the type of relay, that is, impedance, mho or reactance and also with type of comparator employed.

According to IEEE std. 37.113 a short line is one in which the ratio of the source impedance to the line impedance called system impedance ratio (SIR) is large. Ratios of approximately four or greater generally define a short line. Medium lines are those having SIR from four down to 0.5. Long lines are those having SIRs that are very small i.e. 0.5 or less. A short line at one voltage may be a medium or long line at another voltage. Protective system applied depends on the power to be transmitted on line and operating voltage. Voltage of a line has a significant effect on the SIR and classification of line.

3.6.2.2 Type of Line

In radial feeders fault power can flow in only one direction. In case of grid interconnections and parallel feeders power may flow in either direction. In such feeders directional relays are employed.

3.6.2.3 Criticality of Line

Criticality of the line to the system defines desired level of reliability and determines redundancy in protection, instrument transformers communication and even for d. c. auxiliary supply. Less critical lines may be protected with over-current system or step distance relays.

No voltage closing is provided on receiving end breaker and check synchronizing at sending end of grid interconnecting lines.

3.6.2.4 System Factors

System factors affecting application of transmission line protection include following.

a) Fault clearing time: - System stability requirement are affected by fault clearing time and affect relay application.
b) Generating capacity and operating source strength determine fault current levels and operating voltage constraints affect protection system design.
c) Line Configuration: - shunt reactors or series capacitors (extra high voltage system) require special protection system and not discussed in this chapter.

3.6.2.5 Communication

Many transmission line protections depend on communications between line terminals. Communication system selected i.e. power line carrier, microwave, fibre optic, metallic pair or leased telephone lines should be compatible with the protection system chosen. Power line carrier is the most commonly used communication system In India.

3.6.2.6 Old Versus New Technology

These are discussed in Chapter 1 However benefit of new technologies are in areas such as reduced maintenance requirements and additional information. Old technologies are tried and can be trusted. Due considerations need be given to these factors.

3.6.2.7 Redundancy and Back up Consideration

Different protection operating systems in parallel are employed on important lines. The degree of duplication in CTs, VTs, d c. sources etc. is determined by the importance of line.

Local back up schemes e. g. power circuit breaker failure to trip condition may be employed in addition to remote back up protection.

3.6.2.8 Reclosing

Reclosing is employed for considerations of stability, continuity of supply etc.

3.6.3 Feeder Protection Scheme for Hydro Stations

Small hydro are interconnected with grid at distribution (11 kV) or sub transmission (33 kV) level. Step up transformers are solidly grounded. These feeder lines are protected by over current devices both for phase to phase and phase to ground fault protection. Micro hydro are interconnected at 11 kV or group interconnected at 33 kV.

Low cost thermal devices i.e. fuses or circuit breakers fitted with series over current and short circuit thermal elements are used in micro hydro. For other small hydro over current relay protection is provided.

Medium and Large hydro are interconnected with grid by transmission lines and relay protection is provided by distance relays and carrier communication aided protections backed by over current relays.

No voltage closing is provided on receiving breaker and check synchronizing at sending end.

3.6.4 Over current relays

Over current relay schemes are relatively low cost and simple to use. These are
used primarily on distribution and sub-transmission feeders where fault load and currents are in one direction. An over current relay operates when the magnitudes of the current in its circuit exceeds a preset value.

Selectivity with over current relays may be achieved by one of the following methods.

i. Grading the magnitude of the fault current
ii. Grading time of operation
iii. Combination of magnitude and time
iv. Direction of fault current

Following types of over current relays may be used for the protection of outgoing feeders:-

i) The inverse definite minimum time (IDMT) relay having a characteristics which conforms to the requirements of IS 1885 – Part IX.
ii) A combined IDMT relay and high set instantaneous relay, with low transient over reach.
iii) A very inverse definite minimum time relay
iv) Extremely inverse definite minimum time relay
v) Definite time over-current relay

Relay selection and settings is governed by the following Time - Current Characteristics of over current relays.

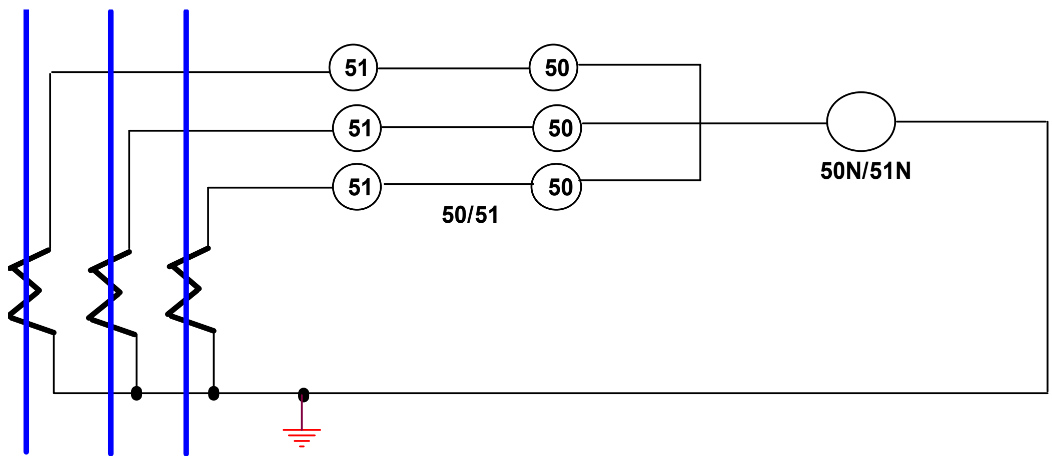
i) Time delay
ii) Instantaneous and
iii) Combination of (i) and (ii)

Time delay is provided by time multiplier setting which varies the time in which the relay will close its contacts for given value of fault current.

Plug setting - Varies range of current setting at which relay will operate.
Characteristics of the relay are given in IS: 38642 Part-1.

Definite time current relays operate at a constant time predetermined by adjustment and are independent of current magnitude as long as it is sufficient to operate the relay.

IEEE std. 37.113 recommends three phase and one ground time over current relay and instantaneous over current relays for sub transmission line feeder. Phase currents are used as operating quantity. Typical connection is shown in Figure 3.33. Phase over current relays operate for all possible faults types, but require pick up settings to be higher than the maximum expected normal or emergency load flow condition. Over current relays in the neutral 50/51 N do not operate for balanced loads or for 3 phase faults but operate for ground faults or unbalanced load and pick up settings are kept well below expected load.



50	-	Instantaneous Over current
51	-	Time Over current
50N	-	Ground Fault Instantaneous
51N	-	Time Ground Fault

Figure 3.33: Typical Connection of Time Graded Over current and Ground Fault Relay

Instantaneous tripping can be applied if the pickup point of the instantaneous unit can be set higher than the maximum contribution to faults outside the protected line. The percentage of a line that can be protected by an instantaneous over-current relay will vary with line length and source impedance. To protect an entire non-radial line, time delays are generally required to achieve coordination with primary protective relays. Figure 3.34 shows how coordination is achieved between a relay with a time and instantaneous element (the primary relay), and an upstream (back up relay) with only a time element. To ensure proper coordination, the pickup point of the instantaneous unit should be set higher than the maximum contribution to faults outside the protected line.

The pickup value of the time element should be set to prevent tripping for the maximum load current that can flow in either direction on the line. The time adjustment (i.e. dial) should generally be set to produce the fastest operating time that will not result in miscoordination with other protection behind or in front of the terminal.

3.6.4.1 Direction Over current Relay

Directional over current relays respond to faults in one direction only. This is accomplished by providing the relay with a measured quantity for reference. This input can be voltage, a current or both.

Application of different types of over current time relays as per IS: 3842 is given in table 3.8.

The basic directional over current relay scheme consists of four time over current relay units or element – one for each phase and one for ground fault (residual) current. Instantaneous trip unit which may or may not be directional can be added to provide high speed relay operation for close – in faults. Three CTs located at the line terminal – one for each phase unit and sum of the three for residual unit are provided. The arrangement is same as for non directional over current relay and co-ordination with other devices is also similar.

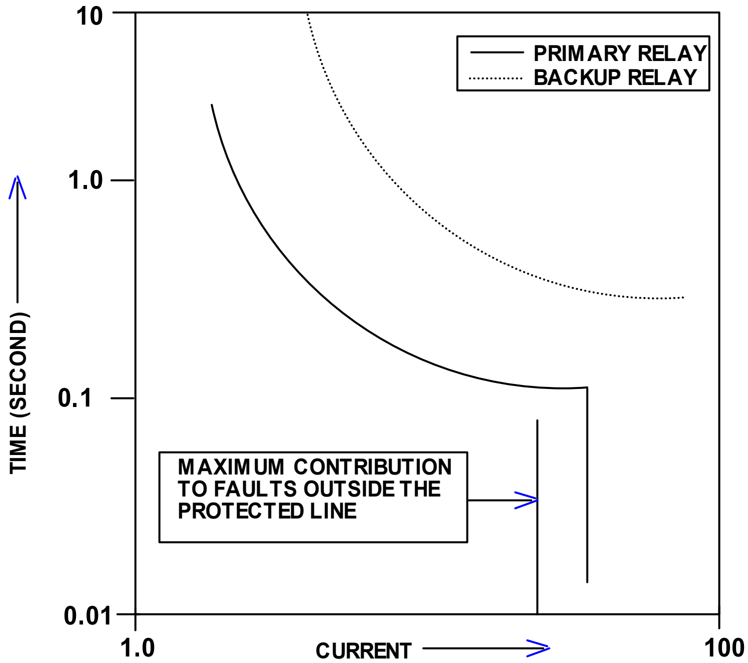


Figure 3.34: Time graded over current relays coordination as backup relays

Directional over current element is generally used to supervise the output of the over current element. In this method, the over current element is free to operate for any current in excess of its pick up setting. However, tripping occurs only when directional element also operates. Typical connections are shown in figure 3.35.

In the other method directional element controls input to the current measuring protection of the over current element preventing its operation unless directional element operates. This is referred to as torque control.

Phase directional relays are polarized by phase voltage (delta) while ground directional relays may also use zero sequence current which is obtained from the transformer star point earth as shown in figure 3.36.

Phase directional over current relay schemes are also used on parallel feeders when fault and/or load current can flow in either direction. The pickup of the time over current elements has to be set higher than maximum load flow in forward direction. The instantaneous element pickup, time current characteristics and time adjustment setting requirements are similar to those of non directional over current relays. Directional ground over current relays are commonly applied on all types of transmission lines. Time over current elements are generally used for backup protection. High set ground directional elements are generally used for direct tripping for close up ground faults.

Table –3.8: Application of different types of over-current time relays

Definite time relays	Instantaneous relays	Inverse and IDMTL relay	Very-inverse relays	Extremely inverse relays
		Characteristics		
Definite time	Operating time up to 240 ms	Refer 9.1.1.1 of IS: 3231	IT = K	I^2 T = K
		Applications		
1. Radial or loop circuits having few sections in series	1. Transformer feeders	1. feeders or loop circuits having large number of sections in series with difference in fault current between relay location	1. Feeders applied from large generating systems where the magnitude of short-circuit current is practically constant	1. Distribution network
2. On systems with variations of fault current due to wide variations in source	2. Places where there is substantial difference in short-circuit currents	2. On systems where system fault current at a particular point does not vary very widely due to the	2. Long sub-transmission lines where there is a substantial reduction in fault current	2. System where discrimination with fuses is

impedance 3. Back-up for distance protection	between two relay locations 3. Near the source of power, used along with definite or inverse relays on systems where source impedance does not vary widely	changes in source impedance 3. Back-up for distance protection	as the distance from the power source increases. 3. Loop systems where it is necessary to have approximately the same interval between operating times for faults at the near end and far end of the protected section 4. where fast operation is required over a restricted current range	required 3. Places where there are large in-rush currents after an outage

(Based on table 2 of IS 3842 – Part I)

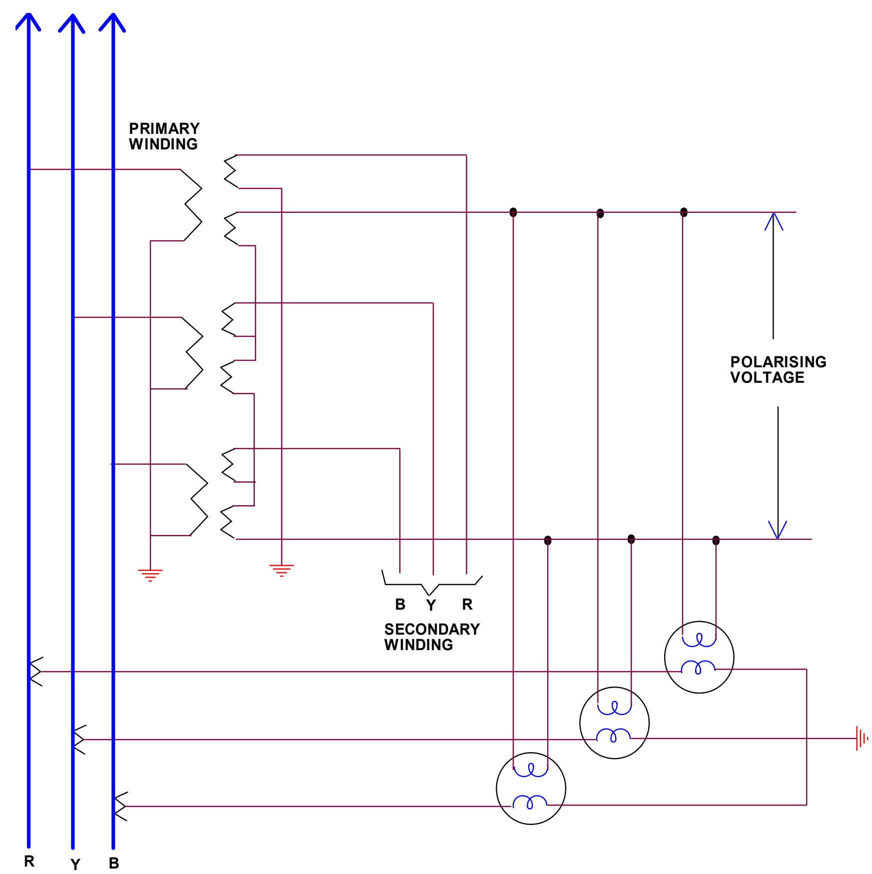


Figure 3.35: Directional Over current with Voltage Polarizing (open delta)

3.6.5 Distance Relays

Distance relays operate by measuring both voltage and current (V_R and I_R in figure 3.37) at the terminal (power house end) of the transmission line feeder to determine if the fault is in the relays zone of protection. The operating characteristics can be described using R – X diagram as shown in figure 3.37 on two terminal lines without tap lines, the impedance of the transmission line is fixed and reach of the relay is largely due to network changes.

The term impedance relay is sometimes used interchangeably with the term distance relay. There are several distance relay characteristics of which impedance relay is only one. The basic distance relay characteristics are as follows:

a) **Impedance.** The impedance relay does not take into account the phase angle between the voltage and the current applied to it. For this reason, the impedance characteristic in the R – X plane is a circle with its center at the origin. The relay operates when the measured impedance is less than the setting (i.e., it is within the circle). The relay has a current coil producing torque equal to $K_1 I$ and a voltage restraining coil producing a torque equal to $K_2 U$. Relay operation occurs when

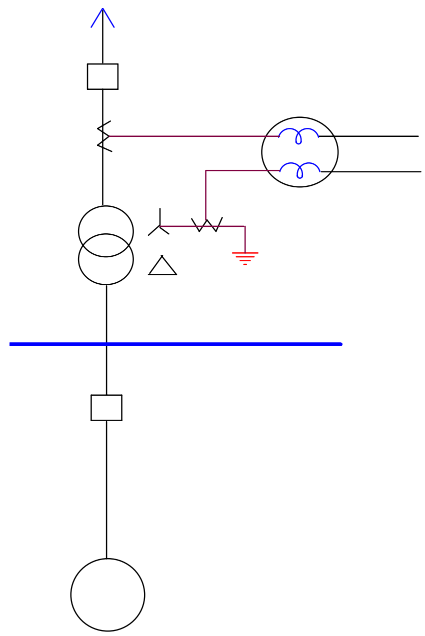


Figure 3.36: Directional Over current with Current Polarizing

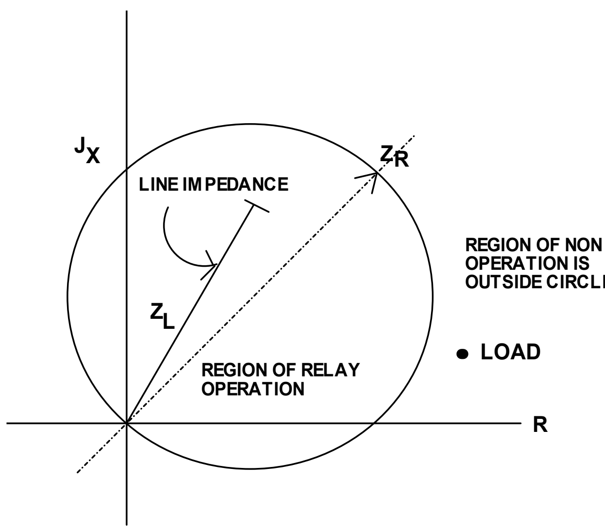


Figure 3.37 – R – X Diagram

$K_1 I > K_2 U$ or $\dfrac{U}{I}$ (=Z) < $\dfrac{K_1}{K_2}$. This unit, when used to trip, must be supervised by a directional unit or be time delayed.

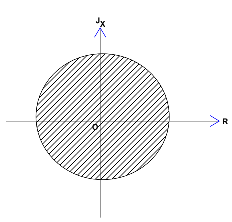


Figure 3.38

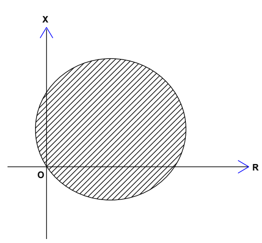


Figure 3.39

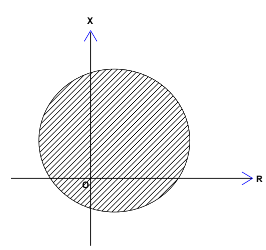


Figure3.40

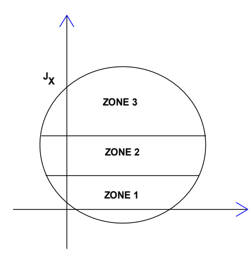


Figure 3.41

b) **Mho.** The characteristics of the mho relay is a circle whose circumference passes through the origin. The relay operates if the measured impedance falls within the circle (figure 3.39). The mho relay is inherently directional and is suitable for long lines.

c) **Offset mho.** The characteristics of an offset mho relay in the R – X plane is a circle that is shifted and includes the origin, thus providing better protection for close-in faults. This unit, when used to trip, must be supervised by a directional unit or be time-delayed (figure 3.40). Offset mho relay has four principal applications.

i) Bus-bar zone back-up protection,
ii) Carrier starting in carrier-distance blocking schemes,
iii) Out-of-step (or power swing) blocking, and
iv) Starters on very long lines

d) **Reactance.** The reactance relay measures only the reactive component of impedance. The characteristics of a reactance relay in the R – X plane is a straight line parallel to the R axis. The reactance relay must be supervised by another function to ensure directionality and to prevent tripping under load (figure 3.41). The relay measures $\frac{U}{I}\sin\phi$ = X and would be independent of atmospheric effects, terrain, tower footing resistance and fault or arc resistance for a radial line.

Numerous other distance relay characteristics e.g. ohm (blinder relays, Quadrilateral, lenticular – modified mho) have been designed by combining the above described basic impedance characteristics. The response of the various characteristics is affected by the polarizing signal.

3.6.5.1 Distance Schemes

In distance relays the fault distance impedance actually measured depends on the actual magnitude of current and voltage, the relay connections, type of fault and impedances in the fault in addition to the line impedance. It is impossible to successfully eliminate these additional features in distance measurement for all possible operating conditions. Therefore composite schemes employing several relays and different relay characteristics are employed.

Starter Relays for Distance Protection: Primary function of starting relays, sometimes referred to as fault detectors is to control the timing relay for extending the reach of measuring relay into second and third zone. They must have directional features when used with impedance and reactance measuring system.

A distance scheme comprises starting relays, impedance measuring unit, zone timers and tripping relays. To cater for the economic and technical requirements of any particular network, a range of schemes is necessary from which a choice may be made. The schemes generally employed to meet the protection requirements of low, medium and high voltage networks may be classified into three main groups:

a) Schemes designed for protection against phase faults only;
b) Schemes designed for protection against all types of faults – phase and earth – using separate units for each type of fault (also referred to as non-switched schemes); and
c) Schemes designed for protection against various type of faults using one set of units only but incorporating switching features (also referred to as switched schemes).

Typical schemes, falling under the three categories are given in table 3.9 as per IS: 38642 (part I) for details refer IS: 38642.

Table 3.9

TYPICAL DISTANCE PROTECTION SCHEMES

Sl No.	Schemes		Basic Units
1	Three zone phase fault protection (Non-switched)	a)	i) Three mho units for phase fault measurement ii) Three mho units for starting
		b)	i) Three reactance units for phase fault measurement ii) Three mho units for starting
		c)	i) One mho unit for 3-phase fault measurement ii) One mho unit for phase-to-phase fault measurement iii) Three offset mho or elliptical starting units iv) One negative sequence starter
2	Three zone phase and earth fault protection (Non-switched)	a)	i) Three mho units for phase fault measurement ii) Three mho units for earth fault measurement iii) Three mho units for starting
		b)	i) Three reactance units for phase fault measurement ii) Three reactance units for earth fault measurement iii) Three mho units for starting
		c)	i) Three mho units for phase fault measurement ii) Three reactance units for earth fault measurement iii) Three mho units for starting
		d)	i) Three mho units for earth and 3-phase fault measurement ii) One mho unit for phase-to-phase fault measurement iii) Three offset mho or elliptical starting units
3.	Three zone phase and earth fault protection	a)	i) One mho unit for fault measurement ii) Two instantaneous over current starters NOTE – The mho unit is switched to the faulted phase by the over current starters
		b)	i) One reactance unit for phase and earth fault measurement ii) One mho unit for directionalizing reactance unit iii) Three impedance starters Note – The mho and reactance units are switched to the faulted phase(s) by the starters
		c)	i) Three impedance units for phase and earth faults ii) Three directional units for phase and earth faults iii) Three impedance starters Note – The impedance and directional units are switched To measure either phase faults or earth faults by the starters
		d)	i) One mho units for phase and earth faults ii) Three impedance starters iii) Over current starters for earth faults Note – The mho unit is switched to the faulted phase by the starters
		e)	i) One mho unit for earth fault and 3-phase fault measurement ii) One mho unit for phase-to-phase fault measurement iii) Three offset mho or elliptical starter i) One negative sequence starter
		f)	i) Three impedance units for phase and earth faults measurements ii) Three directional units for phase and earth faults iii) Three impedance starters iv) Four over current starters

Combination of distance and starter relays commonly used as per IS 3842 (part V).

a) Directional; and over current relays as starters for use with impedance type of distance relay.

b) Over current units only for use with mho type of distance relay (sometime under voltage relays are also used specially on resistance earthed systems).

c) Mho starters for any type of distance relay

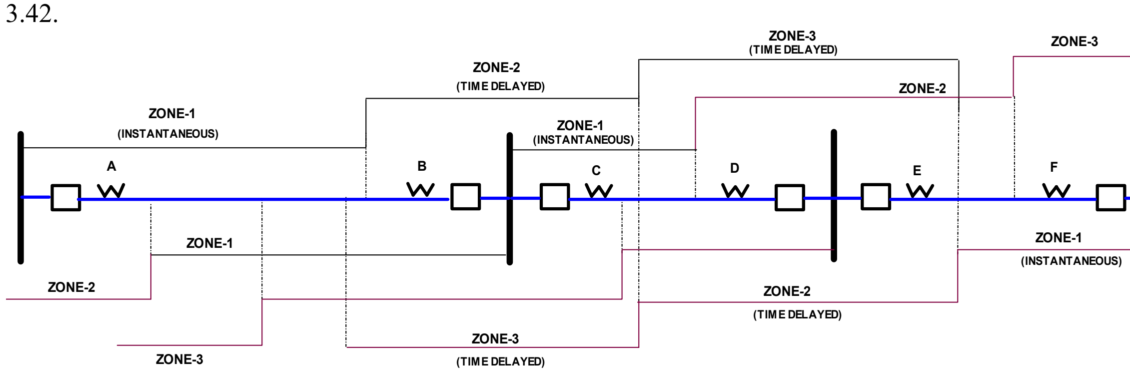
d) Impedance starters for reactance or impedance type of distance relay directionalized by a separate mho relay or a directional relay.

e) Current dependant under impedance starters for distance relays when heavy loads on medium lines are expected. Oh heavy loads the reach of the starting relay reduces and at low currents the reach increases; and

f) Current and angle dependant under impedance starters for distance relays where on heavy loads and long lines the reach, even at high current, is to be maintained in the fault area.

3.6.5.2 Step Distance Schemes

Step distance protection relays are those where pilot application Is not used. Several zones are employed to protect a transmission line. Typical time distance characteristics for a three step relay is shown in Figure 3.42.



Zone 1 – 80% of the protected line length

Zone 2 – Protected line + up to 50% of the next line section

Zone 3 – protected line + second line + up to 25% of third line

Figure 3.42: Typical time distance characteristics for a three step distance relay

The first zone (zone 1) is instantaneous zone of protection and set to trip with no intentional time delay. Zone 1 is usually set for approximately 80% of the transmission line. This limitation is necessary to ensure ample margin against possible over reach due to current transients, current and voltage transformer errors and variation of line impedance. The second zone (zone 2) is set to protect the line plus an adequate margin. The reach of zone 2 may vary considerably depending upon application. In general zone 2 should not overreach any zone 1 relays on a line beyond the remote terminal. Minimum setting for zone 2 that ensure full coverage of the line with safety margin is 120% of the line impedance. In special cases reach of zone 2 may be extended see figure 3.43 for a short line where setting as high 200% can be helpful. Zone 2 relays are time delayed to co-ordinate relay at remote bus. Typical time delays are in order of 15 – 30 cycles.

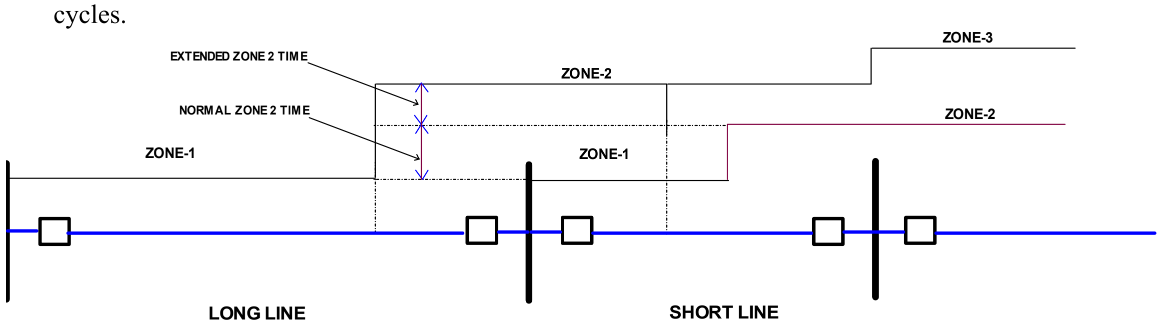


Figure 3.43

Although zone 1 and zone 2 provide full protections to the transmission line, a third forward reaching zone 3 is employed as back up for zone 2 and may be employed as remote backup. This relay must be time delayed to coordinate with the remote zone 1and zone 2 relay. Further discussion on time setting of zone 3 may be made to IEEE std. C-37113.

In order to detect faults in the second and third zones it is necessary to include starting relay sensitive enough to detect faults occurring beyond third zone under minimum generating condition, but capable of discrimination between this and normal load conditions at the end of the first section of line.

3.6.6 Power Line Carrier and other Pilot Schemes

A fault in the end zone of a feeder scheme protected by step distance relay will be within the zone of local distance relays at the local line terminal and in the second zone of relays at the remote terminal. Clearance times at the two terminal will result in an undesirable time delay in clearing the fault. The discrepancy in time does not permit auto reclosure to be applied. Inherent delay in the second zone measurements at the remote end of the line may be overcome by transmitting a trip signal to the relay breaker at the remote terminal via communication channel. The inter trip signal is initiated by local zone 1 relay operation. This information provides high speed tripping to occur for faults occurring on 100% of the protected line. In addition to transfer trip schemes, unit schemes are employed in which both ends of the line contribute information via communication channels to identify the fault as internal and allows high speed tripping from both ends. Both current comparison schemes and directional comparison schemes are common. Current system sends information related to phase angle, and in some cases magnitude of the fault current between relay locations. Directional comparison schemes fault current directional information between the terminals.

3.6.6.1 Communication Channels

Following communication channels are employed for transmission line protective relaying.

i) Power line carrier communication
ii) Metallic pair and fibre optic cable
iii) Microwave communication system
iv) Radio communication system

3.6.6.2 Power line carrier communication

High frequency power line carrier communication signal transmission along over head power lines has been commonly need in India for voice communication as well for pilot signal for transmission line protection because of following.

i) For longer line lengths capital and running costs are lower;
ii) Transmission path is fully controlled by the operating authority;
iii) The signaling channel is not affected by faults in electrically independent circuits;
iv) The transmission medium is robust and therefore reliable.

Signal injection on the power line and extraction from it are achieved through high voltage capacitors used in conjunction with drainage coil, in order to provide isolation of the equipment from high voltage line. It is practice to provide coupling capacitors and capacitor dividers with intermediate voltage terminal for a electromagnetic unit of coupling voltage transformers. The capacitor is rated at feeder voltage and is designed to pass through the carrier frequency for communication and provide low voltage for protection and metering. The coupling capacitors should comply with the provisions of IS 9348 – 1998. A high frequency barrier line trap is installed on the station side of the injection (or receiving) side of the transmission line to prevent dissipation of signal throughout the system. Figure 3.44 shows the general arrangement of the terminal equipment when power line carrier facilities are used in the protection scheme. The protection relays are energized from voltage and/or current transformers depending on the type of the protection schemes.

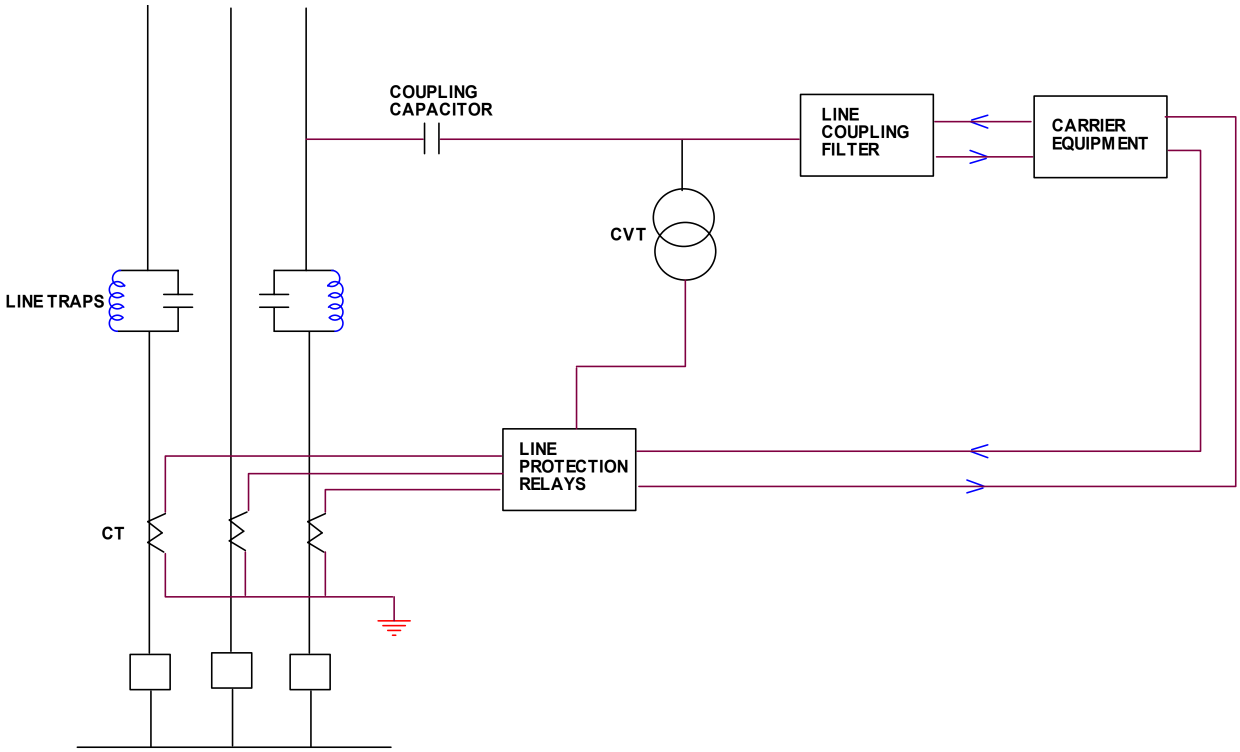


Figure 3.44: Line Protection Relay Scheme Using Power Line Carrier

3.6.6.2 Channel (Pilot) Aided Distance Protection Scheme for High Voltage Line for Large Power Station Interconnection

Following pilot aided protection schemes are used for high voltage lines for interconnecting large hydro.

Communication channels are used in connection with distance relays to speed up fault clearance for internal zone 2 (end zone) fault. Communication channel is used either to provide tripping signal for internal zone 2 faults or to prevent (block) tripping in case of external faults. Communication channel power line carrier is mostly used in India. Following pilot aided schemes are used. For details refer IEEE std. 37.113. A typical example of selection is given in Para 3.7 (EHV lines).

- Transfer tripping (inter-tripping)
- Permissive under reaching transfer trip scheme
- Permissive over reaching transfer trip
- Zone Acceleration
- Directional Comparison Blocking
- Phase Comparison Scheme
- Other Protection Schemes

Special schemes have been developed for following conditions and need to be provided for large hydro interconnecting lines.

a) Out of step protection for heavy load swings
b) Transient blocking for parallel lines
c) Switching on to fault

For comprehensive information on the subject reference may be made to IEEE std. 37.113 – Guide for protective relay application to transmission lines.

3.6.7 Numerical Line Protection Relays

3.6.7.1 Over-current Relays

Multifunction and digital over current protection relays providing flexible integration of protection control, monitoring and measurement function for line protection are now available. Over current relays (e.g. Areva relays catalogue for MICOM relay) are used for small hydro. Single line diagram is shown in figure 3.45 & protection functions provided are summarized in table 3.10. `P12X are for non directional series of relays from single phase/earth fault P120 up to the multifunction three phase and earth fault P123.

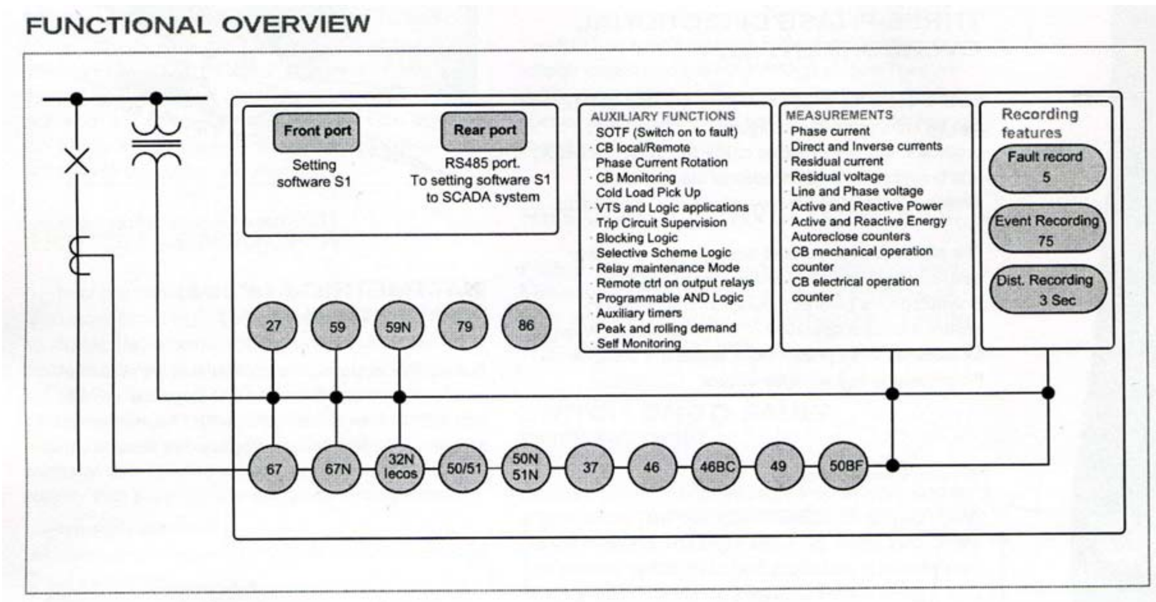


Figure 3.45: Functional Overview – Areva Over-current Relays (catalogue)

P12Y are directional relays ranges from single phase to earth fault P125 up to the multifunction three phase and earth fault P127.

Woodward and other companies also offer these multifunction digital relays.

Table 3.10

Functions overview		12X	12Y
		P123	**P127**
67/50/51	Three phase directional non directional over current		●
50/51	Three phase over-current	●	
49	Thermal overload	●	●
37	Three phase under-current	●	●
46	Negative phase sequence over current	●	●
67N/50N/51N	Earth fault directional non directional over-current		●
50N/51N	Earth fault (single-phase) over-current	●	
32N	Earth fault watt metric / ie* cosφ	●	●
59N	Residual overvoltage	●	●
27/59	Phase/line under/over voltage	●	●
79	Autoreclose	●	●
	Switch on to fault (SOTF)	●	●
	CB control local/remote	●	●
	Phase current rotation	●	
50BF	Circuit breaker failure detection	●	●
	Circuit breaker maintenance and trip circuit supervision	●	●

46BC	Broken conductor detection 12/11	●	●
	Cold load pick up	●	●
86	Output relay latching	●	●

3.6.7.2 Distance Relays

Distance relays (e.g. Areva relays catalogue for MICOM relay) are used for large hydro. Single line diagram is shown in figure 3.46 & protection functions provided are summarized in table 3.46. P442 & P444 allow single phase tripping and pilot aided earth fault protection (67N).

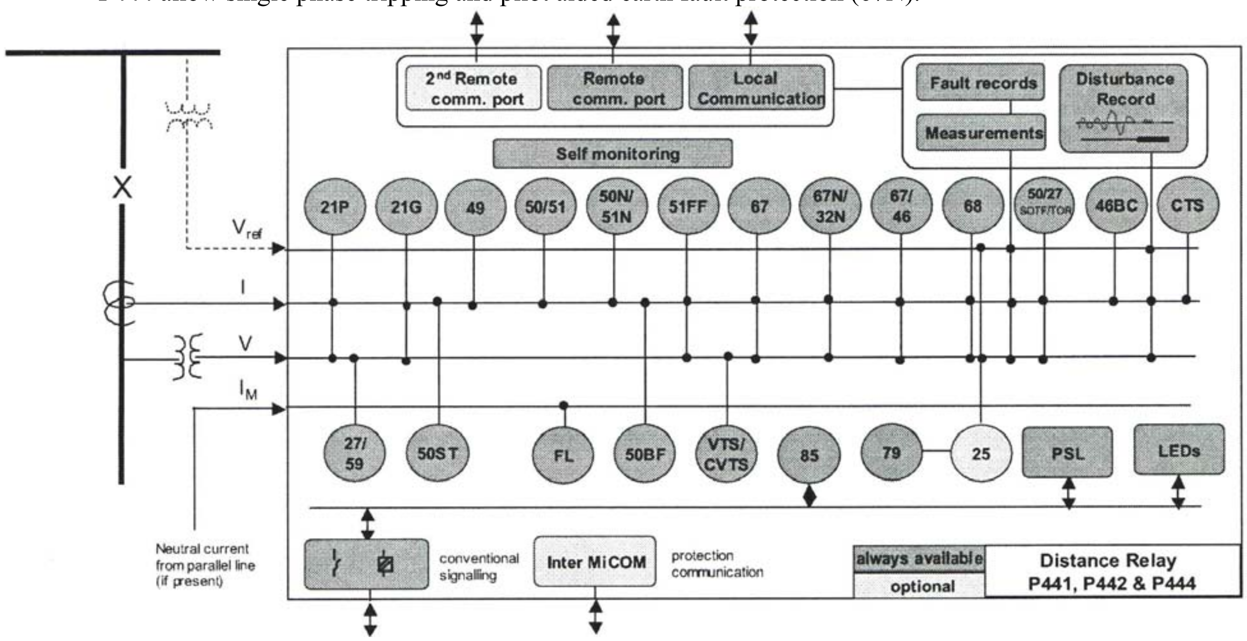


Figure 3.46: Single Line Diagram – Areva Distance Relays

Protection Functions (P441, 442 & 444)	
21P	Quadrilateral full scheme phase distance protection (5 zones)
21G	Quadrilateral full scheme ground distance protection (5 zones)
50/51/67	Directional/non-directional phase over current (4 stages)
50N/51N/67N	Directional/non-directional stand by earth fault (2 stages)
67N	Chanel aided directional earth fault protection (DEF)
32N	Directional zero sequence power protection
67/46	Directional/non-directional negative sequence over current
	Directional comparison (using PSL)
68	Power swing blocking & out of step tripping (using PSL)
50/27	Switch on to fault/trip on reclose
85	Channel aided schemes
40	Thermal overload protection
79	Auto reclose (4 shots)
25	Check synchronizing
27	Under voltage (2 stage)
59	Over voltage (2 stage)
46BC	Broken conductor (open jumper)
50BF	Circuit breaker failure
VTS	Voltage transformer supervision (1, 2 & 3 phase fuse failure detection)
CVTS	Capacitive voltage transformer supervision
CTS	Current transformer

Multi-functional line protection distance numerical relays includes the following (Areva relays catalogue for MICOM relay) and should be used as primary protection. The secondary protection in that case should be by static /electromagnetic relays.

3.6.8 Typical Protection Schemes for Two Terminal Transmission Lines (Interconnection with Grid)

3.6.8.1 Typical Protection Schemes for Two Terminal Transmission Lines – 66kV to 220 kV (Interconnection with Grid of Large Hydro)

220 kV Lines

Primary Protection: Pilot aided (carrier communication) Phase comparison or Directional comparison type carrier relaying for phase to ground and phase to phase faults with additional distance elements for three phase faults (digital).

Secondary protection: i) High speed three stage directional distance protection relays, employing non-switched mho/reactance type relays with stepped characteristics (static/electromagnetic) with separate instrument transformer. **ii) Back up protection:** Time graded earth fault directional over current relays.

Dehar- Ganguwal 220 kV line was provided the above protection.

66 kV & 132 kV Feeder Protection

Primary Protection: Pilot aided (carrier communication) High speed 3 step directional distance protection for phase to phase and phase to earth and three phase faults (digital) or phase comparison type carrier relaying for short important lines.

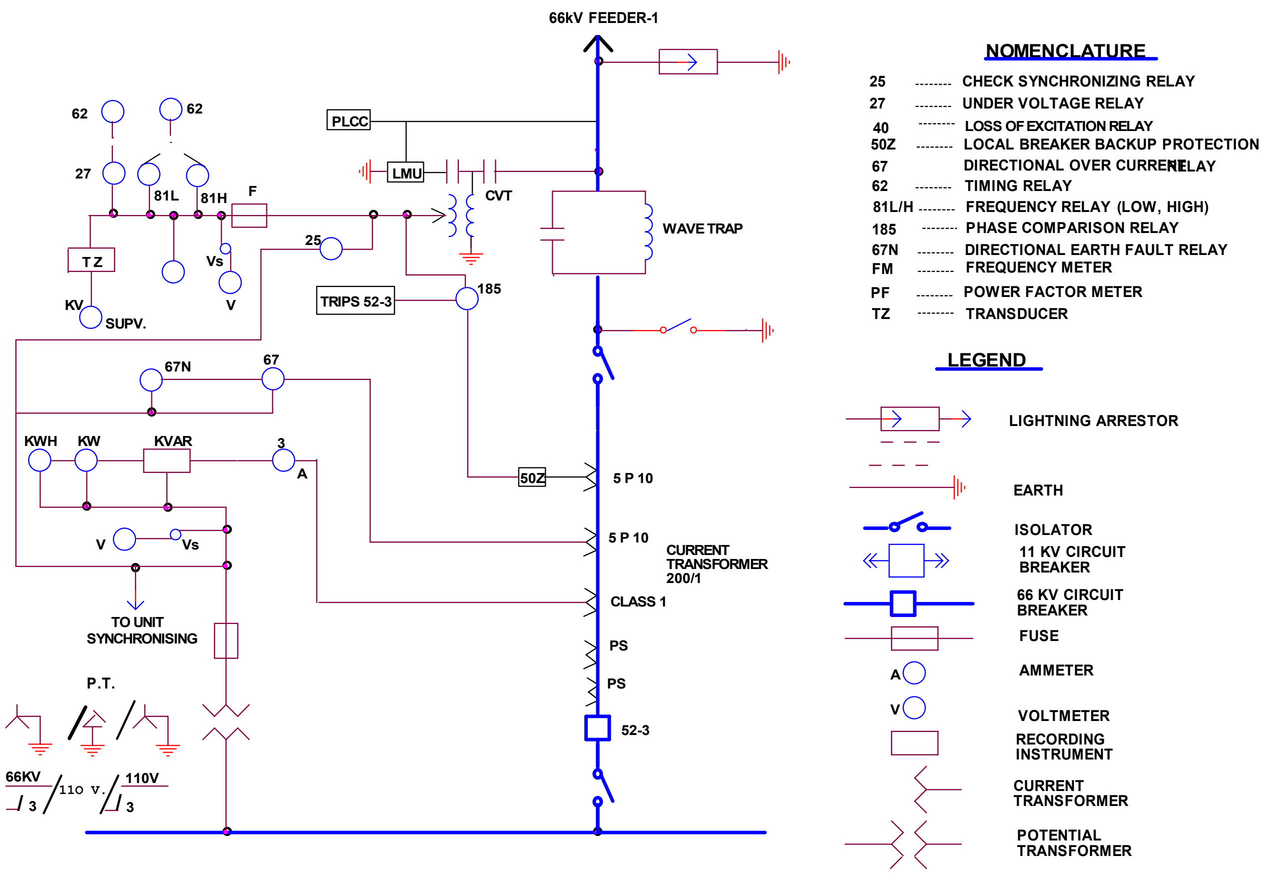


Figure 3.47: Mukerian Project Grid Interconnection – Two Terminal 66 kV (short & important) Line Protection (As designed)

Main Protection: Phase comparison relay/ Digital Quadra talaral phase and grout distance protection

Secondary Protection: Directional over current and earth fault relays.

A typical example is shown in figure 3.47 for 66 kV line interconnecting Mukerian Project with grid by short lines.

3.6.8.2 Typical Protection Schemes for Two Terminal Sub Transmission Lines (Interconnection with Grid of Small Hydro)

33 kV Lines

Directional over current and earth fault relays
Over frequency, under frequency, over voltage, under voltage

A typical example is shown in figure 3.48 of interconnection of Sikasar project by 33 kV interconnecting line. Check synchronizing at sending end is provided as generator protection. Dead line charging (under voltage relay) was provided at the receiving end 33 kV circuit breaker.

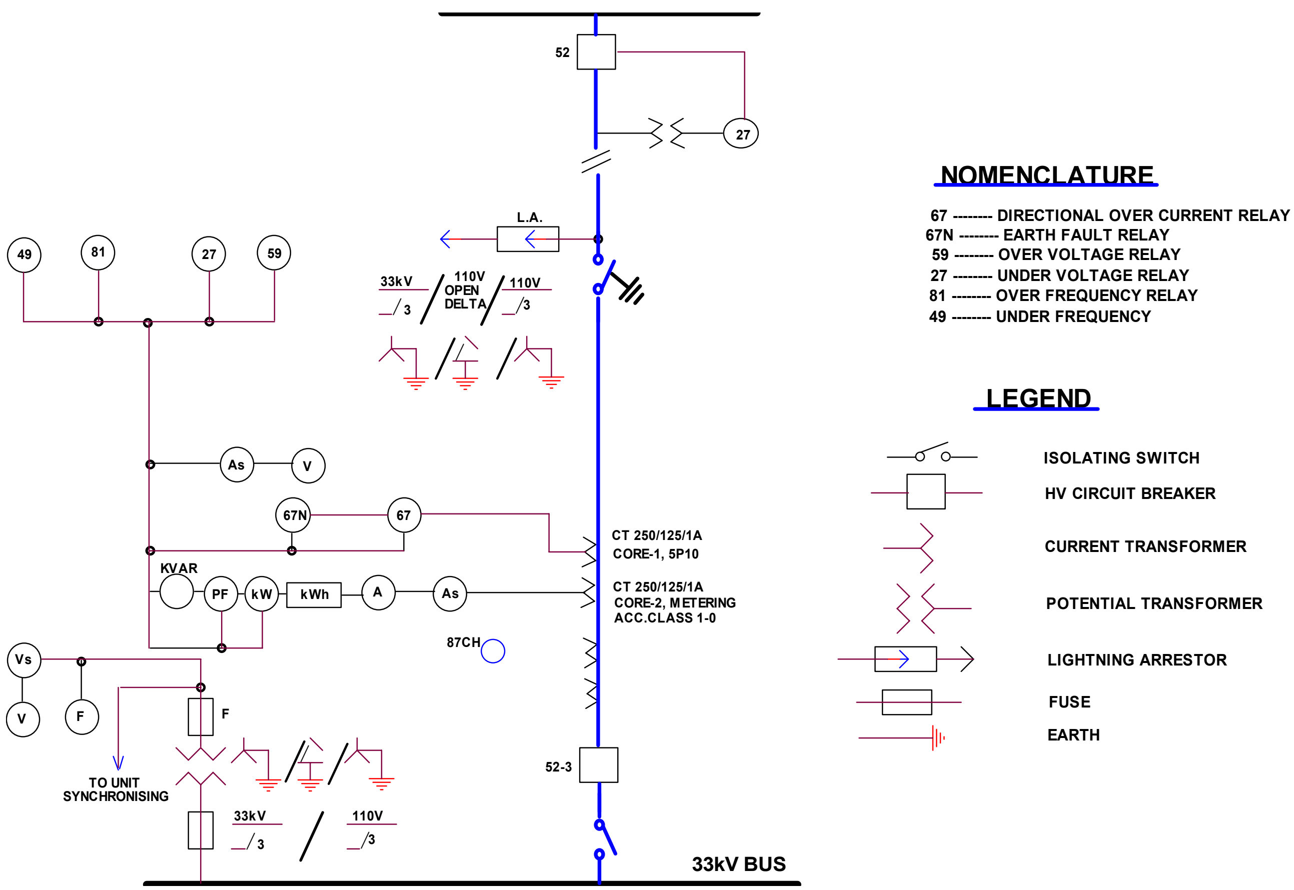


Figure 3.48: Sikasar Project Grid Interconnection – Two Terminal 33 kV Line Protection (As designed)

11 kV Lines

a. Combined over current (two phases) /earth fault is shown in figure 3.49. Reverse power and check synchronizing relays provided on each generator breaker. Over-frequency/under-frequency relay is also being provided.

b. **Group Interconnection with Grid:** A typical group interconnection of small hydro to 33 kV grid substations as proposed is shown in figures 3.50 (a) & (b).

3.6.8.3 Typical Protection Schemes for Interconnection with Grid of Micro Hydro

Relay protection is provided on the generators. Lines are protected by HRC fuse see figures 3.22 (a), (b) & (c). Over current protection is adjustable over load to cater to provide protection when overloads are less than short circuit due to part load operation in water shortage months when water inflows are low.

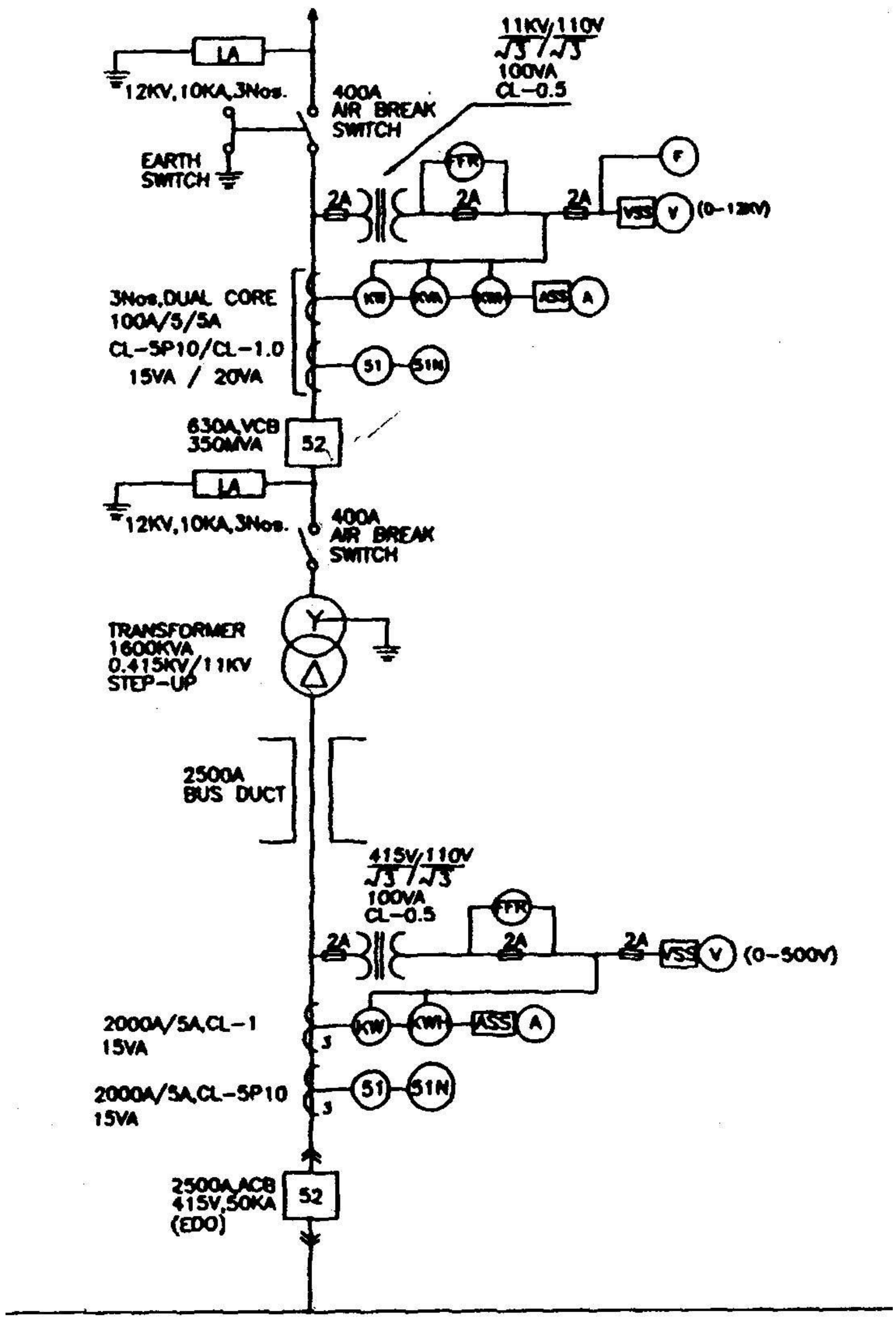


Figure 3.49: Dhelabagh Project Grid Interconnection – Two Terminal 11 kV Line Protection (AHEC Project)

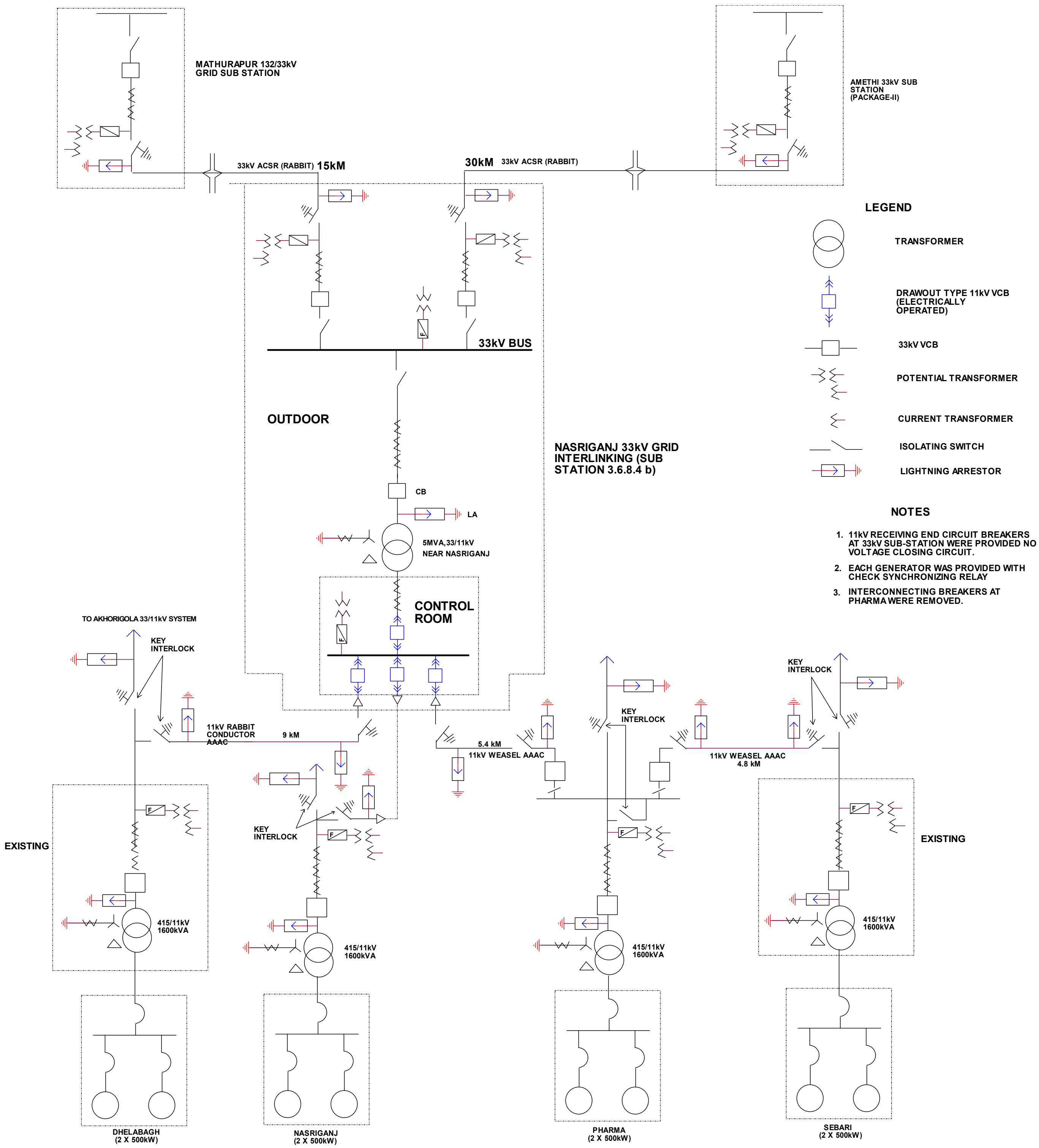


Figure 3.50 (a): Group Interconnection of Four SHP 415 Volts generators to grid at 33 kV (As designed)

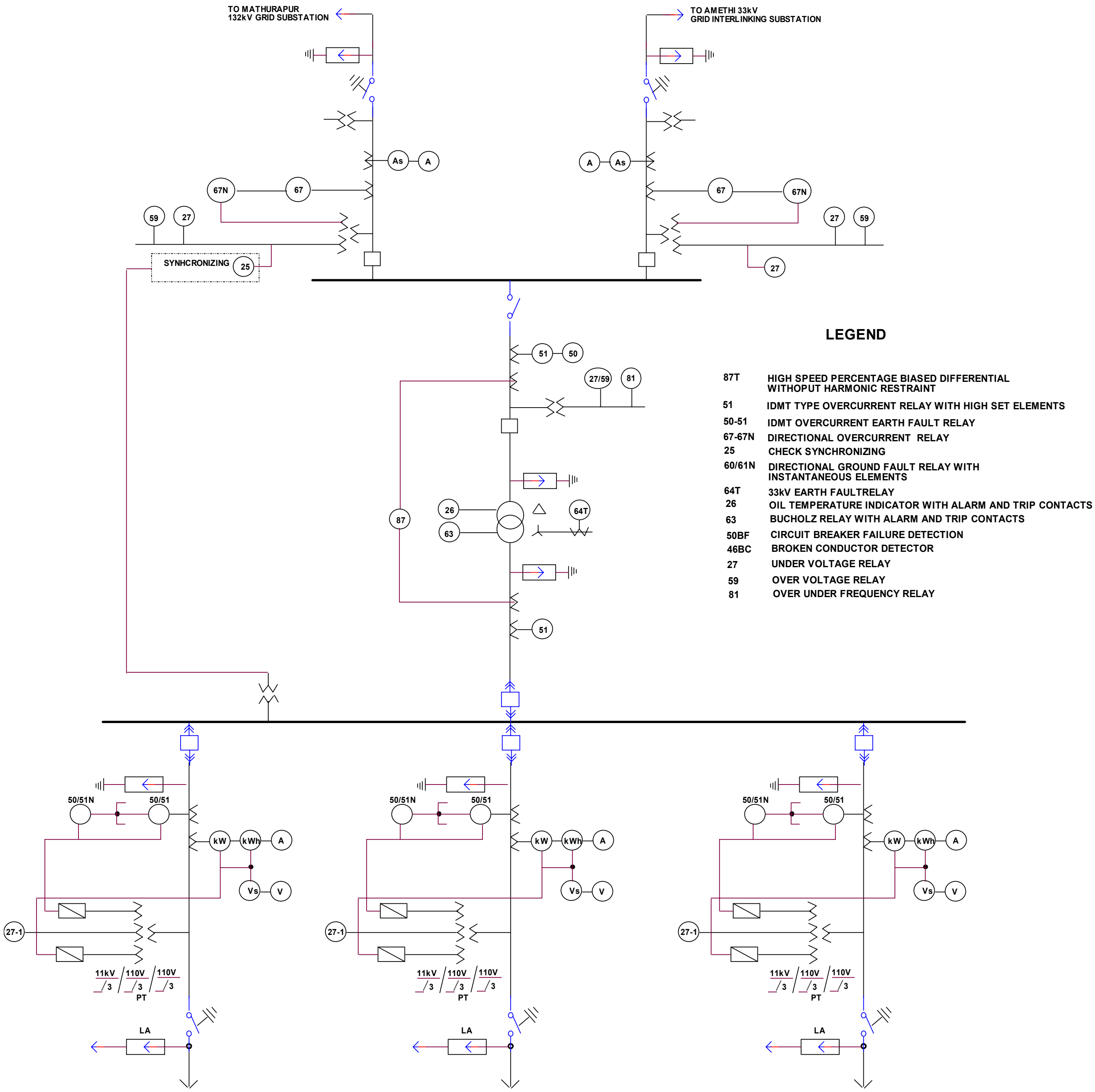


Figure 3.50 (b): Nasriganj Grid Interlinking 33kV Substation (As designed)

3.7 RELAYING FOR E.H.V. SYSTEM (420 kV and above)

(Based on the paper entitled relaying for 400 kV EHV system by Author; Refer Proceedings 42nd Annual Research Session Central Board of Irrigation and Power June 1972)

3.7.1 Introduction

i) Large sized hydro units at remote points require provision of heavy transmission ties for transferring bulk loads from the generating station to the interconnected grid. Transmission at E.H.V. at 420 kV and above is being provided in the country. E.H.V. lines have not only higher power capabilities but also higher fault capability. It becomes, therefore, increasingly important to clear all E.H.V. faults with high speed relaying and faults must be cleared quickly to prevent adverse effects on the interconnected power stations involved.

ii) Planning, engineering and selection of relaying for 420 kV and above E.H.V. system requires special consideration and is outlined with special reference to Dehar Power Plant 420 kV system of the Beas project. This power plant located on Beas-Sutlej Link was designed to have 4 units of 165 MW each in the first stage. Two more units of similar capacity were proposed to be added at a later date.

iii) This power plant is characterized by its remote location with respect to load centre. 245 kV double circuit 64 km long line to Ganguwal substation and a single circuit 420 kV line 280 km long to Panipat was proposed for interconnecting the power plant to the grid in the first stage. A second 420 kV line was proposed to be added along with second stage units. Special problems that are likely to arise in the applications of relaying to an E.H.V. system, in the initial stages of its development due to weak system lower short circuit level are discussed.

3.7.2 Description of 420 kV System

Figure 3.51 shows the interconnected 420 kV system. Dehar E.H.V. 420 kV sending end step up substation has a double bus arrangement and 420 kV breaker arrangements are as shown in Figure 3.51. The interconnection of the 420 kV system with the existing 245 kV network was proposed by 420/245 kV auto-transformer at Dehar and Panipat substations. Switched shunt reactors connected to tertiary winding of transformers at receiving end were proposed to be provided for the purpose of voltage control. E.H.V. shunt reactors directly connected to the E.H.V. line were to be provided to control line over voltages after further studies.

3.7.3 Design Consideration

Various considerations and problems areas in selection of suitable relaying for E.H.V. systems may be classified as follows:

(a) Fault currents
(b) Stability requirements
(c) Substation bus arrangements
(d) Protective relay design

3.7.3.1 Fault Currents

Fault studies based on minimum and maximum generating conditions for conceivable operating conditions for both three phase as well as for single phase to ground faults for Dehar E.H.V. system were made for the following operating conditions:

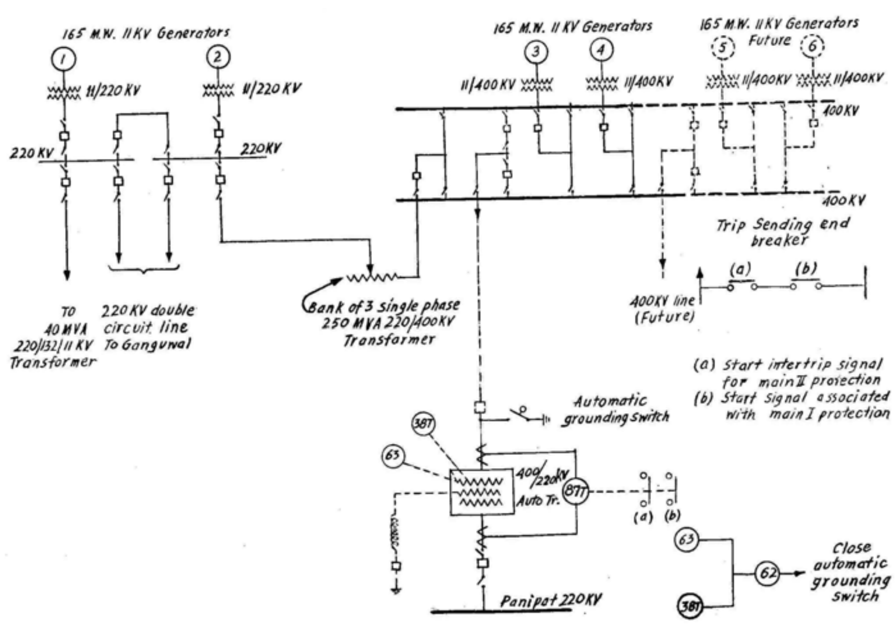


Figure 3.51: Interconnected 420 kV System (As designed)

(a) Maximum Generating Conditions – Four generators, in operation at Dehar – All lines in.
(b) Maximum Generation – Four generators in operation on 245 kV bus at Dehar – All lines in.
(c) Minimum Generation – Only one generator in operation on 245 kV bus at Dehar – All lines in.
(d) Minimum Generation – Only one generator in operation on 420 kV bus at Dehar – All lines in.

Fault currents and post-fault voltages for three phase fault studies for 420 kV system are shown Figure 3.52. Fault currents and post fault voltages for single phase fault studies for 420 kV systems are shown in Figure 3.53.

These studies showed that it is not possible to apply phase comparison solid state relaying for 420 kV lines as further detailed in a subsequent paragraph. Further due to low residual voltages at Dehar 420 kV bus in the post-fault period high speed dependable relay operation is considered essential. Low fault levels in the initial stage of development of E.H.V. line in the region further indicated that sensitivity of relays will play a major role for proper relay selection.

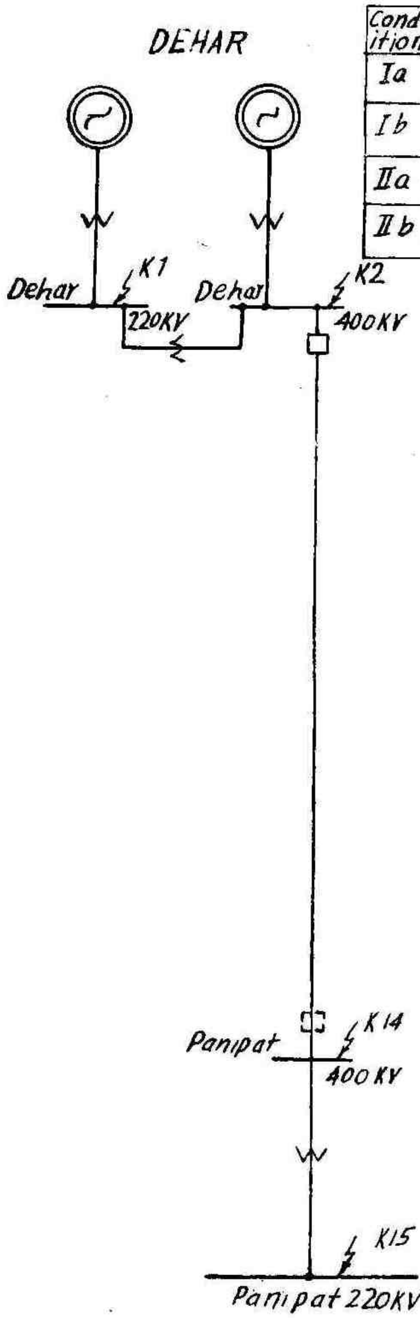
3.7.3.2 Transient Stability

i. In the early stages of design of power plant it was decided that generators with normal characteristics be specified and parameters of stability be achieved by optimizing parameters of static excitation system and fault clearance time. Detailed digital computer studies for the purpose were carried out with the help of M/s English Electric Co. in U.K.

ii. The stability criteria adopted was with the main aim to design a system which would be transiently stable for a permanent fault on the 420 kV line involving unsuccessful reclosure on to the fault, and dynamically stable for all conditions where the 420 kV line was removed. It was considered desirable that these aims be met under three phase fault conditions; the probability of such faults occurring in practice although small, were not considered small enough to be regarded as an acceptable risk.

iii. Initial transient stability studies with a “constant voltage behind transient reactance” representation carried out indicated that the aim might not be realized in the severe case of unsuccessful reclosure. The case of a three phase fault at Panipat end of the 420 kV line followed, however, by successful reclosure indicated significant deviations from the normal frequency though there was no loss of synchronism between machines. These results indicated that if the aims described above were to be at all possible to attain minimum fault clearance time and high value of excitation system response will have to be provided.

iv. Fault clearance time on the E.H.V. 420 kV system was proposed 80 milliseconds based on the equipment available at that time. This time is composed of 40 milliseconds for circuit breaker operation and 40 milliseconds for protection operation. It was considered that with modern industry practice in relays, the above fault clearance times could be achieved.



Total fault current

Condition	K2
Ia	3635
Ib	3460
IIa	2155
IIb	2595

Short circuit currents from Dehar machines 400KV side-fault at location

Condition	K1	K2	K14	K15
Ia	865	1240	680	610
Ib	842	1240	680	610
IIb	433	577	386	375

Post fault voltage in KV at Dehar 400KV bus-fault at location

Condition	K1	K2	K14	K15
Ia	156	0	205	230
Ib	164	0	204	230
IIa	72	0	125	134
IIb	114	0	142	150

NOTE
Values of fault current have been expressed in amperes at a base voltage of 400 KV.

Short circuit current in Dehar-Panipat line-fault at location

Condition	K1	K2	K14	K15
Ia	450	924	1290	924
Ib	539	954	1270	940
IIa	478	866	745	520
IIb	404	814	889	605

Total fault current

Condition	K14
Ia	3070
Ib	3040
IIa	2280
IIb	2480

Post fault voltage at Panipat 400 KV bus-fault at location

Condition	K2
Ia	148.8
Ib	153.6
IIa	134.4
IIb	134.4

Figure 3.52: Three Phase Faults, Fault Currents and Voltages

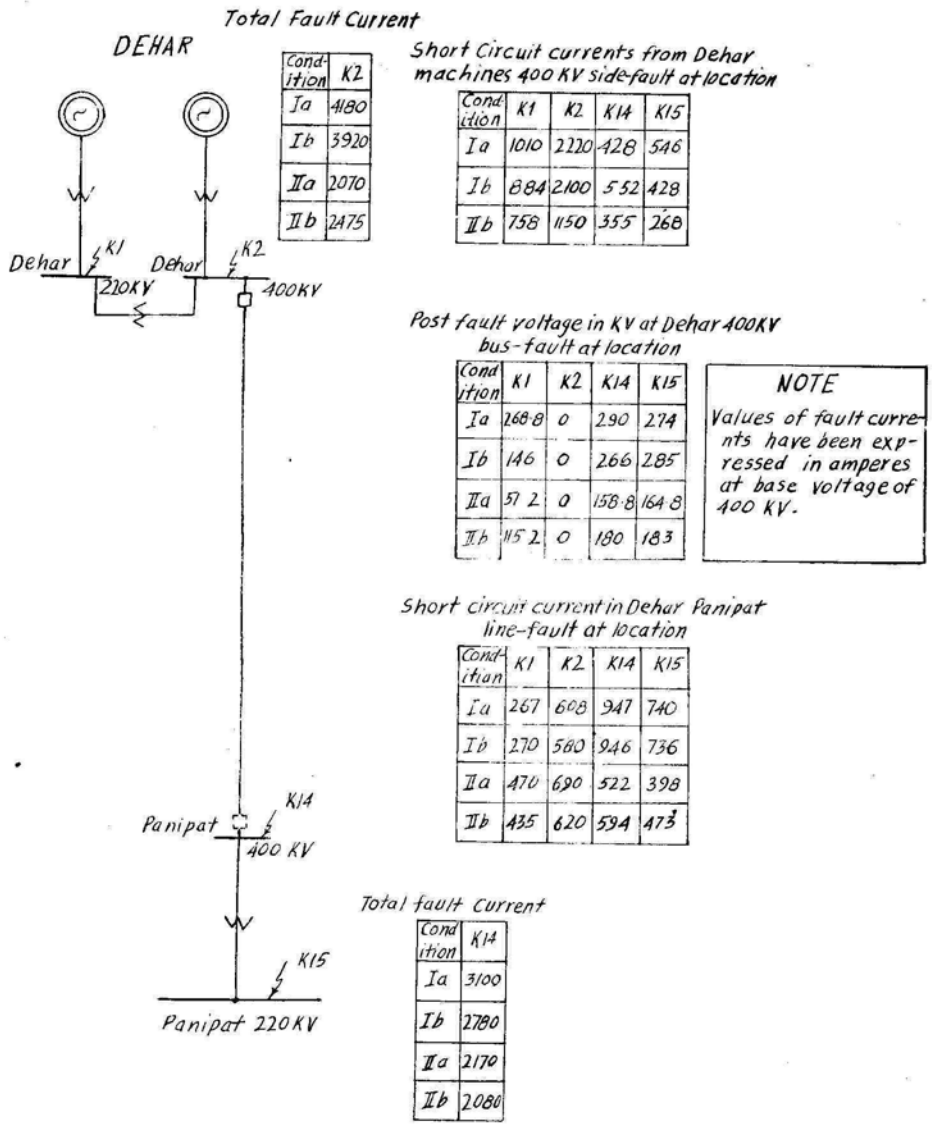


Figure 3.53: Phase to ground Faults, Fault Currents and Voltages

v. All transient stability studies were carried out with a total fault clearance time of 0.1 sec. the detailed transient stability studies were carried out with detailed representation of excitation system, governors and generators. The stability run was continued up to a period of 8 to 10 sec. real time. Following fault clearing times based on the most advanced relay schemes available at that time for high voltage transmission system were accordingly considered desirable.

vi. Main I (Normal) Clearing: Tripping initiated by Main I protective relays 4 cycles (2 cycles for relay operations and 2 cycles for breaker operation).

vii. Main II (back-up) Clearing: Tripping initiated by zone 1 of main II back-up electro-mechanical relays 80-100 milliseconds (4-5 cycles). Fault clearance time for tripping initiated by zone 2 of main II back-up relays (25 cycles) tentative.

viii. End zone faults of 420 kV line are thus to be fully cleared in 80-100 milliseconds through carrier intertripping channel.

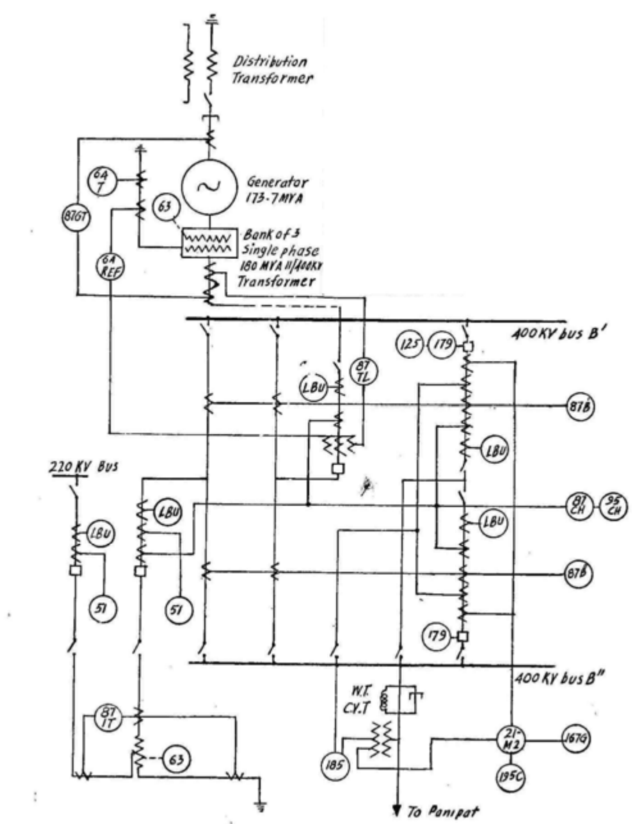
ix. Circuit breaker Failure Clearing: Tripping initiated by main I relays or zone 1 of main II relays 12-15 cycles (tentative), tripping initiated by zone 2 of Main II (back-up) relays 35 cycles (tentative). Further studies were contemplated to find out critical fault clearance times and fix clearance time accordingly for back-up protection. Stability studies, however, indicated fast clearing of all faults. The proposed protection scheme is shown in Figure 3.54.

3.7.3.3 Substation Bus Arrangement

i. Taking into consideration large power that is carried by 420 kV line, it was considered desirable to protect 420 kV lines by two breakers at the sending end. This could be done by providing a ring bus, double bus, breaker and a half arrangement or other similar arrangements as feasible at site. Taking into consideration very high costs of E.H.V. breaker installations, practice is now developing of relaying receiving end E.H.V. transformer as apart of E.H.V. line and thus save the cost of E.H.V. breaker installations at the receiving ends.
ii. Bus and breaker arrangements proposed for Dehar step up station are shown in Figure 10.8 (main single line). Outgoing 420 kV line is proposed to be protected by two breakers. It was further considered that in the first stage of operation when only one 420 kV line is in operation one of the two 165 MW generating units supplying the Dehar 420 kV bus may be switched out simultaneously with the line so as to aid stability. The other machine on 420 kV bus could remain connected and feed the system through 245 kV network. Thus in the event of disconnection of the faulted 420 kV line the system would lose capacity equal to only one machine of 165 MW. Spinning reserve of this magnitude was likely to be available in the grid to cater to machine outage of this magnitude.

3.7.3.4 Protective Relay Design

Protective relaying problems encountered in the Dehar 420 kV system were thus due to the initial development of 420 kV E.H.V. line resulting in low short circuit levels due to weak system. Long distance of the E.H.V. line and critical transient stability conditions added to the problem. High speed relaying became a major consideration because of these considerations. Normal clearing of line faults including end zone faults was proposed to be accomplished in about 2 cycles employing solid state carrier relaying and circuit breakers with two cycles interrupting time. As solid state relays for bus and transformer protection may not be available, clearing time for this equipment may be of the order of 50 milliseconds (2 ½ cycles). Back-up clearing times were proposed to be the fastest practical times obtainable with electro-mechanical relay devices available at that time. The main features of the protection system proposed were as follows:



LEGEND

21 M-2	MAIN II DISTANCE PROTECTION
51	BACK UP O/C PROTECTION
63	GAS RELAY
878', 878"	BUS BAR PROTECTION - MAIN
87CH	BUS BAR PROTECTION - CHECK
64REF	RESTRICTED EARTH FAULT RELAY
64T	TRANSFORMER EARTH FAULT RELAY
87 GT	GENERATOR TRANSFORMER DIFF. RELAY
87 TL	TRANSFORMER LINK LINE DIFF. RELAY
87 IT	INTERLINKING TRANSFORMER DIFF. RELAY
95 CH	SUPERVISION RELAY
125	SYNCHRONISM CHECKING RELAY
167 G	DIRECTIONAL GROUND O/C RELAY
179	RECLOSING DEVICE
185	DIRECTIONAL COMP. MAIN I PROTECTION
195 C	CARRIER INTERTRIPPING RELAY
WT	WAVE TRAP
LBU	LOCAL BREAKER BACKUP PROTECTION
CVT	CAPACITIVE VOLTAGE TRANSFORMER

Figure 3.54: 420 kV EHV System Protection Scheme (As designed)

(a) Provision of two independent high speed main protection called Main I and Main II (back-up) protections, one solid state carrier relay acting as a primary protection and the other high speed electro-mechanical distance protection with separate carrier channels for isolating the line from both ends.

Numerical relays now available are preferred as Main I protection as software logic replaces many components and thus increasing reliability.

(b) Separate current transformers for the two main protections for the two main protections so as to obtain maximum isolation.

(c) One potential device per phase for each line terminal with separate secondary winding (independently fused) supplying potential to the primary and back-up relays.

(d) Two independent remote tripping systems in case receiving end transformers connected without breaker.

(e) Provision of separately fused D.C. tripping with separate auxiliary tripping relays or devices.

(f) Provision of local back-up protection for either of the following contingencies:

- Failure of Main I and Main II relays to function due to failures in their control circuits.
- Failure of a breaker or a faulted circuit breaker to operate or interrupt.

3.7.4 Transmission Line Protection

Transmission line protection design requires considerable attention for relay devices based on the factors described in a separate section. In general solid state (numerical) relay devices offer high speed operation, greater sensitivity, reduced space requirements and less maintenance and could be used with advantages for Main I protection. Further to take advantage of Main II or back-up relaying operating on a different principle, conventional electro-mechanical relays were chosen for this function.

3.7.4.1 Main I (Primary) Protection

Following two types of static solid relays were generally applied for primary protection of E.H.V. lines at that time. Numerical relays were not available.

(a) Phase comparison type
(b) Directional comparison type

Phase comparison type static carrier relaying for phase to ground and phase to phase faults with additional distance elements for three phase faults has got the following main inherent advantages and had accordingly been employed on many recent E.H.V. installations at that time.

- Dependable high speed tripping from both ends.
- The main scheme works without potential transformers or potential sources.
- Relaying is not affected by mutual induced ground fault currents.
- Relaying is not sensitive to power swing.

But before this relay is adopted for an E.H.V. line it is necessary to ascertain that this type of relay can be applied on the E.H.V. line and will not maloperate especially for long lines of over 160 km in length. Following factors in this respect need consideration.

- Attenuation: The transmitted level and the receiver sensitivity must be such as to ensure satisfactory signal transmission, under worst condition of signal attenuation to be expected. This requires that lower carrier frequencies be reserved for longer lines.
- Charging current: it requires to be ascertained that relay will not maloperate and cause incorrect tripping due to line charging currents leaving both terminals, i.e., appearing to the relay as an internal fault.

- Fault Levels: the minimum fault level must exceed the load prior to fault plus charging current required by the impulse setting network.
- Stability for External Fault: Possibility of incorrect tripping due to phase angle error caused by phase shift on account of capacity currents and low load currents or clearance of external faults also needs to be ensured.
- A phase comparison relay, therefore, cannot be considered if line lengths are more than 300 to 400 km long approximately.
- On Dehar-Panipat 420 kV line of Beas Project the maximum and minimum load as per load flow studies was as follows:

	Sending End	**Receiving End**
Maximum load current on 420 kV line	220 MW 15 MVA (Leading)	218 MW 87 MVA (Lagging)
Minimum load on 420 kV line	44 MW 66 MVA (Leading)	

The fault currents are indicated in Figure 3.52 and Figure 3.53.

- Taking into consideration the above factors it was found at that time phase comparison type of relaying cannot be effectively applied to Dehar-Panipat 280 km long line unless the fault currents increase 3 to 4 times.
- It was accordingly decided to provide solid state directional comparison distance carrier blocking scheme type of relaying as first main (primary) protection for this line.
- Main I protection proposed for Dehar-Panipat 420 kV line consists of directional comparison/distance static type protection scheme using carrier current blocking principle. The scheme may basically consist of three-step-static mho distance scheme using an end to end signaling channel to give high speed clearance of both phase to phase and phase to earthfaults anywhere on the line. The total protection operating time including time required for relay operation blocking signal time for end zone faults and conventional tripping relay time may not be greater than 40 m.s. Provision for fuse failure relays and out of step blocking relays was also proposed to be made. The scheme may have provision of independent high speed zone 1 protection in the absence of carrier blocking signal and/ or if the signal channel is faulty or taken out of service. Zone 2 and zone 3 may have independently adjustable time delay range. Main I and Main II relaying were specified to be connected to separate current transformers and separate windings of the capacitive voltage transformers (coupling capacitor potential devices).

3.7.4.2 Second Main Protection

As already discussed electro-mechanical relays be provided for second main protection which also acts as a back-up protection to the adjoining line section. Further this relay is to act as an alternate protection for the periods the primary protection is out for maintenance or for other reasons. For this purpose distance measuring type of relays for phase faults and also for ground faults with a provision for interrupting over phase-phase coupled carrier may be used. Ground fault distance protection is complicated because of the following reasons:

- Measured zero sequence voltage does not represent actual protected line drop unless compensated.
- Zero sequence mutual reactance between parallel lines.
- Likelihood of high fault resistance on ground fault.
- Effect of transient.

Modern relays provide compensation for most of the above mentioned conditions.

The relays for Main II back-up protection for Dehar-Panipat E.H.V. 420 kV line are detailed below.

- For the secondary protection of this line, very high speed, 3 step directional distance (Mho, type) protection relaying scheme, with provision of carrier inter-tripping for isolating the line without time lag for end zone faults were proposed. It was proposed that the protection be provided for phase to phase, phase to ground and three-phase faults with equal speed of operation. The total protection operating time including time required for relay operation, inter tripping for end zone fault and conventional tripping relay time may not be greater than 40 milliseconds. PT fuse failure blocking device and out of step blocking relays were also proposed to be provided. The distance protection scheme may work in conjunction with carrier communication equipment for the purpose of carrier inter tripping channel.

3.7.4.3 Back-up Protection

Taking into consideration that majority of the faults on an E.H.V. line are single phase to ground faults and to provide for contingencies, it was considered desirable to provide back-up relays for earth faults. Time graded earth fault directional over current relays were accordingly proposed for Dehar-Panipat E.H.V. line at the sending end.

3.7.5 420 kV Bus Bar Protection

High speed differential protection is required to be provided for each bus bar section. Supervision and check feature should also be provided so as to obviate possibility of false tripping. For each 420 kV bus bar section at Dehar high speed, high impedance type bus-bar differential protection was provided. Separate and independent check and supervision features were incorporated in it. Separate CT core were proposed at the incoming and outgoing circuits for check features. The main zonal relay and check relay scheme was proposed to have their contacts connected in series in the trip circuit. Supervision relays were proposed to be provided to detect open, crossed or broken CT secondary and pilots by employing sensitive alarm relays, which were to be connected across the bus wires of each protected zone. It was to be capable of taking the protection of the effected zone out of service by shorting the appropriate bus wires.

"No Volt" relays to indicate failure of DC alarm and trip supply to the bus bar protection was also proposed to be provided.

Receiving end transformer if connected without breaker and associated bus sections can be relayed as part of the associated 420 kV transmission line.

3.7.6 Protection of 420 kV Transformer

High speed differential relay with suitable back-up is required to be provided for the protection of transformer.

For the protection of 420 kV auto-transformer at Dehar an instantaneous high speed differential relay without harmonic bias, load bias or time lag was proposed to be provided. Three sets of CT's of same turns ratio were proposed as shown in Figure 3.55. it consists of one set at the neutral end (for which purpose each phase neutral end is proposed to be brought out of tank through a separate bushing); one set on 420 kV (HV) side and one set on 245 kV (LV) side. Thus magnetizing inrush current or any unbalance that may occur due to tap changing will not have any effect on relay operation.

3.7.7 Circuit Breaker Failure Relaying (Local Breaker back-up Protection)

Due to need of reliability and ever decreasing critical fault clearing time in E.H.V. interconnected system, it is not possible to rely on remote back-up protection and accordingly breaker failure protection becomes an important ingredient in the electric power system protection. This protection is required to ensure security as well as speed. A separately fused failure circuit is normally installed for each breaker. The circuit is supervised by a special current operated relay with fast resetting time. This protection can be arranged to energise bus bar tripping relays, initiate transfer trip signals to the remote breaker and stop the appropriate carrier blocking signals (or phase comparison signals) to the remote terminal. The basic arrangement is shown in figure 3.56. An alternative scheme uses one timer per bus for all breakers and is thus cheaper, but has the following disadvantages:-

i. In the case of a spreading fault (e.g., a fault that starts on one line and spreads to other line), the common timer is kept energized and may operate even though breaker of both lines could have cleared the fault normally.
ii. if the bus breakers have different rated interrupting times, the timer has to be set for the lowest breaker, thus sacrificing some clearing speed, which could otherwise be gained for the faster breakers.

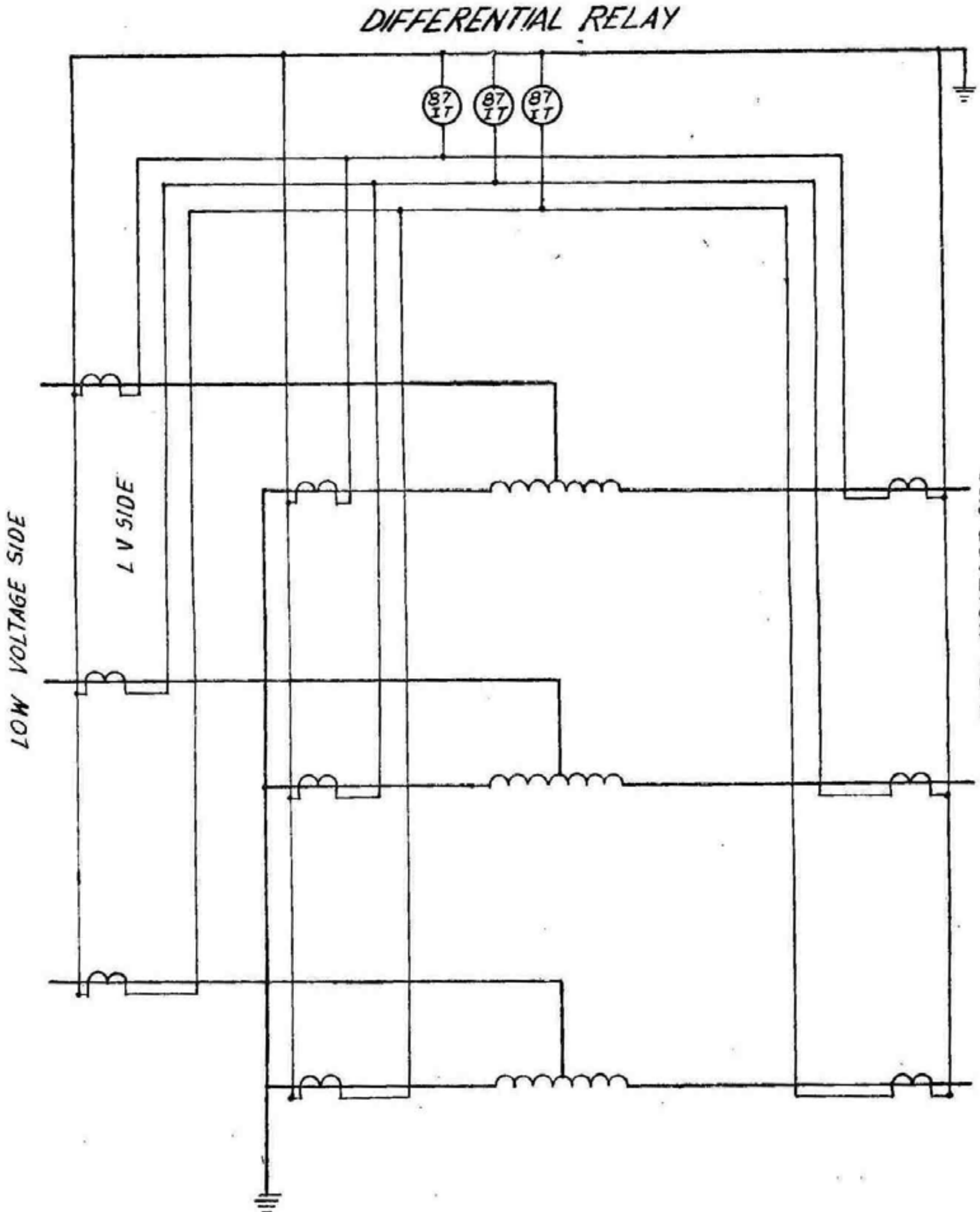


Figure 3.55: Schematic Diagram of Differential Protection for Interlinking Transformer (As designed)

Circuit breaker failure protection scheme using one timer per circuit breaker was proposed to be provided for all breakers connected to 420 kV buses at Dehar E.H.V. substation. The protection may be so arranged so that if any circuit breaker fails to trip in the event of a fault, then after a short time delay (say of the order of 15 cycles) from the time Main I/Main II protection gives the trip signal to the breaker) all the circuit breakers connected to the bus section, to which the faulted circuit breaker is connected are tripped and locked out. The scheme may also be arranged to initiate transfer trip signals to the remote end breaker and stop the appropriate carrier blocking signal to the remote terminal. The circuit breaker failure may also block auto-reclosing scheme, if provided at a later stage.

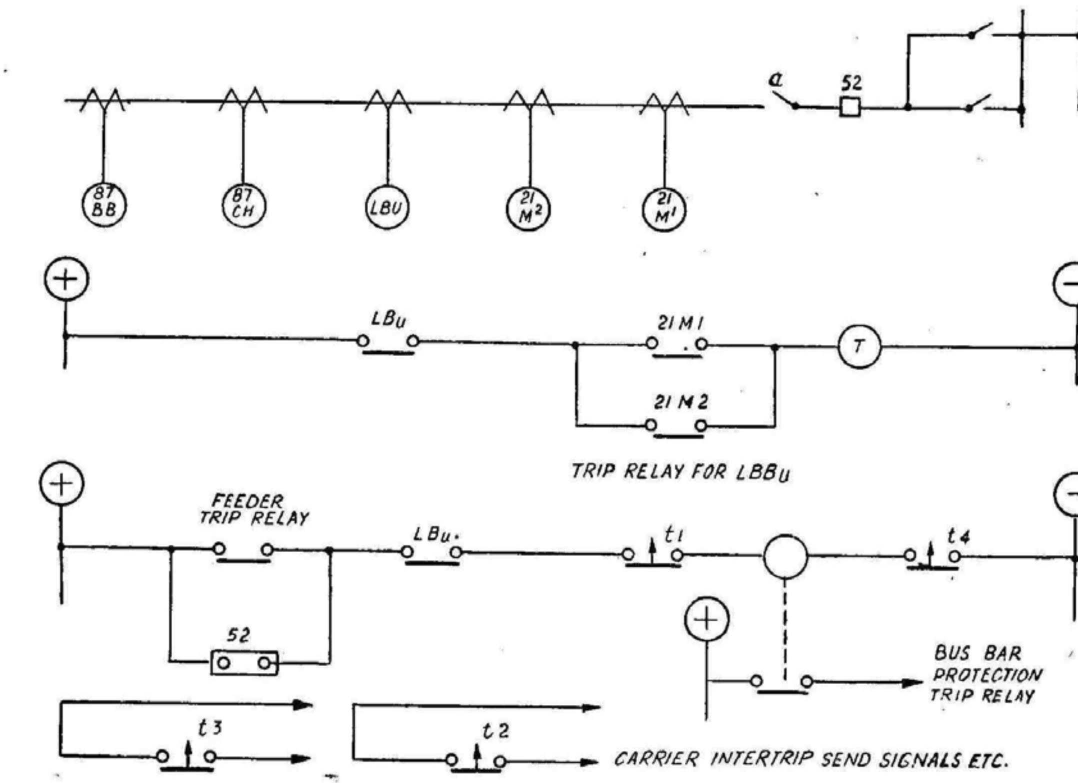


Figure 3.56: Typical Load Breaker Back-up Protection (As designed)

3.7.8 Auto-Reclosing 420 kV Line

Automatic reclosing of an E.H.V. lines depends upon system conditions including the following.

i. Stability considerations
ii. Operating restrictions imposed by transient over voltage conditions.

Desirable method of reclosing, i.e., whether 3 – phase or single phase, whether instantaneous reclosing or delayed reclosing needs to be carefully investigated. Although instantaneous reclosing is generally desirable to maintain stability and provide better operation, but may not be applicable to a particular system as in Keystone. In particular the required circuit dead time for 420 kV is approximately 20 cycles. If this is a system separation time, it may be too long to retain in synchronism when reclosing is affected. Further in case of critical stability conditions effect on the system of unsuccessful reclosure, i.e., reclosing into a fault also needs to be ascertained.

Delayed reclosing provided for necessary dead time and transient overvoltage conditions do not remain and is quite frequently applied. In the British system at that time very much delayed 3-phase reclosing is applied.

Single pole automatic reclosing was employed to maintain synchronous stability for single phase to ground faults, but application of this type of reclosing introduces many problems. Determination of the nature and duration of secondary arcs is important before single pole automatic reclosing is adopted. Staged fault tests have been performed to determine the acceptable reclosing time and other unknown aspects of single pole switching at 525 kV voltage level. In general the longer the time the lower the stability limit is likely to be and the shorter the tolerable outage time on the faulted phase. However, the longer the line the greater is the capacitive coupling between phases and a longer outage time required to extinguish the secondary arc. At some point these two requirements become incompatible and successful reclosing cannot be achieved.

Further application of single pole reclosing introduces some very pertinent question the selection of a relaying scheme. If phase comparison is used, it is necessary to develop suitable faulted phase selectors. If circuits have ground wires and low tower footing resistance, then ground distance relays can provide faulted phase selection. If directional comparison is used with permissive over-reaching ground relays suitable faulted phase selectors will have to be provided.

For Dehar 420 kV system, the question of providing reclosing was not decided although equipment was being procured which will be suitable for single phase or 3-phase reclosing. This aspect was proposed to be studied after the installation of reactors and their size finalized so that operating restrictions imposed by transient overvoltage conditions can be fully ascertained. Further, duration of secondary arcs for single phase automatic reclosing also needed to be established.

Relaying scheme for 3-phase reclosing proposed for second stage of operation at Dehar is shown in Figure 3.54.

3.7.9 Other Relaying

Shunt reactors are employed in E.H.V. system for controlling over voltages. Permanently connected E.H.V. reactors are generally used to lower temporary and switching surge over voltages. Shunt reactors in the tertiary winding of receiving end transformer are generally used for the purpose of voltage control in the system.

Relaying for low voltage shunt reactor generally consists of differential protection, backed by over current relays, ground relays and ground pressure relays are also used. A typical diagram is shown in Figure 3.57.

E.H.V. reactors primary protection is usually provided by one or a combination of the following relays.

Line relay; over current relays; differential relays; reactor distance relays and rate of rise pressure relays.

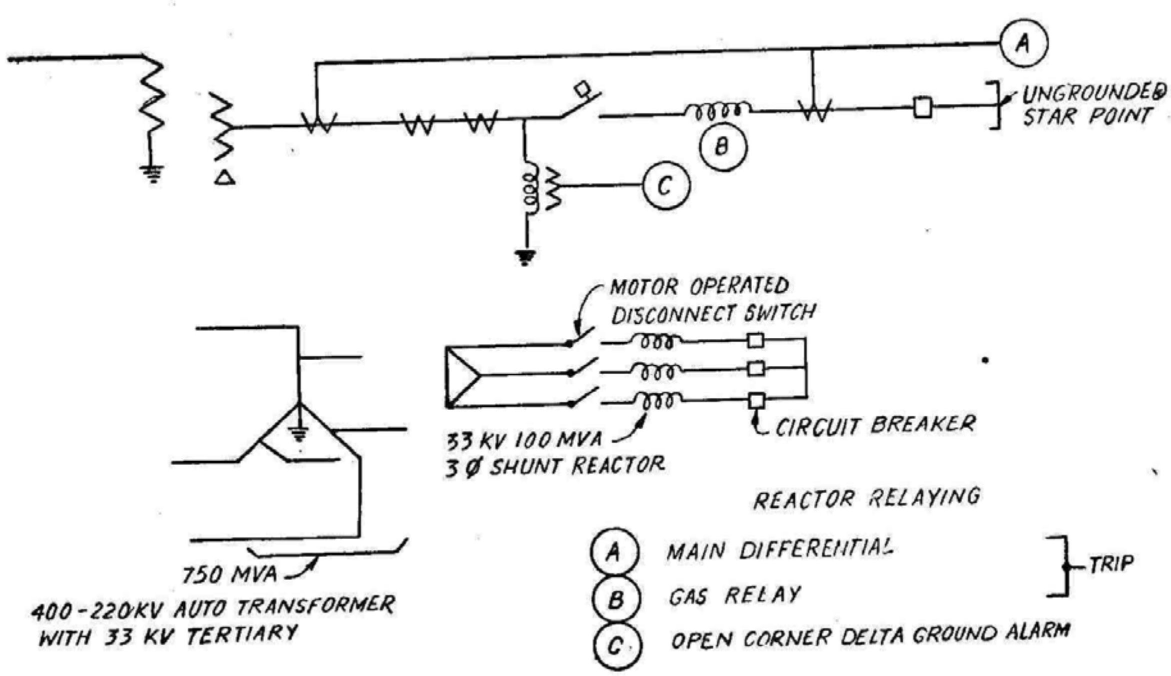


Figure 3.57: Typical 33 kV Reactor Connections and Relaying (As Proposed)

3.7.10 Conclusion

One EHV line can transmit as much power as several 245 kV lines. Because of its great importance to the operation of a power system, the relaying selected for protecting this equipment must be of the highest reliability and have a high security factor. Accordingly E.H.V. lines should be protected by two main protections one numerical and the other solid state static type/electro-magnetic type. Back-up protection should include local breaker back-up protection.

In the initial stage of development of E.H.V. system in the regional grids in India stability conditions are liable to be critical because the EHV line has the capability of transmitting large amount of fault current and consequently have a damaging effect on the entire system. This requires high speed relaying. Low fault levels in the weak regional systems demand application of not only more sensitive relaying but also proper selection of the type of relays.

Planning, engineering and selection of relaying for E.H.V. be generally based on its specific requirement as a result of system studies which may include load flows, fault studies and stability studies.

3.7.11 Numerical Digital Line relays

Multi function high speed digital relay suitable for EHV lines including high speed pilot aided phase comparison and distance protection etc. (e.g. M/s Areva relay Micom P547 – phase comparison relay) is shown in figure 3.58. Main functions for P547 80TE version are summarized in table 3.11. Exact data be obtained from suppler/manufacturer.

Table 3.11

<table>
<tr><th>ANSI</th><th colspan="2">FEATURE</th><th>MODEL (P547 80TE)</th></tr>
<tr><td>87</td><td colspan="2">Phase segregated phase comparison</td><td>●</td></tr>
<tr><td></td><td colspan="2">2 and 3 terminal lines/cables</td><td>●</td></tr>
<tr><td>21P/21G</td><td colspan="2">Distance zones, full-scheme protection</td><td>5</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Characteristic</td><td>Phase elements</td><td rowspan="2">Mho and quadrilateral</td></tr>
<tr><td>Ground elements</td></tr>
<tr><td></td><td colspan="2">CVT transient overreach elimination</td><td>●</td></tr>
<tr><td></td><td colspan="2">Load blinder</td><td>●</td></tr>
<tr><td></td><td colspan="2">Easy setting mode</td><td>●</td></tr>
<tr><td></td><td colspan="2">Mutual compensation (for fault locator and distance zones)</td><td>●</td></tr>
<tr><td>85</td><td colspan="2">Communication aided schemes, PUTT, POTT, blocking, Weak Infeed</td><td>●</td></tr>
<tr><td></td><td colspan="2">Accelerated tripping-loss of load and Z1 extension</td><td>●</td></tr>
<tr><td>50/27</td><td colspan="2">Switch on to fault and trip on recluse – elements for fast fault clearance upon breaker closure</td><td>●</td></tr>
<tr><td>68</td><td colspan="2">Power swing blocking</td><td>●</td></tr>
<tr><td>78</td><td colspan="2">Out of step</td><td>●</td></tr>
<tr><td>67N</td><td colspan="2">Directional; earth fault (DEF) unit protection</td><td>●</td></tr>
<tr><td>50/51/67</td><td colspan="2">Phase over current stages, with optional directionality</td><td>4</td></tr>
<tr><td>50N/51N/67N</td><td colspan="2">Earth/ground over current stages, with optional directionality</td><td>4</td></tr>
<tr><td>51N/67N/SEF</td><td colspan="2">Sensitive earth fault (SEF)</td><td>4</td></tr>
<tr><td>67/46</td><td colspan="2">Negative sequence over current stages, with optional directionality</td><td>●</td></tr>
<tr><td>46BC</td><td colspan="2">Broken conductor (open jumper), used to detect open circuit faults</td><td>●</td></tr>
<tr><td>49</td><td colspan="2">Thermal overload protection</td><td>●</td></tr>
<tr><td>27</td><td colspan="2">Under voltage protection stages</td><td>2</td></tr>
<tr><td>59</td><td colspan="2">Over voltage protection stages</td><td>2</td></tr>
<tr><td>59N</td><td colspan="2">Residual voltage stages (neutral displacement)</td><td>2</td></tr>
<tr><td>81U/O/R</td><td colspan="2">A 4-stage underfrequency, 2-stage overfrequency and advanced</td><td>●</td></tr>
</table>

	4-stage rate of change of frequency element as well	
50BF	High speed breaker fail. Two stage, suitable for re-tripping and back tripping	●
CTS	CT supervision	●
VTS	Current and voltage transformer supervision	●
79	Auto-reclose-shots supported	4
25	Check synchronism, 2 stages with additional system split detection	●

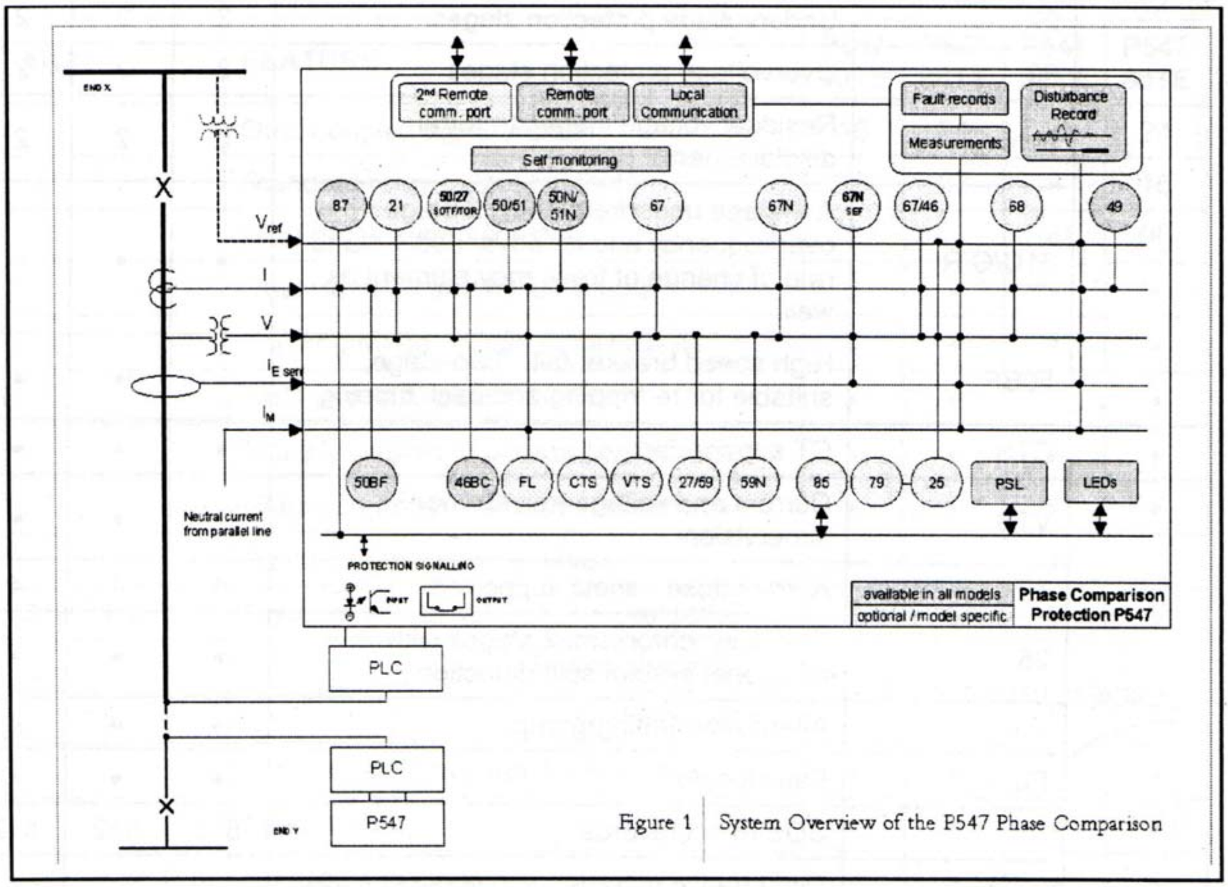


Figure 3.58: Functional Overview - MICOM Distance Protection Relay for High and Extra High Voltage System

3.8 SPECIFICATIONS FOR PROTECTION SYSTEM FOR LARGE HYDRO STATIONS

3.8.1 General

The protective relays required for generators, their associated step up unit auxiliary transformers, including interlinking transformers, bus bars and out-going transmission lines is described with special reference to protective equipment specified for Dehar power Plant of Beas Satluj Link Project. 6 units of 165 MW each including 4 1st stage unit are provided in the power plant. Two 1st stage unit are stepped up to 245 kV and the other 4 units are stepped up to 420 kV by unit connected transformers. 245 kV and 420 kV bus bars are interlinked by 245/420 kV interlinking transformers. A 40 MVA 245/145/12 kV transformers is provided to feed local area loads. Single line diagrams is shown in figure 3.51 special considerations involved in selecting relaying for 420 kV EHV system in its initial development stage are outlined in 3.7. Main single line diagram is shown in figure 10.8

The power plant is located in seismic zone. Therefore, the protective equipment was specified for suitable operation at site and the electromagnetic relays were specified according to mechanical stability class index S2 of BS: 142 – 1966. Mercury contacts in the relays were specified to be unacceptable.

Static relays in place of electromagnetic relays were specified to be quoted separately along with operating experience and other technical details. Unit transformers in single phase units because of transport restriction were located in the power house on the transformer deck. Outdoor switchyard is about 1 km away.

The protective relays for outgoing lines (420 kV, 245kV and 145 kV), busbars, interlinking transformer and 245/145/12 kV 40 MVA transformer were proposed to be mounted in the control room.

The secondary current CTs located in switchyard were specified to be normally 1 ampere. The CT secondary current may be of 0.5 ampere also. The tenderer were asked to recommend the secondary current rating (1 ampere/0.5A) for CTs located in switchyard for ensuring efficient and accurate operation of their protective scheme.

3.8.2 Multifunction Digital Protection Relay

Multifunction digital protection relay were not available at the time the specification were issued for Dehar Power Plant. These relays are now being provided as follows for all large hydro station in addition to electro-magnetic/static relays as complete back up with additional protection as follows (specific advantages discussed earlier):

a) Each generator so as to include over-fluxing and pole slipping
b) Each generator transformer and to include over-excitation and V/F function protection
c) 220/420 kV line protection to include high speed phase comparison protection/sub cycle distance protection as required

Following needs to be confirmed for successful application of numerical relays.

i) Input and output to be optically isolated.
ii) Following Global function should be available in the relays.

- Relay setting flexibility
- Event recording
- Disturbance recording

b) Self Monitoring: Watch dog timers facility to monitor operating status on continual basis is required to be provided so that any potential malfunction is identified and communicated to control room and possibility of a non functional relay in the plant protective relay system is avoided. This means communication channel should be available to the relay.

iii) Communication: Digital communication scheme which allows the relay to communicate with the control system is required and the serial data ports should be based on IEC protocol.

iv) Calibration: Relays are to be provided a self calibration routine in the relay software programme. Programmable set points: Disc operating system (DOS) software programme be provided with detailed instruction and recommended set points for each protective relay function based on system characteristics.

v) Event Storage: Provision of recording waveform before and after the protective relay has operated as an oscilograph record is required to be provided.

vi) Provision of training utility Operators/Engineers in the new technology should be included in supplier scope.

3.8.3 Generator, Generator Transformer and Auxiliary Transformer Protection

3.8.3.1 Generator Differential Protection

The generator shall be protected by high impedance type of circulating current relays having proper setting range. The relays should be of high speed type and immune to AC transients. Necessary provision should be made in the relay to ensure that the relays do not operate for faults external to the protected zone. The relays shall not maloperate due to harmonics in spill current produced by through faults or due to saturation of one set of current transformers during an external fault. A control switch with a red lamp shall be provided, if required, to cut out the auxiliary tripping relay where necessary to prevent false tripping due to the by passing of current transformer. The red lamps shall light to indicate that the trip circuit is cut out. Contacts shall also be provided to short circuit the secondary leads at the relay; if required to protect the relay operating coils. Provision shall also be made for alarm/indication in case of current transformer secondary circuits fault.

3.8.3.2 Generator Transformer Differential Protection

A sensitive percentage biased differential relay shall be provided for this purpose with proper operating and bias setting. The relay operating time shall be clearly specified. It shall have harmonic restraint feature to prevent its mal-operation due to magnetizing inrush surges encountered in normal power system operation. Provision shall also be made for alarm indication in case of current transformer secondary circuits fault.

The CT's on 12 kV side shall be located in the generator neutral and on 245 kV side (for units -1 and 2) and 420 kV side (for units 3 and 4) in the high voltage bushings of the main 12/245 kV and 12/420 kV bank of 3 single phase transformers. The auxiliary/interposing current transformers if required for this protection shall be provided.

3.8.3.3 Link Line Differential Protection

A high speed suitable differential relay proper setting range shall be provided for this purpose. The relay operating time shall be clearly intimated. Provision shall also be made for alarm/indication in case of current transformer circuits fault. For this protection the current transformers shall be located in the high voltage bushing of the three single phase transformers at one end and near breaker in the switchyard at the other end.

3.8.3.4 Generator Ground Fault Protection

The generator neutral will be earthed through the primary winding of a distribution transformer of proper capacity and ratio. The secondary will be loaded by a suitable resister rated for 60 seconds. A suitable voltage relay with continuous coil rating with proper setting range and operating time shall be offered for this purpose. The relay shall be insensitive to voltages at third harmonic frequencies.

The relay shall have two stages of settings. First stage shall give only alarm and annunciation while the second stage after some suitable time delay will carry out the tripping functions as shown in drawing.

3.8.3.5 Gen. Transformer HV restricted earth fault protection

High impedance type of relays shall be provided for this purpose. A suitable CT will be provided in the transformer HV neutral to earth connection, which will be balanced with the main CT's of the generator transformer overall differential protection through suitable interposing CT's.

3.8.3.6 Generator Over-Voltage Protection

A set of single phase relays with suitable time delay setting so that operation of the relay under transient conditions is avoided. The relay setting range shall be from 110% to 170%. The relays shall be immune to frequency variation. Provision of instantaneous tripping element at some suitable setting will also be possible either in this set of relays or in different set of relays which may be offered separately.

3.8.3.7 Unit Auxiliary Transformer Protection

Differential Protection: A sensitive percentage biased differential relay shall be provided for this purpose, which shall be capable of remaining stable up to 20 times through fault current. The relay setting range and the operating time shall be clearly intimated. Provision shall also be made for alarm/indication in case of current transformer secondary circuits fault.

Over current Protection: Suitable relays shall be provided for unit auxiliary transformer over load protection. The relay operate from the three current transformers on the high voltage side of the transformer and will be arranged to trip the low voltage breaker as shown in the drawing.

Back-up Protection (Generator): This shall be provided by impedance type of relays with suitable ranges. The relay shall measure accurately for phase to phase faults. Definite time delay relay having suitable range may also be used in conjunction with impedance relay. The current transformer for this protection shall be located in the generator neutral side.

3.8.3.8 Negative Phase Sequence Current Protection (Generator)

A two stage protection complete with filter net-wok is proposed for this purpose. The first stage with a lower suitable range shall be instantaneous and shall be arranged to give alarm and annunciation and the second stage with a higher range will energise a timer which shall perform the various tripping in two stages at different time settings. The current transformer for this protection will be located in the generator neutral side.

3.8.3.9 Generator Field Failure Protection

An offset mho type relay having its circular characteristics adjustable both in offset and diameter, along the X-axis of the R-X plane, shall be provided for this purpose.

It shall be ensured that the unit will not trip in case the polarity of field is reversed, since negative excitation is likely to be resorted to at Dehar Power Plant, because of line charging conditions.

The protection shall consist of two stages. The first stage with a lower range shall be arranged to give alarm and annunciation. The second stage with a higher range shall carry out the tripping functions.

3.8.3.10 Standby Earth Protection

For this protection inverse definite minimum time lag type relay having suitable setting range and operating time shall be supplied. The relay shall be energized by zero sequence current supplied to it through current transformer in the power transformer neutral.

3.8.3.11 Generator Over speed Protection

For this protection the device, will be operated off the permanent Magnet techno-generator being supplied by the generator supplier.

The protection shall be arranged to energize the immediate action shut down relay, which shall also be energized from other protections and shall perform the various tripping functions as required.

3.8.3.12 Generator Rotor Earth – Fault Protection

'Direct current injection' type of protection shall be supplied for this purpose. The relay will be suitable for the field system voltage and be capable of detecting deterioration of insulation level below about 0.2 Mega-ohms. 110 volts alternating current potential transformer auxiliary supply will be available but the relay will have its own internal rectifiers etc., to derive the DC injection supply. Failure of AC auxiliary supply will not totally incapacitate the protection.

3.8.3.13 Potential Transformer Fuse Failure Protection

Suitable voltage balance relays shall be provided to monitor the fuse failure of 3 sets of potential transformer and to block the relays or other devices that may operate incorrectly on the absence of voltage due to fuse failure of potential transformers. Presently the provision of only alarms shall be made but the relay may be required to carry out protection blocking functions as required and therefore sufficient number of contacts may be provided for the purpose.

3.8.4 245 kV Bus-Bar Protection

A high speed, high impedance type bus-bar differential protection shall be provided for each 245 kV bus. The scheme will have separate and independent check and supervision features incorporated in it. Necessary separate CT cores shall be provided at the incoming and outgoing circuits for check features. The main zonal relay and check relay scheme will have their contacts connected in series in the trip circuit.

The protection will be capable of detecting all types of faults on the bus-bar. The sensitivity of protection shall be such that it does not operate for faults on the CT secondary wiring of the mostly heavily loaded circuit. CT's on either side of the bus coupler/section breaker.

The supervision relay will be capable of detecting open; cross or broken CT secondaries and pilots by employing sensitive alarm relay, which shall be connected across the buswires of each protected zone. It shall be capable of taking the protection of the affected zone out of service by shorting the appropriate bus-wires.

'No-volt' relays to indicate failure of DC alarm and trip supply to the bus-bar protection scheme shall also be provided.

High speed tripping relays shall be provided to trip each circuit breaker.

3.8.5 220/132/11 kV, 40/36/4 MVA Transformer Protection

Primary Protection: For this purpose, high speed differential protection relays having second harmonic restraint feature shall be provided. the relay should be capable of tripping instantaneously for heavy internal faults such as bushing flash over and should not restrain under such conditions due to harmonic which may be produced by CT's in such circumstances.

Back up Protection: For the back up protection on high voltage side, 3 nos. Inverse definite minimum time lag over current relays with suitable setting range should be offered. Similar protection shall also be offered as back up protection on medium and low voltage sides.

3.8.6 245 kV Feeder Protection

Primary Protection: The primary protection of 245 kV double circuit line (length approximately 65 km's) shall be by phase comparison type static carrier relaying for phase to ground and phase to phase faults with additional distance elements for three phase faults.

Secondary Protection

i) As a secondary protection for phase to phase, three phase as well as for phase to ground fault, suitable high speed three stage directional distance protection relays, employing fully non-switched mho/reactance type electromagnetic relays shall be offered. The relays shall have stepped characteristics with three zones of operation. First zone will have instantaneous operation, 2nd and third zones shall operate with adjustable time delays. The setting time and ranges shall be clearly indicated. The scheme shall be suitable for inter tripping through carrier channel to ensure instantaneous clearance of end zone faults. Carrier inter tripping for secondary protection shall be offered if separate transmitters and receivers are not required, and the scheme is suitable for operation in conjunction with carrier communication equipment, which is being procured under a separate contract. The inter tripping time shall be clearly mentioned, which shall be complete with carrier starting relays, starting relays meant for measuring units and other equipment required to complete the scheme. The protection schemes working on distance measuring principle when offered shall be complete with PT fuse failure blocking device. Out-of-step blocking relay shall also be required and should be included in the offer and detailed description of scheme should be given. Full details suc as CT requirements, carrier boost facility required to cater for extra attenuation under internal fault shall be supplied.

ii) As a further back up protection for phase to ground faults, time graded earth-fault directional over-current relays shall be provided. the relays shall be current polarized through neutral CT's however voltage polarized directional relays may also be offered. Potential from bus PT's broken delta tertiary winding can be made available for the polarization of earth fault element.

The scheme shall be complete in all respects including auxiliary relays required for various trip, alarm annunciation and various other purposes.

3.8.7 245 kV Bus Coupler Protection

For this purpose suitable over current and Earth-fault relays shall be provided on the bus coupler breaker panel. Setting ranges for over current and earth-fault relays mentioned.

3.8.8 245 kV/420 kV interlinking transformer protection

Interlinking Transformer Differential Protection: For this purpose an instantaneous high speed differential relay without harmonic bias, or time lag shall be offered. Three sets of C.T.'s of same turns ratio shall be provided as follows – one set at the neutral end (for which purpose each phase neutral end shall be brought out of tank through a separate bushing), One set on the 420 kV side and one set on the 245kV side. The magnetizing in rush current or any un-balance that may occur due to tap changing shall have no effect on protection/differential relay.

Back up Protection: It shall be provided by suitable triple pole over-current relays on 420 kV as well as 245 kV sides. Higher setting or time delay shall be used on the high voltage side. Auxiliary and intertripping relays shall be supplied to complete the scheme.

3.8.9 420 kV Line Protection (280 km long line)

Main I Protection: For this protection, directional comparison/distance static type protection scheme using carrier current blocking principle shall be offered. The scheme offered shall be for both ends i.e, sending as well as receiving end. The total protection operating time including time required for relay operation, blocking signal time for end zone faults and conventional tripping relay time shall not be greater than 40 ms. The actual operating time for various elements of the protection scheme shall be clearly intimated. Static fuse failure relays and out of step blocking relays shall also be offered. The scheme shall provide independent high speed zone 1 protection in the absence of carrier blocking signal and /or if the signal channel is faulty or taken out of service. Zone 2 and zone 3 shall have independently P.T. adjustable time delay range. Independent set of C.T.'s and separate PT circuits will be provided for this protection. The frequency at which the carrier equipment can cover 280 K.M. length of line shall be stated. The protection shall be suitable for single and three phase tripping of both ends of the line section simultaneously.

This protection shall be offered with its independent power line carrier equipment with transmission time of less than (20 ms.) 1 cycle. However, the carrier equipment shall be capable of sharing the broad band line traps and coupling capacitor's with other communication / tele-metering/inter tripping channels. Factors such as C.T. requirements, P.T. requirements, attenuation over the line length, effect of noise on carrier equipment, effect of reactors location on line protection and carrier equipment shall be intimated in detail. Non operation under maximum load must also be ensured.

Suitable fast acting phase selectors shall be incorporated so that the scheme shall also be suitable for single and three phase auto – reclosing of both ends.

The scheme shall incorporate built in test facility. It shall be possible to carry out a limited test with the equipment in service and this test should automatically be suppressed in case a fault occurs on the line during testing. The scheme operating time under such condition shall not be greater than its normal time.

The scheme shall be complete in all respects including auxiliary relays required for various trip, alarm annunciation, tests and other purpose etc.

Main II Protection: For the secondary protection of 280 K.M. long single circuit, 400 kV line, very high speed, 3 – step, directional distance (Mho type) protection relaying scheme, with provision of carrier inter tripping , for isolating the line without time lag for end zone faults shall be offered. The protection scheme shall be capable of offering with equal speed of operation, protection against phase to phase, phase to earth and three phase faults. The scheme shall be suitable for single and/or three phase tripping. The total protection operating time including time required for relay operation, inter tripping for end zone fault and conventional tripping/relay time shall not be greater than 40 ms.

The design of the starting elements be such that if required they can be given an offset characteristics of reach up to 20% of their rated forward reach. Further, they should be capable of tripping the scheme instantaneously on current alone such as closing on a line with earthing clamps on. It should be ensured that under such tripping, auto-reclosing circuits are blocked so that no auto-reclosing can take place.

The scheme measuring elements should have negligible transient overreach by employing well designed and continuously adjustable line and neutral replica impedance. Further, the measuring units should be continuously adjustable within a range of $45^0 – 75^0$.

The protection scheme shall be complete with PT fuse failure blocking device. Out of step blocking relay shall also be required and shall be included in the offer and detailed description of scheme should be given.

The distance protection shall be suitable for operation in conjunction with carrier equipment, on ‘carrier inter tripping principle’. That is to say that the remote end relays should trip directly through the fault detector contacts on receipt of a carrier signal without loosing time by first extending the reach of measuring relays, allowing them to operate and then trip. The scheme should also be suitable for single and /or three phase auto-re closing. Auto-reclosing circuitry should automatically be blocked when the scheme trips in either zone II or III time or when carrier fails. The distance protection supplier shall undertake, to co-ordinate with the carrier and circuit breaker equipment suppliers for successful working of his scheme.

Transistorized relay scheme will be accepted provided its accuracy and life are guaranteed under site conditions where ambient temp. can vary from 0^0 C to + 50^0 C and relative humidity may be as high as 100% during monsoon month.

Directional over current relays: Suitable time graded Earth fault directional over current relays, which shall be used as backup protection for ground faults will be offered.

3.8.10 Auto-Reclose Relaying for 245 kV Lines, Bus Coupler and 420 kV Line

The auto reclosing scheme for 245 kV lines, bus coupler on 420 kV line may be installed at a future date. The tenderer may however, supply the detailed scheme, keeping the following requirements in view:-

Bus Coupler and 245 kV Lines: A typical auto-reclose scheme, which shall be suitable for single shot and single and /or three phase auto-reclosing of air-blast circuit breakers may be offered. The scheme may be such that one end of line is reclosed after no voltage check and the other end reclosed when it is energized, voltage established and after synchronizing check. Provision may be made such that the circuit breaker failure shall block auto-reclosing scheme. The relay supplier may have to undertake to coordinate with the circuit breaker supplier to ensure satisfactory working of the auto-reclose scheme.

420 kV line: For 420 kV line which is controlled by two breakers at Power house end, one breaker shall be reclosed after no voltage check and the other breaker, after it is energised, voltage established and after synchronizing check. Provision may be made such that the circuit breaker failure shall block auto-reclosing scheme (Refer Para 3.7.7). The relay supplier may have to undertake to coordinate with the circuit breaker supplier to ensure satisfactory working of the auto-reclose scheme.

3.8.11 420 kV Bus – Bar Protection:

This shall in general be similar to that described under Para 3.7.5 i.e. a high speed high impedance, two zone type of protection having separate and independent check and supervision features. The necessary C.T. cores shall be provided at the incoming and outgoing circuits for the check feature. A single zonal relay shall have its contacts in series with those of the independent check relay in the trip circuits.

3.8.12 Circuit Breaker Faults Protection

A back up type of protection for the circuit breaker faults for all breakers connected to the 245 kV and 420 kV buses shall be provided. The protection scheme shall be so designed that if any circuit breaker fails to trip in the event of a fault, then after a short time delay all the circuit breakers connected to the bus section to which the faulted circuit breaker is connected, are tripped, The circuit breaker failure shall also block auto-reclosing scheme (Refer Para 3.7.7). The relay protection scheme supplier shall undertake to coordinate with the circuit breaker supplier to ensure satisfactory working of this protection scheme. Protection scheme complete in all respects shall be supplied for this purpose.

3.8.13 132 kV Feeder Protection

Primary Protection: For the primary protection of approximately 100 K.M. long single circuit 145 kV line for power supply to Himachal Pradesh high speed 3 step directional distance protection relaying, scheme employing switched Mho/ Reactance type electro-magnetic relays shall be provided. The protection scheme will be capable of offering with equal speeds of operation, protection against phase to phase, phase to earth and 3 phase faults.

The scheme shall be complete with all auxiliary, flag indicating, timing, P.T. fuse failure and tripping relays. The scheme shall provide high speed zone I protection. Zone II and Zone III shall have independently adjustable time delay range, which shall be clearly intimated.

Secondary Protection: The secondary protection shall consist of directional over current and earth fault relays, which shall have suitable setting range adjustable in appropriate and preferably equal steps.

3.9 TYPICAL TECHNICAL SPECIFICATION OF SMALL HYDRO PROTECTION SYSTEM OF 2 x 2 MW WITH MANUAL BACKUP

3.9.1 General

Single line diagram is at figure 3.59 and metering & relaying at figure 3.60.

3 x 2 MW synchronous generating units coupled to pelton turbines synchronized at 3.3 kV, brushless excitation and governing systems being digital.

i) 3 step up generating transformers of the rating 3.3 kV/33 kV, 3.15 MVA
ii) 2 nos. 33 kV feeder
iii) 1 no. 315 kVA, 3.3kV/415V station transformer

3.9.1.1 Metering

(a) All panel meters shall be digital at least 2 cm digit size, at least three and-a-half digit LED display accuracy class of 1.0.
(b) Energy meters on feeders and generators shall be microprocessor based trivector meters of appropriate class.

3.9.1.2 Protection Relays

i. Each generator and generator transformer shall be provided with a multifunction digital relay incorporating all protection functions, measurements and fault data logging features.
ii. Generators and generator transformers shall have additional back up protection using static relays.
iii. Digital relays shall be provided for the protection of feeder and station transformer.

3.9.1.3 Protection

Protection relay panels for the generating units and 3.3/33 kV generator transformers shall use microprocessor based (digital) and static (analog) relays as described in Generator protection. The 33 kV feeder shall be protected with microprocessor based digital relay as described in 33 kV line protection herein after. Protective relays for other equipment shall be digital type. Details of protection requirements are shown in drawing No. 3.9.2.

3.9.1.3 Protection and Metering Details

Requirements of metering and protection/metering and the function performed by various relays are explained in following tentative drawings:

Figure 3.59: Single Line Diagram
Figure 3.60: Metering and relaying single line diagram

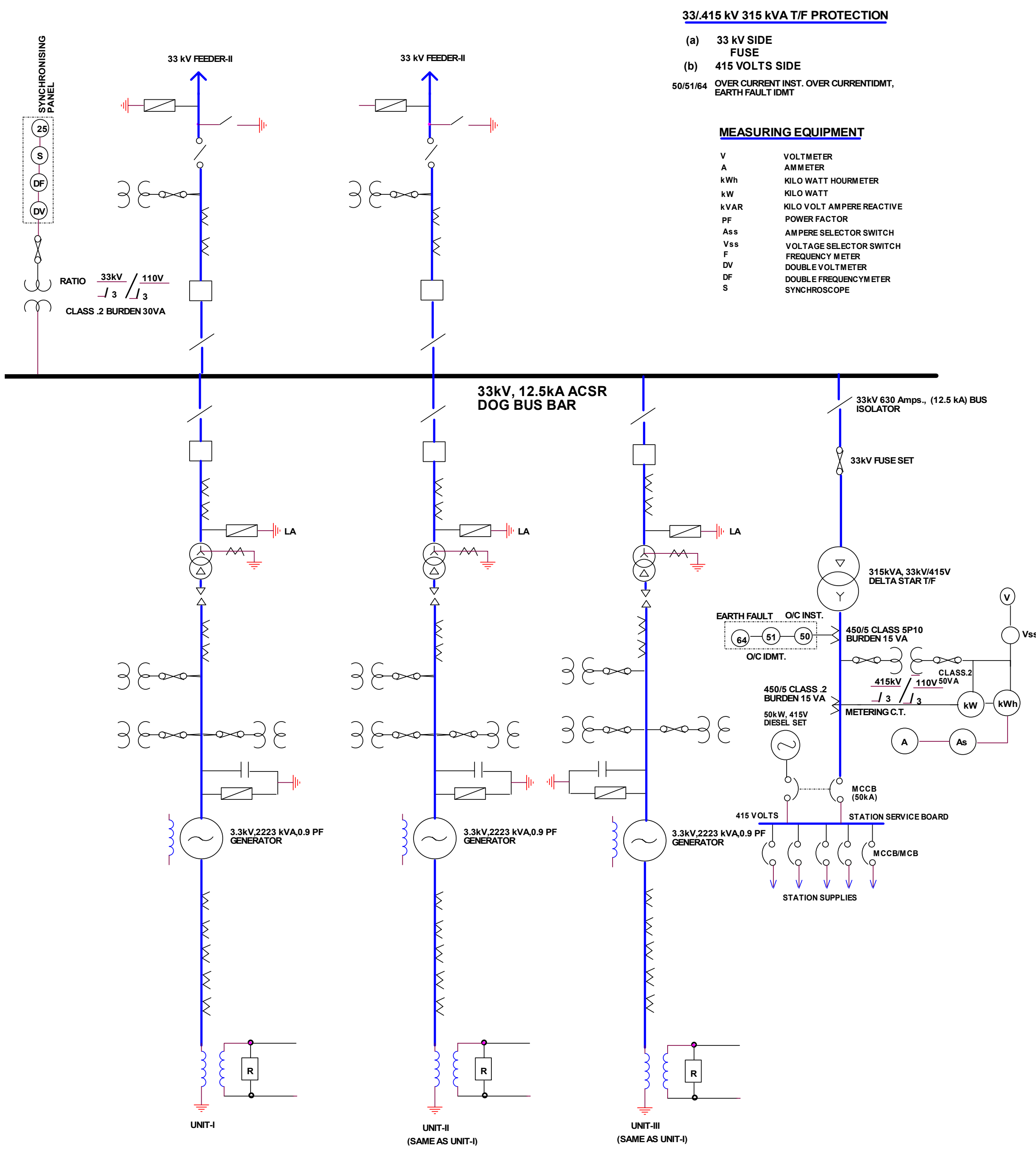


Figure 3.59: 3 x 2000 kW SHP –Single Line Diagram (As designed)

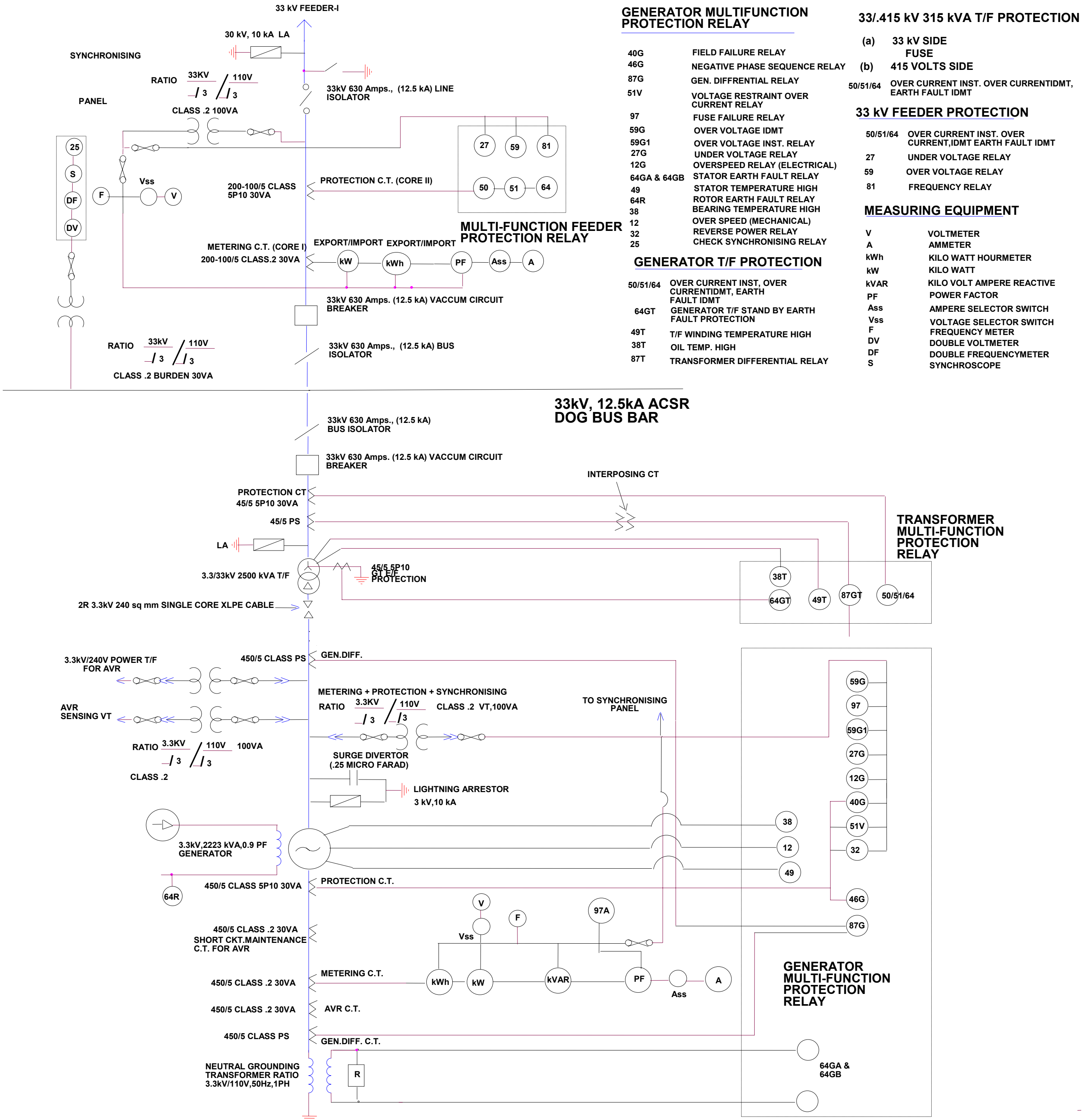


Figure 3.60: 3 x 2000 kW SHP –Metering & Relaying Single Line Diagram (AHEC Project)

All the protective relays will be housed in the control room of the power plant. The tentative locations of CTs and PTs housed in Generator terminal (GT) and Neutral grounding (NG) cubicle for the protection and metering.

The final drawings for the protection & metering shall be submitted by the contractor and will be subject to the approval by the purchaser.

All current and voltage transformers required for protection system of the unit shall have adequate VA burdens knee point voltage, saturation factor and characteristics suitable for the application. Special Features of proposed Protection System

i. The protection system shall be built on latest technology and the bidder has to guarantee for supply of spares for at least 10 years. Moreover, the bidder should have range of manufacturer of the system offered.
ii. Wide setting ranges with fine setting steps for each protection shall be available.
iii. The offered system shall have proven record of satisfactory performance for at least 2 years and in two power stations.
iv. The protective relays shall preferably be housed in draw out type of cases with tropical finish.
v. Common tripping relays (each for similar functions) will be provided with lock-out facilities. All these relays shall have potential free contacts for trip and alarm purpose and externally hand reset type of flag indicators.

Generator and transformer Protection

An integrated numerical protection relay incorporating the following functions shall be provided for each generator.

3.9.2 Generator

i. Generator differential (high impedance circulating current (87 G)
ii. Negative phase sequence (46G)
iii. Generator reverse power protection (32)
iv. Voltage restrained over current protection (51V)
v. Stator earth fault protection (64S)
vi. Loss of excitation protection (40)
vii. Over frequency protection (81)
viii. Rotor earth fault protection (64R)
ix. Over voltage protection (59)
x. Over speed relay – Mechanical and electrical (12)

3.9.3 Transformer

i. Generator transformer differential protection (87GT)
ii. Generator T/F over current and earth fault protection with high set instantaneous element (50, 64)
iii. Generator T/F stand by earth fault protection (64 GT)
iv. Measurements
v. Sequence of events recording
vi. Disturbance recording
vii. Self diagnosis and supervision

In addition, the following static (analog) protective relays shall be provided:

i. IDMT over current relay (51)
ii. Stator earth fault protection (64G)
iii. Generator Transformer standby earth fault protection (64 GT)
iv. Check synchronizing relay (25)

The bidder may propose additional protection as an option.

Following protection provided on the generator transformers shall also be integrated with the main protection described above:

i. Oil temperature indicator with alarm

ii. Bucholtz relay with alarm and trip control
iii. Winding temperature indicator with alarm and trip control
iv. Oil gauge with low level alarm

Following mechanical protections shall be provided:

a. Resistance temperature detectors (pt. -100) in stator core (12 no.) and in the bearings for indication, alarm and recording. RTDs are to be provided by generator suppliers.
b. Turbine and generator bearing, metal and oil temperatures – alarm/shutdown
c. Governor oil pressure low to block starting and very low for emergency tripping.
d. Over speed for normal and emergency shutdown depending upon its extent.

Note: Though the generator shall be synchronized at 33 kV neutral displacement protection should be provided through a neutral grounding transformer of 5 kVA rating with a ratio of 3.3/$\sqrt{3}kV$/110/$\sqrt{3}V$volts (Ratings are tentative and subject to confirmation). There shall be a provision in the relay for time grading to avoid operation of the relay function on 33 kV bus fault. The ratings of this transformer are tentative; the bidder shall submit detailed calculations.

3.9.4 33 kV Line Protection

A numerical directional inverse over current and earth fault relay and over/under voltage and relay frequency with high set unit shall be provided on 33 kV line.

References

(1) DEWEY, C.G. and MODGES, M.E.: "Transistorized phase Comparison relaying". Principles and Circuit, AIEE trans., Power Apparatus and System, Vol. 79, pp. 373-381, August 1960.

Specification No. 25 BLD – Beas project Unit -1 Dehar Power Plant – July 1971.

(2) O. D. THAPAR – Electrical Protection of Large Hydro-Electric Generators (Power Engineer, , Vol. 11, No. 1, PP. 12-17. 1961.

(3) SUTTON HOWARD J.: "The Application of Relaying on an E.H.V. System" IEEE Trans. On Power Apparatus and systems. Vol. 86, pp. 408-415. April 1967.

(4) COMMITTEE REPORT, "Relaying the key stone 500 kV Systems". IEEE Transaction on Power Apparatus and System, Vol. 87, pp. 1434-1439, June 1968.

(5) Committee Report on "500 kV A/C substation Design Criteria-Summary of Industry Practices". IEEE transaction on Power Apparatus and Systems, June 1969.

(6) HALL, J.E. & SHACKSHAFT, G.: "Development in the Stability Characteristics of the Power System of England and wales'. 32-05, CIGRE, Session, 24 August-2 September, 1970.

(7) HINMAN, W.I.: "Breaker Failure Relaying". Presented to 23rd Annual Conference for Protective Relay Engineers, Taxes A & M University, College Station, Taxes April 20-22, 1970.

(8) CORCORAN, DR. J.C.W.; GUPTA, DR. S. and PAL, Dr. M.K. in COLLABORATION WITH GRADE, DR. V.P. and THAPAR, O.D.: "System Studies to Determine Excitation Characteristics of Dehar Generators'. Engineering Report No. PSD 884/2- June 1971, Power System Department English Electric Power Transmission Ltd., Stafford, England.

(9) EDWARD, LEO; CHADWICK, J.W.; REISCH; H.A. and SMITH, L.E. : "Single Pole Switching on TVA's paradise- Davidson 500 kV line – Design Concepts and Staged fault Test Results". T.P. IEEE Winter Power Meeting, New York, January 31, February 5, 1971.

(10) THAPAR O. D. – 'Relaying for EHV System; Proceedings research Design; Central Board of Irrigation & Power June 1972.

(11) Central Board of Irrigation and Power -1987 – Manual on Transformers

(12) IEEE std. C37. 102 – 1995 – IEEE Guide for AC Generator Protection

(13) IEEE standard 242-2001 Chapter 11 Transformer Protection

(14) IS: 4722 – 2001: Rotating Electrical Machine

(15) Siemens PTDEA Application of SIPROTEC protection relay – 2005

(16) Alternate Hydro Energy Centre "Micro Hydro Quality Standards" – 2005

(17) IS: 2026 – Power Transformer Part – 1: General; Part 2, Temperature rise Part 3; Insulation Level and Dielectric tests

(18) IEC 1116 – standard for E & M Equipment for small hydro up to 3 MW

(19) English Electric – Protective Relay Application Guide (book)

(20) Hydropower project reports and specifications

(21) AHEC/MNRE/SHP Standards/E& M Works- Guidelines for Monitoring, Control, Protection and Automation of SHP

(22) www.areva-ted.com

(23) www.govconsys.com/woodwar_prtective-relays.htm

(24) IS; IEEE & IEC standards and guides as mentioned in draft.

(25) IEC-60255 (Part 1 to part 23) - Electrical relays