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Speed Control of DC Drive using SEPIC Converter in Solar Power Application using Closed Loop Fuzzy Logic Controller (FLC)

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Abstract In this paper, a single ended primary-inductor converter (SEPIC) is applied for the speed control of DC Motor using the fuzzy logic controller. The fuzzy logic controller is applied to the closed loop system of the DC motor employing the duty cycle control over wide range of speed. The proposed converter uses a single inductor to allow a continuous-conduction mode by making the current never fall to zero. The proposed converter is controlled using the fuzzy logic controller that operates both in buck and the boost operation; unlike the conventional methods the output is non-inverted. The SEPI Converter used is more applicable for the wide range of voltage applications and as it is independent of the input voltage as the average current through the inductor is same as the load current. The proposed method is simulated using the MATLAB program. An experimental verification is done for a DC motor operated by Fuzzy controlled SEPIC and the results are shown.

Keywords: *DC motor, fuzzy logic controller, zero voltage switching, single-ended primary inductor*

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1. Introduction

Great demands for unity power factor to achieve better efficiency have been placed in the field of electrical and electronics engineering. Power factor is the ratio of real power and apparent power. When the reactive power is zero, unity power factor is achieved, which gives better efficiency. Many works were developed in order to improve the operation characteristics of the power converter utilized in HPF universal input rectifier. The Boost converter is the usual structure utilized in HPF rectifiers in order to improve power factor and reduce the total current harmonic distortion [THD]. However for universal input voltage application the efficiency can be reduced mainly in the lowest input voltage and the worst operation condition must be considered in the power converter design procedure. The improvement of the efficiency at lower line voltage is important. The use of high static gain and low -switch voltage topologies can improve the efficiency operating with low input voltage. The theoretical analysis and experimental results obtained with the proposed structure are compared with the classical boost topology. The classical Single-Ended Primary Inductance Converter [SEPIC], is better than the Boost converter, however the output voltage range is less. The voltage multiplier technique is used in order to increase the static gain with reduced switch voltage. The integration of the voltage multiplier cell with a classical SEPIC is proposed in order to obtain a high step-up static gain operating with low input voltage and a low step-up gain for the high input voltage operation. The power circuit of the proposed converter can be integrated with a simple regenerative snubber obtaining soft-switching commutation and increasing the efficiency. In the proposed system the SEPIC is used as DC-DC converter for the Maximum Power Tracking. The converter is controlled using the fuzzy logic converter for the greater efficiency.

2. Modeling of the Proposed System

The proposed method consists of a solar panel to convert the solar power to electrical power using the solar cells. The solar panel output depends on the input factors like the temperature, angle of inclination and the atmospheric conditions. The power output obtained should be independent of the input, which is the output obtained should be constant for any change in the input factors. A typical DC-DC converter can operate in both buck and the boost operation such that the optimized output is obtained. The proposed system uses a Single Ended Primary Inductor Converter as a new DC-DC converter to track the maximum power from the solar panel. The SEPIC uses series capacitor to couple energy form the input and utilizes the energy when the input is less than the required. The SEPIC operation as buck-boost converter is achieved by adjusting the duty cycle using controllers. In the proposed method, the fuzzy logic controller to control the firing pulse of the thyristor switches. The fuzzy logic rules are set such that the gate pulses are produced with reference to the desired output values. The proposed method is shown in the Figure 1.

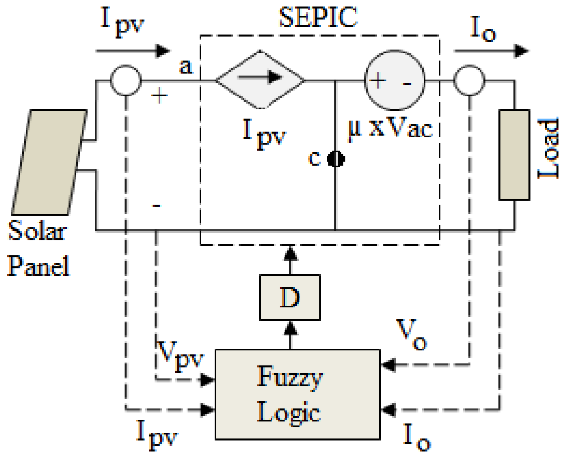

Figure 1. Block Diagram of the proposed system using fuzzy controlled SEPI Converter

2.1. Modeling of Solar PV Panel

The solar PV can be modeled by a current source acting as the PV panel current (I_{pv}) connected to the parallel diode. The equivalent structure implies the photo-diode operation producing the current (I). The combination of the series resistance (R_s) and the parallel resistance (R_p) refers to the solar array consisting of the solar cells connected in series and parallel combination. The modeling of the PV cells describes the I-V characteristics of an ideal PV cell. The equivalent circuit of the PV cell is shown in Figure 2

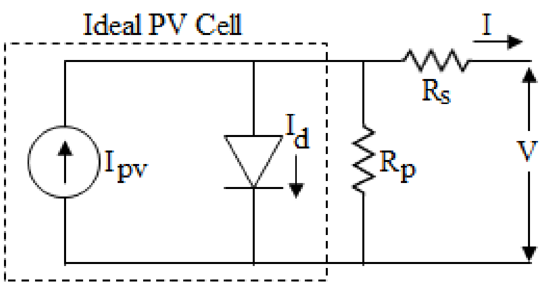

Figure 2. Equivalent circuit of solar PV Panel

The output of the current from the PV cells is given as,

$$I = I_{pv,cell} - I_d \tag{1}$$

Where,

$$I_d = I_{0,cell}\left[\exp\left(\frac{qV}{akT}\right) - 1\right] \tag{2}$$

Therefore,

$$I = I_{pv,cell} - I_{0,cell}\left[\exp\left(\frac{qV}{akT}\right) - 1\right] \tag{3}$$

Where,

$I_{pv,cell}$is the current generated by the incident light (it is directly proportional to the Sun irradiation),

I_d is the Shockley diode equation,

$I_{0,cell}$ is the reverse saturation or leakage current of the diode,

q is the electron charge (1.60217646 × 10−19 C),

k is the Boltzmann constant (1.3806503 × 10−23 J/K),

T (in Kelvin) is the temperature of the p–n junction, and a is the diode ideality constant.

The Figure 2 shows the origination of the I – V curve for the equation (2.2). Practical arrays are composed of several connected PV cells and the observation of the PV array requires the inclusion of additional parameters to the basic equation.

Hence,

$$I = I_{pv} - I_0\left[\exp\left(\frac{V + R_s l}{V_t \alpha}\right) - 1\right] - \frac{V + R_s l}{R_p} \tag{4}$$

Where,

V = $N_s kT/q$ is the thermal voltage of the array with N_s cells connected in series.

The output voltage is increased by increasing the number of the series cells because the voltage gets added up in series combination. Similarly, the current is increased on parallel connection of the solar cells as the current gets added up in parallel combination under same direction. If the array is composed of N_p parallel connections of cells the photovoltaic and saturated currents may be written as,

$$I_{pv} = I_{pv,cell} * N_p$$
$$and\ I_0 = I_{0,cell} * N_p.$$

This equations originate the I-V curve in Figure 3.

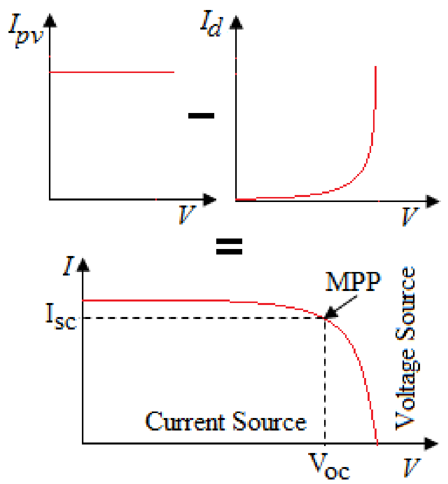

Figure 3. Origin of I-V equation of an Ideal PV Cell curve of a practical PV module and Characteristics I-V curve of a practical PV module

The mathematical modeling equations of the PV panel are modeled using suitable equations programmed in the MATALB. This simulation is done for standard test condition (STC) when temperature is 35°C and Irradiation is 3000 W/m^2. The modeling is done for a 500W solar panel.

Table 1. Parameters of the PV Panel – TAATBP1235

Open Circuit Voltage V_{oc}	500 V
Short circuit Current I_{sc}	10.9 A
Maximum Voltage V_m	487.5V
Maximum Current I_m	10.35A

2.2. Modeling of SEPI Converter

The duty cycle is controlled to operate the DC-DC converter both buck and boost operation. The proposed

SEPI converter is used as the DC-DC converter to obtain continues conduction mode with non-zero current output. This continues current operation improves the output stability of the converter, thereby producing high efficient output. The Figure 4 shows the circuit diagram of the proposed SEPI converter.

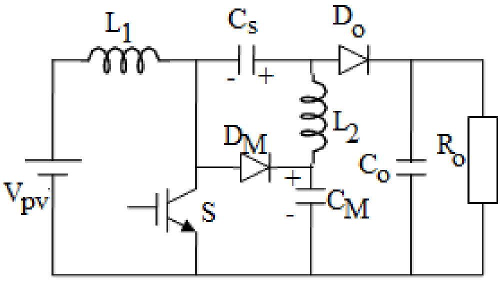

Figure 4. Proposed SEPI Converter

The Single-Ended Primary-Inductor Converter (SEPIC) operates as buck, boost and the output equal to the input. This varied operation is controlled through the duty cycle of the thyristor switch S. The converter produces a non-inverting output, isolation between the input and the output, with the true shutdown mode. The true shut down mode allows the voltage output to drop to zero when switched off. This eliminates the power transferred to the source thus providing a better output compared to other conventional DC-DC converters. The figure shows the circuit of the SEPIC. The gain value of the SEPIC is characterized for the wide range of voltage operation, but to satisfy the basic KVL equation the voltage output is restricted to certain value.

The proposed converter allows the switch to operate at a voltage lower than the output having the current ripple lower than the conventional converter current. The SEPIC can be included with the protective circuits like snubber circuit to increase the soft-switching commutation. This improves the output efficiency of the converter. The gain value of the proposed converter is improved by introducing the capacitor C_M. The capacitor C_M charges with the output voltage for the boost operation. These charges are utilized in the inductor L_2 during the commutation.

2.2.1. Switching Operation of SEPIC

During the initial condition t_o the thyristor switch S is open. The input voltage (V_{pv}) from the solar panel generates the input current. The current flows through the inductor L_1 and the energy is stored in the inductor. The energy stored is transferred to the capacitor C_S, to the diode D_o and capacitor C_M through the diode D_M. Now the switch voltage is equal to the capacitor C_M voltage. The Figure 5 shows the stage 1 operation of the SEPIC.

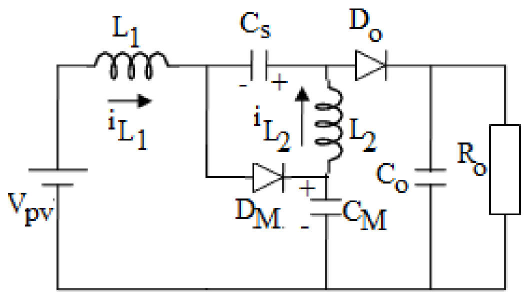

Figure 5. Stage 1 operation of SEPIC

When the time period $t=t_1$, the switch closes and the diode D_M and D_o are reverse biased. During this period the inductors L_1 and L_2 stores the energy. The voltage across the inductor L_2 becomes V_{CS}-V_{CM}. The Figure 6 shows the stage 2 operation of the SEPIC.

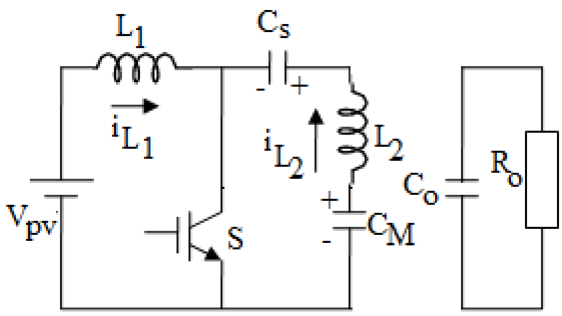

Figure 6. Stage 2 operation of SEPIC

The voltage in all diodes and the power switch is equal to the capacitor C_M voltage. The output voltage is equal to the sum of the C_S and C_M capacitors' voltages. The average L_1 inductor current is equal to the input current and the average L_2 inductor current is equal to the output current.

2.3. Modeling of Fuzzy Logic Controller

The maximum power point tracking is a technique that involves the voltage and current peak values. This electrical method applied, tracks the power which is maximum available with respect to the temperature and radiations of the solar. This method of tracking the power is more efficient compared to that of the mechanical tracking which requires additional power to the drives operating the panels. This control technique can be implemented using the fuzzy controller which is comparatively more efficient in MPPT technique. The functional block diagram of the fuzzy logic based MPPT system is shown in the Figure 7.

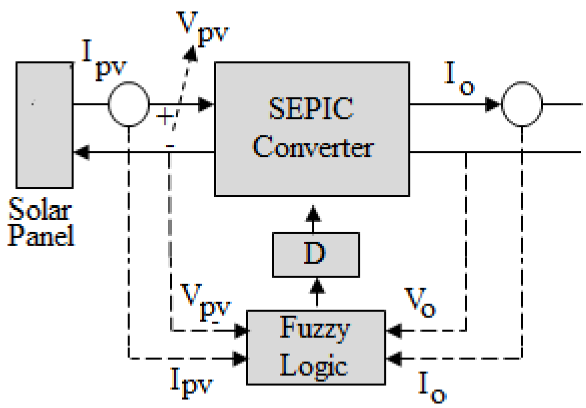

Figure 7. Modeling of Fuzzy Logic Controller

Table 2. Fuzzy Rule Table

ΔVpv/ΔPpv	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NS	NS	NS	Z	Z
Z	Z	Z	Z	PS	PS
PS	Z	Z	PS	PS	PS
PB	Z	PS	PB	PB	PB

3. Simulation Model of the Proposed System

The proposed fuzzy controlled SEPI Converter is mathematically modeled using the matlab program. The solar panel and SEPI converter are programmed using mathematical equations and are synchronized to work as a proposed design.

The Figure 8 shows the voltage output obtained from the solar panel under variable conditions. It is observed that the voltage output from the solar panel is oscillating proportionally with respect to the input variations. However, the SEPI converter generates an output that is bucked or boosted or equal to the input according the desired output required. The solar panel is designed to produce 500W at normal condition. The desired output voltage without losses with for a purely resistive load is taken as 400V.

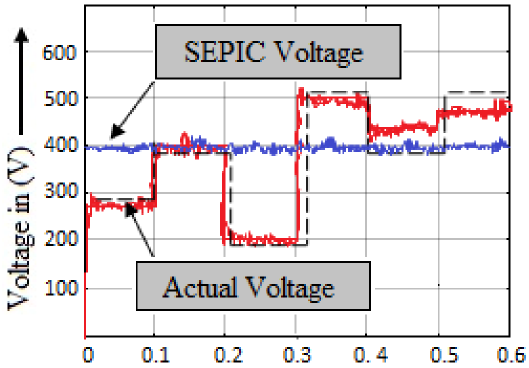

Figure 8. Voltage output from solar PV and SEPIC output voltage for a purely resistive load

During the initial time period the output from the solar panel is nearly 300V. The SEPIC is operated in boost mode such that the desired output is reached.

When the time t=0.3 sec, the voltage reaches 500V and now the SEPIC is operated in buck mode. When t=0.4 sec, the solar panel output obtained is 400V and since the error is zero, the same output is obtained from SEPIC. This varied operation is obtained by changing the gate pulse of the thyristor switch.

The output current and the voltage of the SEPIC are taken into a feedback system with optimized gain value such that the fuzzy controller produces and error with respect to the output obtained. The fuzzy rules are set such that the desired output voltage is obtained.

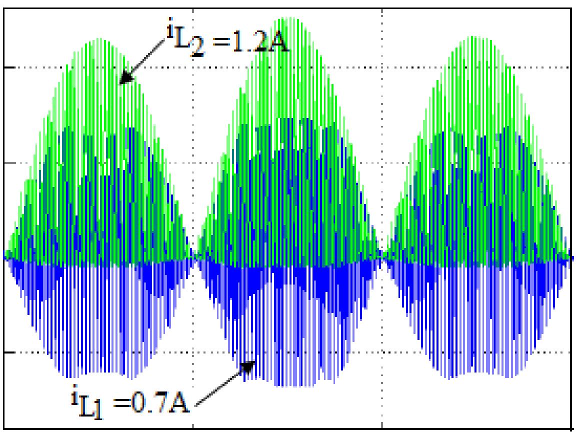

Figure 9. Inductor current iL1=0.7A and iL2=1.2A for an input voltage of Vpv=400V

The SEPIC output voltage is obtained by the inductor charging during the different stages of operation. The switch turns OFF and ON during the zero current crossing. Inductor charging and discharging are shown in the Figure 9.

The Figure 10 shows the voltage across the capacitor C_M and C_S. The net value of the capacitor voltage is obtained as 400V at the load side.

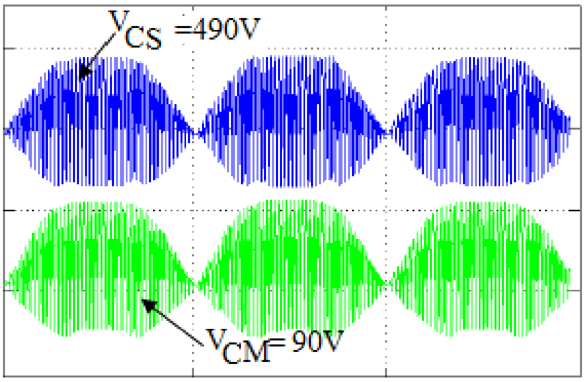

Figure 10. Capacitor voltage of the SEPIC for varying duty cycle

4. Modeling of Proposed Experimental Model

A DC motor drive is designed to operate under the solar power through the SEPI Converter. For instance, the solar panel is allowed to charge the battery and later supplied to a DC motor, however, for light loads; direct operation of the solar panel can be implemented. In this experimental design, the speed of the DC motor is controlled using the closed loop speed control using the PIC controller. The experimental setup is designed as shown in the Figure 11.

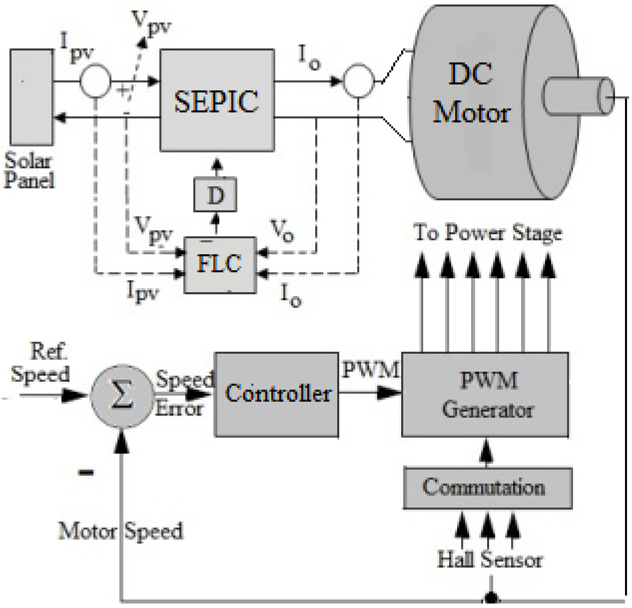

Figure 11. Experimental model of the proposed system for the speed control of DC Motor

The experimental model is experimented and the results are shown. The Figure 12 shows the voltage output of the SEPI converter. The voltage obtained is 337V from the solar panel.

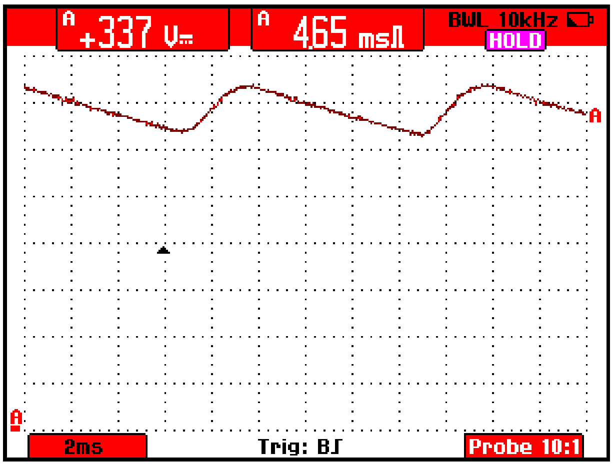

Figure 12. DC voltage (V=337V) of the SEPIC obtained to charge the battery for supplying the DC motor

The Figure 13 shows the voltage across the capacitor C_M. The voltage obtained is 5.66V.

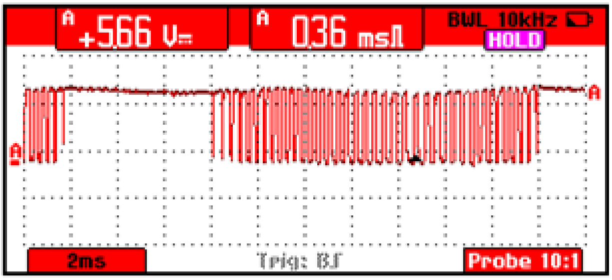

Figure 13. DC voltage (V_{CM}=5.66V) across the capacitor C_M

The Figure 14 shows the voltage across the capacitor CS. The voltage obtained is 341V. Therefore the net voltage obtained is 336V. The output voltage is used to operate the DC motor. The DC motor is controlled using the closed loop speed control. The speed of the DC motor is set for 1000 rpm and the actual speed is obtained is 995rpm. The Figure 15 shows the motor speed output obtained through the PIC controller.

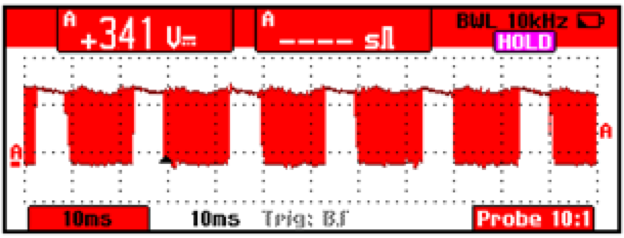

Figure 14. DC voltage (V_{CM}=5.66V) across the capacitor C_M

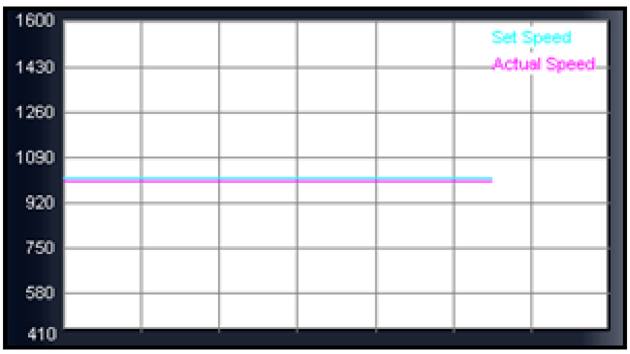

Figure 15. Speed of the DC motor

5. Conclusion

The DC motor speed is controlled using the proposed method. The simulation is performed for the verification of the system. The experiment results have proved the speed control of the DC motor is effectively performed. However the solar power is optimized using the SEPI converter in the speed control of the DC Motor. The application of the DC motor can be used in many industrial applications by replacing the non-renewable energy with a renewable energy like solar power. The efficiency of the proposed system is increased by the zero voltage operation of the converter switches.

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