APPLICATION OF MODERN CONTROL THEORY FOR THE POWER-SYSTEM ANALYSIS AND CONTROL

DR. MULUKUTLA S. SARMA and DR. EARL D. EYMAN

Department of Electrical Engineering
University of Iowa, Iowa City, Iowa 52242

Abstract

With the current rise in the demand of electrical energy, present-day power systems which are large and complex, will continue to grow both in size and complexity. Also, our dependence on electrical energy is so great that it is essential to have uninterrupted supply of electrical power within set limits of frequency and voltage levels, and that it becomes a dire necessity to develop methods for effective control and operation of power systems. Modern control theory concepts have been effectively used and will continue to be utilized for the power system analysis and control. This paper attempts in assessing the present situation in this regard and indicates the future trends.

Introduction

Present-day power systems are large and complex. Modern power systems represent the largest man-made system in existence from the viewpoint of invested capital and offer a great challenge to a control-systems engineer. A typical power system may require thousands of state variables for adequate description. The changing character of the system on a daily and yearly scale, the vulnerability to environmental influences of statistical nature in view of the geographical spread, difficulties in data transmission, impossibility to conduct meaningful full-scale system tests due to the 24-hour operation, the mixed nature (continuous as well as discrete) of control inputs, power-system reliability not attaining the 100% level, and the range of system dynamics over a very broad bandwidth (line transients of the order of milli- and micro-seconds; short-circuit phenomena of the order of milliseconds to seconds; generator-rotor swings and frequency transients of the order of seconds to minutes) are but some of the unique features of a modern power system. The control of such a power system is a many-faceted complex problem, including several operational actions which have as their final objective to maintain the system in its normal operating state and deliver uninterrupted supply of electrical power within set limits of frequency and voltage levels.

The availability of the computer is drastically changing the role of the human operator and the computer is taking over more of the decision-making job. As more and more of the various sub-controls have been made automatic, man's role has changed accordingly, but he has never been fully replaced by machines. Man has always been an integral part of the control of power systems and will continue to have an increasingly important role in the future control centers.

It is the purpose of this paper to discuss briefly the present status of power systems control, look into the future and point out various areas of probable development in the power-system analysis and control with the application of modern control theory.

Present Status

Frequency and voltage control are the primary control functions[1] in all power systems. The load frequency control (LFC) or megawatt-frequency (PF) control[2] maintains a continuous close balance between generated and demanded real power by detecting the frequency error. This enables the power demands to be met at all times at the various load points and the sytem frequency to be maintained within very rigid limits. Frequency control is thus probably the most important single power system control function.

The megavar-voltage (QV) control maintains a balance between the demanded and generated reactive power[3] by detecting the voltage errors, and helps in achieving a specified voltage profile throughout the network. If the system is a part of a power pool, it is also necessary to keep the tie-line powers or the power exchanges with the neighbors at certain fixed values. This is accomplished by adding to the control signal of the load-frequency control system an error signal corresponding to the deviations in the specified power exchange to neighboring pool members.

The frequency and voltage controls are performed these days automatically in closed loop fashion. It is interesting to note that the turbine torques which are the control forces in the frequency control have little or no effect on the voltage magnitudes which are the state variables in the voltage control. Similarly the manipulation of excitation voltages has little effect on the frequency. Also the voltage controls of individual generators geographically dispersed interact only weakly. Thus the frequency and voltage controls are essentially non-interacting.

The control system design for power systems has been developed by the philosophy of decomposition. As it is not possible to design a single central control system to perform the overall control of a complex power system, the overall system is subdivided into smaller, manageable parts which are simple enough to lend themselves to analysis and understanding. Natural lines of division such as the real and reactive power controls can be found by intuition. Time response of different phenomena is another important decomposition base, besides the geographical and functional features of the sytem. Sensitivity analysis[4] is particularly useful in determining the basis for decomposition Besides the frequency and voltage control channels that have been mentioned already for the normal mode of operation, the control systems may be divided along the lines of automatic switching, system splitting, fault-clearing, automatic feeder restoration, load transfer, and load shedding to take care of the fault and post-fault states of the overall system.

Impact of the Computer

The human operator used to keep a vigil over the system frequency and command appropriate position changes of the generator turbine valves, before the frequency control loops have gone automatic. More and more of the several subcontrols went automatic in the recent years. The control jobs during the normal mode of operation for the 99 per cent of the time have been made almost entirely automatic. This may seem to indicate that the human operator has become a passive observer and the impact of the computer is to render man superfluous. But this is just not the case. However, the role of the human operator is undergoing drastic changes. The availability and proper use of the computer make it possible for the operator to predict how the system is going to behave in the minutes ahead and take appropriate corrective measures in anticipation. The human operator will have an increasingly important role in the future control centers in exercising a constant vigil over the system trends and formulating the best strategy decisions. No computational robot can ever replace the human operator, but only enhance his ability in decision making.

A modern dispatch center may typically monitor line loads, perform load-flow analysis and econoic dispatch optimization, compute unit commitment and pool scheduling, send generation commands to the generator units under control, perform load forecasting and reserve analysis besides data logging. Almost all the modern dispatch centers enjoy a large computer facility. This computer performs several simultaneous tasks, depending upon the sophistication of a given system and the quality of the data transmission system in use. The dispatch center usually has a large display map showing transmission network, generator stations and bulk power substations. All important components are indicated with symbols, giving the operator instantaneous visual information of system interconnection status. Individual generations, tie-line flows, frequency, loads etc. can usually be seen on chart recorders.

The human operator has to maintain a constant vigil on the progress of the system operation and make sure that uninterrupted supply of electrical power is delivered within set limits of frequency and voltage levels. Preventative measures have to be taken by foreseeing the possible troubles, based on the data outputs from charts, display, and the computer programs. On-line computation of load flow, power angle and frequency dynamics are predicted to increase system security. In spite of the operator's best efforts, should the system develop a fault, corrective measures must immediately be taken to clear the fault and to see the system return quickly back to the normal mode of operation.

The impact of the availability of computational robots has been tremendous in the field of power-system analysis. Computer methods[5] in power-system analysis have become extremely popular in several areas including short-circuit studies, load-flow studies,[6,7] economic dispatch[8] and unit commitment, and system stability. To mention a few examples, nonlinear programming has been used for the dynamics of load-frequency control systems[9] and optimal short-term unit commitment,[10] while the maximum principle,[11] geometric programming as well as functional analysis[12] have been applied for the economic dispatch optimization. Security evaluation[10] in steady and transient states of power systems using pattern recognition is becoming popular. On-line transient control of capacitor switching,[13] determined by optimal control theory concepts, to improve system stability, on-line identification of interconnected equivalents from operating data utilizing the system identification and parameter estimating techniques, sensitivity analysis for decomposition, and hierarchical control of power systems are but some of the areas of current research interest.

Future Trends

Future trends include on-line load-flow displays, computer monitoring[14] of power systems, improved data acquisition and state estimation, dynamic rescheduling and control, dynamic stability assessment, dynamic energy balance,[15] and using the computers for more of the decision making jobs, including as a part of the protective relay system.[16,17] A brief discussion about these probable development directions will now follow.

With the availability of the present-day fast load-flow computation techniques, it is quite conceivable that the on-line load-flow displays will be a reality pretty soon. The visual minute-by-minute display of the load flow as an overlay on the wall display will help the dispatch-center operator to spot the critical lines and take appropriate preventive measures.

The most recent area of computer application in the power industry is that of operational control and scheduling, which include system security and monitoring, equipment control, operational scheduling, forecasting, on- and off-line studies. This application area is most likely to grow in the future. While the off-line programming has been very well advanced, present trends indicate that the majority of new application will be in the on-line real-time mode.

State estimation techniques are being applied these days to acquire more reliable data. After all, the completeness and accuracy of the input data determines the quality of operation of any control system. The data collecting process is a difficult problem in power systems because of the distances involved. The amount of data can sometimes be so large that it becomes difficult to choose really significant data, interpret it, and utilize the same. Also the control signals have to respond in a few cycles of the 60 Hz system frequency. Thus one can see that much research work can be done in this direction.

When a situation of overheated or overloaded lines develops or when dynamic stability is impaired, there is a need to reschedule the generators within a limited time so as to obtain a new and better load flow configuration. Thus dynamic rescheduling is another area of research interest. Also dynamic stability assessment is highly desirable and this may be done by means of real time computation of swing curves. Transient instability is probably the greatest potential operating danger and one has to look for improved means of continuous assessment of the stability margins. The problem of frequency transients is closely related to the problem of dynamic stability. Dynamic energy balance concentrates on frequency rather than rotor angle dynamics and is another new area that is being developed.

Control and operation of bulk power system control centers are now being accomplished through the use of the latest in computer systems. While more and more sophistication will be incorporated in the future dispatch centers, local control would also not lose its significance. Mini-computers would be used to process the local data and perform local control in generator stations, substations, and local load centers. Mini-computers may also be utilized as a part of the protective relay system and for assessing and diagnosing instantaneously the actual situation under complex fault situations.

Concluding Remarks

The control of a modern power system is a many-faceted complex problem, offering a great challenge to a control systems engineer. Several concepts of modern control theory have been utilized and will continue to be used for the power system analysis and control.

References

1. Elgerd, O. L., "Electric Energy Systems Theory: An Introduction," Text Book, McGraw-Hill Book Company, New York, 1971.

2. Fosha, C. E. and Elgerd, O. L., "The Megawatt-Frequency Control Problem - A New Approach via Optimal Control Theory," Proceedings of the Power Industry Computer Application Conference (PICA), May 1969.

3. Sullivan, R. L., and Elgerd, O. L., "Minimally Proportioned Reactive Generation Control via Automatic Tap-Changing Transformers," Proceedings of the Power Industry Computer Application Conference (PICA), May 1969.

4. Peschon, J., et al., "Sensitivity in Power Systems," Proceedings of the PICA, 1967.

5. Stagg, G. W., and El-Abiad, A. H., "Computer Methods in Power System Analysis," Text Book, McGraw-Hill Book Company, New York, 1968.

6. Dommel, H. W., and W. F. Tinney, "Optimal Power Flow Solutions," IEEE Trans. on PA & S, Vol. PAS-87, No. 10, pp. 1866-76, Oct. 1968.

7. Sasson, A. M., "Nonlinear Programming Solutions for Load-flow, Minimum-loss, and Economic Dispatching Problems," IEEE Trans. on PA & S, Vol. PAS-88, No. 4, pp. 399-409, April 1969.

8. Kirchmayer, L. K., "Economic Control of Interconnected Systems," Text Book, John Wiley & Sons, Inc., New York, 1959.

9. Aggarwal, R. P., and Bergseth, F. R., "Large Signal Dynamics of Load-Frequency Control Systems and Their Optimization Using Nonlinear Programming: I and II," IEEE Trans. on PA & S, Vol. PAS-87, No. 2, pp. 527-538, Feb. 1968.

10. Pang, C. K., "Studies on Security Evaluation by Pattern Recognition and Unit Commitment by Dynamic Programming in Power Systems," Ph. D. Thesis, Purdue University, Dec. 1972.

11. Hano, I., et al., "An Application of the Maximum Principle to the Most Economical Operation of Power Systems," IEEE Trans. on PA & S, Vol. PAS-85, No. 5, pp. 486-494, May 1966.

12. El-Hawary, M. E., and Christensen, G. S., "Optimum Scheduling of Power Systems Using Functional Analysis," IEEE Trans. on Automatic Control, pp. 518-522, August 1972.

13. Grause, P. C., and Mauger, W. C., "On-Line Transient Control of Capacitor Switching to Improve System Stability," IEEE Trans. on PA & S, Vol. 92, No. 1, pp. 321-329, Jan./Feb. 1973.

14. "Computer Monitoring of Power Systems," IEEE Short Course 73-SC-02, 1973.

15. Stanton, K. N., "Dynamic Energy Balance Studies for Simulation of Power-Frequency Transients," Proceedings of the PICA, pp. 173-179, 1971.

16. Dyliacco, T. E., "Processing by Logic Programming of Circuit-Breaker and Protective-Relaying Information," IEEE Trans. on PA & S, Vol. 88, pp. 171-175, Feb. 1969.

17. "Power System Computer Feasibility Study," IBM Research Division Report in 4 volumes, San Jose, Calif., Dec. 1968.