Chapter- 11

CONCLUSION

11.1 General conclusion

The changes are instantaneous in a system having only dissipative elements e.g resistance or friction. But all physical systems have energy-storing elements. Presence of these energy-storing devices, give rise to transients. The duration of the transients, the changes between peaks and the leans, and their magnitudes are determined by the type of faults and the switching actions. It is also determined by the parameters of the circuit, which may be linear or non-linear. As about all real-world systems are more or less non-linear, analysis of non-linear systems assume great importance in electrical engineering. In chapter-1, power system and utilities, general concepts and constraints of high voltage systems have been discussed in details with special reference to Indian power sector.

In chapter-2,mathematical models for simple linear and non-linear circuits have been developed and their transient analysis has been made. The results obtained have been graphically displayed. This has been followed by MATLAB simulations and the results obtained from them. In the next phase, software ETAP has been used for the analysis of a 2-bus system on occurrence of a fault. A computer simulation has been developed for the study.

In chapter-3, steps for performance analysis of short, medium and long transmission lines have been made. ABCD-parameters have been found out considering transmission lines as 2-port devices. Lumped parameter representation has been used for medium lines. Both T and π representation have been used. The effect of distributed parameters has been included in the study of long transmission lines. Expressions for equivalent T and π have been given. Case-studies have been made on real-world transmission lines- short, medium and long. The medium line considered is from RISHRA-220 and DURGAPUR-220. The long line is between stations: CHUKHA-220 in Bhutan and BIRPARA-220 in Coochbehar of West Bengal (under NHPC).

In the next phase discussions have been made on transmission line compensations- both capacitive and inductive. Both shunt and series compensation of transmission lines has been discussed. Shunt capacitive compensation is required for short and medium lines to improve the power factor and reduce the burden of reactive power generation. Series capacitive compensation is used to increase the power transfer capability of a long transmission line.

Inductive compensation is required for long lines characterized by high capacitance which tend to create overvoltage due to Ferranti effect. Switchable compensators are preferred-FACTS devices are used for this purpose. Mathematical expressions for distributed compensation have been given. Case-studies on compensation have been made on a fictitious loss-less transmission line and a real world long transmission line- from Farakka400 to Jeerut400.

Chapter 4 deals with the design procedure for high voltage transmission lines. Much calculation and many steps are involved in the design. Therefore recourse is made to computer to avoid the tedium of long-hand calculations. Both technical and economic considerations are to be made- the design has to be technically feasible and economically viable. It is generally desired to find out a feasible solution at first and then gradually move to the optimal solution. The problem becomes more complicated, if the optimization has to be made in the presence of design constraints which is generally the case. To get a feasible solution, the general approach is to adopt the analytical method. Synthetic method is used to keep certain performance variables at or very near to specified values. The optimal design seeks and finds out the best possible solution from many feasible solutions with reference to a specified objective function, generally in presence of constraints. The computer program developed for this purpose finds out the configurations as well as the performance variables. The program, indigenously made, finds out a quasi-optimal solution. Two case-studies on transmission line design have been made- one on medium line and another on long line using this program.

Chapter 5 deals with design analysis and design of high voltage alternators. The constructional features and the design procedure have been elaborated. Design analysis has been made for a 210 Mw turbogenerator set to gain idea of the normally used values of design variables. This idea has been used for the design of a H.V. alternator of different rating. Also the constructional features and design procedure for H.V. generator-transformer have been discussed. It is economically advantageous to use 3-winding transformers at generator terminals. The tertiary is used to supply the station auxiliaries, also to suppress the triplen harmonics and the zero sequence components arising out of unbalanced loading. Case-studies have been made on both and given at the end of the chapter.

Chapter-6 deals with the design procedure for high voltage power capacitors and power inductors. These are used for power system compensation. The computer program for power capacitor design has been made with a look to the constructional features and the electrostatic phenomena. Power capacitors are used mainly for improvement of power factor in distribution systems and as elements of shunt and series compensators in the transmission lines. These are also used for self-excitation of induction generators coupled to isolated wind-turbine systems. To get an economic design, a construction using Al-foils wound over mandrels with insulating layers in between has been used. A case-study has been made on a 3 MW feeder line catering lagging power factor load. Capacitors used for improving power factor from 0.82 lagging to 0.95 lagging (considered to be economically optimal) have been designed. The design details have been given and the performance variables evaluated.

In the 2nd part of the chapter, procedure for power inductor design has been discussed. It is used for VAR-compensation of long transmission lines, also for creating current sources for the power inverters. The capacitive VAR drawn by a long transmission line dominates over the lagging VAR. Unless properly compensated, this capacitive VAR creates cross-country overvoltage during the lean hours of night. Therefore, long EHV lines are provided with inductive compensation. FACT-devices are often used for better ease of control and maneuverability. A program has been developed for the design of EHV power inductors in this chapter- the algorithm has been given. A case study has been made on the design of power inductors of appropriate rating at the terminals of the EHV line between Farakka400 and Jeerut400. Performance evaluation has been made once without and then with compensation to get a comparative view.

Chapter 7 deals with dynamic stability of power system. The concept is of rather recent origin. In the earlier regime, only transient stability analysis was made, based on simplifying assumptions. Dynamic stability analysis has found importance with growing interactions in the high voltage grids. It is, in essence, a kind of steady state stability. It applies to operating conditions of a machine or a group of machines, subjected to small perturbations. Both oscillatory and exponential modes are created under small impact. It has to be ascertained whether the modes are growing or decaying with time. In order to ascertain the nature of the long-standing transients, the matrix model for dynamic stability is framed- either using currents or flux-linkages as states. The matrix is linearized about the quiescent point by algebraic and trigonometric manipulations. The eigenvalues of the linearized state matrix indicate whether the system is stable or not. The stability margin can also be found out by transfer function approach.

Dynamic stability analysis has been made for 210 MW set using current state space model for three different conditions of loading. Each machine has been idealized as one machine on infinite bus. The effect of exciter has been neglected in these case-studies. Then in the next case-study a reduced order model based on the constants K_1 to K_6 of Concordia and D'Mello has been used. The effect of saturation and exciter control has been included in the study. The parameters of the machine have been modified accounting for saturation and The exciter has been modelled according to IEEE model 1s. At places, Routh's criterion has been applied to the characteristic equation to determine the stability.

Chapter-8 is devoted to the phenomenon of loss of excitation of synchronous generators in a grid system. Computer programs based on detailed mathematical model have been developed for the study of asynchronous operation following LOE. Also the scope for running the generators for limited time under asynchronous mode till resynchronization can be made has been explored. It has been observed that for the same asynchronous power at rated voltage, for a turbogenerator compared to a hydrogenerator

a) The pulsating power component is much lower
b) The absolute value of the slip is much lower
c) The reactive power absorbed from the system is much lower
d) The armature current is much less and is below rated.
e) The frequency of slip cycle is also lower.

On the basis of these observations, sustained operation as induction generator is permitted for 15-30 minutes for a turbogenerator. If the field fault can be removed within this time, the generator can be resynchronized. Otherwise a shutdown is to be opted. It has been recommended by Bharat Heavy Electricals Ltd. to reduce the active power to 60% within 30 seconds and further reduce it to 40% (which comes out to be 0.34 p.u. for the machines rated for a power factor of 0.85 lagging) within 90 seconds for their makes.

In the earlier days, the voltage profile under LOE-condition was very poor. But now-a-days the reactive power generation by long HV/EHV transmission lines is substantively high which partially offsets the reactive power burden imposed by the faulty generator(s) and allows sustained operation of the grid system with one machine under LOE without voltage collapse. Moreover, FACTS devices have been installed in many systems which may come for rescue under this fault.

Voltage stability of a power system is the area dealt with in chapter-9. The voltage stability is equally important as power angle stability. For economic reasons, modern power systems operate with low margins. The transmission lines are heavily loaded in which voltage instability may occur, particularly if there be reactive power mismatch. Cascaded failure and voltage collapse that has occurred in Indian Power System in the recent years is partly due to the unplanned growth of the grid system and partly due to failure to make planned load flow causing undesirable amount of reactive power flow and unacceptable voltage profile eventually leading to voltage collapse and black out. The vulnerability of a system and the needed operating margins should be given due consideration before hand. Otherwise, there are chances of system failure. The effect of high degree of reactive power loading has been established through a no of case studies in this chapter. The voltage profile for a sample system has been shown to deteriorate with increasing reactive power mismatch. This phenomenon has to be remembered while planning the operation of a system.

Another recent and interesting area of application of high voltage is the HVDC-links used for asynchronous coupling of two areas or regions. This has been the subject matter of discussion in chapter 10. Synchronous coupling cannot be used to connect two areas operating at different frequencies or with frequency mismatch. Large scale synchronous coupling also gives rise to poor damping and power system oscillation. In order to obviate these difficulties, HVDC-links are used as tie-lines between two areas or regions poses. In some cases two areas cannot be connected with overhead transmission lines due to geographical barriers. Underground transmission is used in such cases. UG-cables are highly capacitive- they create overvoltage due to Ferranti effect under small load. There, HVDC links are better options for scheduled exchange. In HVDC transmission, there are two vital sections which need be closely controlled- the rectifier section and the inverter section. In addition, reactive power management has to be made and the quality of power has to be ensured reducing harmonic distortions. The mathematical modeling and describing equations for HVDC-links are sophisticated. Design and performance evaluation of HVDC links by long-hand calculation are tedious. Hence, computer programmes have been developed and used in this chapter for specific case-studies of practical importance. It eases out the task.

11.2 Novelty of the work

Much work has been done on design of electrical rotating machines and transformers of various types and bulk of papers have been published in this area. Papers indicating methods to optimize the design subject to given constraints constitute a major portion of the published literature. But unfortunately the design of transmission lines has remained neglected. The design has been kept secret for so many decades until Ramamoorty published a treatise on power system design. But he has not covered computer-aided design of transmission line and other power system components. In this research work, computer-aided design has been made for the following:

1. EHV long transmission line
2. HV Medium transmission line
3. HV Generator - Transformer
4. Compensating devices- power inductor and power capacitor.

Attempts have been taken to reach the optimality. These are new works, also valuable works as the software can be used for design and performance evaluation of these devices.

Dynamic instability of high voltage inter-connected power system is an area of concern now-a-days. In the earlier regime, the interconnections in a grid system were limited and the system damping was positive. But due to large scale expansion in modern grid systems and extensive synchronous coupling, at specific points or specific time, the system damping may turn to become extremely low to cause high degree of oscillations or even oscillations gradually growing in magnitude, if the damping turns to become negative. This phenomenon leads to catastrophic failure of the grid system as a result of long-standing transients.

Analysis of dynamic stability can be made only by modeling the machine in details. It is advantageous to use the state space description. The detailed modeling has been made by using both current states and flux-linkage states. Anderson and Fouad have used the eigenvalue technique to predict the stability. But in this work, Routh's array has also been used on the characteristic equation of the state matrix to predict the same. The modeling of the exciter type 1 of IEEE used for rotating exciter, has been replaced by type 1s of IEEE which is a more appropriate model for solid state exciter used now-a-days. It has been established though case-studies that the machine is more vulnerable to instability under leading power factor condition.

Turbine-alternators are switched off by the action of offset type mho-relay on occurrence of Loss Of Excitation (LOE) after a few cycles to accommodate recoverable swings. It gives rise to large scale loss of generation. Recently it has been established that a cylindrical pole turbogenerator can be run for considerable time in the asynchronous mode without chances of thermal injury and other possible damages arising out of LOE. Detailed analysis has been made on this phenomenon and computer programs have been developed on the basis of the mathematical model. The effects have been studied for varying loads, varying bus-voltage and varying field-discharge resistance. It has also been established that sustained operation of salient pole hydrogenerator is not possible ensuring safe operation. So they must be switched off as usual. A comparative view of operation under LOE for cylindrical pole turbogenerator and salient pole hydrogenerator has been made to establish the truth.

Studies on the operation of power system under large reactive power burden have been made. It has been found for a sample 6-bus system that the voltage profile gradually deteriorates on increasing the reactive power burden, eventually leading to collapse. The fact has been established by conducting load flow studies by a self-built program.

Computer programs have been developed for computer-aided High Voltage Direct Current (HVDC) systems. It saves us from the burden of long-hand calculations- also adjustments can be made more easily. In this work, most of the problems have been solved by self-built programs. Supports of MATLAB-tools have been taken only in limited areas.

11.3 Futuristic trends and future goals

The power system is undergoing rapid changes with population outburst, industrial and economic growth, and urbanization all over the world. The futuristic trends in power system can be summarized as:

i. Generation:

1. Growing demand of electricity and large scale expansion in power production.
2. Larger unit sizes- 500 MW and above in India.
3. Higher voltage of generation- 18 Kv and above.
4. Advent of modern techniques- employment of dual cycle combustion- use of fluidized bed boiler, installation of desulphurization and denoxication plants etc.
5. More economic design with lighter rotors, less inertia constant and higher synchronous reactance

6. Greater dependence on AVR-exciter control.
7. Mixed hydro-thermal (or peak-base) coordination leading towards optimality.
8. Environmental concerns- dispersed and distributed generation.

ii. *Transmission and distribution*

1. Large scale interconnection of systems, operating at different voltage levels.
2. Increase in the operating voltage of long transmission lines
3. VAR-generation management and VAR-IN phenomena during lean load periods
4. Active and reactive power mismatch and resulting swing in power angle and voltage.
5. Growing stability problems- electromechanical: transient and dynamic, electromagnetic: voltage
6. Increasing need of power system compensation: series and shunt- inductive and capacitive.
7. Use of FACTS devices- formation of smart grids.

iii. *Power system operation*

Modern power systems are operated against low margins for greater economic efficiency. The generators, transformers and the utilization devices are being designed with higher values of design variables. Same is the case for transmission and distribution lines. Introduction of high voltage in alternators, transformers and transmission lines have given rise to increased over-all economy but has also given rise to more troubles, more failures and less reliability. The major problems encountered at present are the stability problems- electromechanical and electromagnetic. The large scale interconnection is improving the transient stability due to higher inertia but it is making the system prone to dynamic instability due to small impacts. One way to counteract the tendency of growing oscillation is by incorporating Power System Stabilizers (PSS). The voltage collapse that may occur due to reactive power mismatch or reactive power burden may be combated by the use of power system compensators and/or FACTS-devices [94]. The operation should be preceded by proper load-flow studies so as to ensure trouble-free operation [104]

Another way to solve the problem of hunting is by limiting the extent of synchronous coupling. The generators belonging to a particular area should remain synchronously coupled to each other but the individual areas in the future should be coupled asynchronously by HVDC-links.

A distinction should be made between a faulted system and a system which has undergone some changes in parameters and variables but is still capable of safe and secure running. That is the case with sustained operation of synchronous generators under LOE. It is now an established fact that cylindrical pole alternators are capable of running for an hour or more at reduced load under LOE without any chance of injury, provided its VAR-demand can be met without appreciable voltage dip in the neighbourhood.

Automated generation control, control in load dispatch centers by SCADA, optimal load flow, economic operation and its matching with ABT-requirements, etc. are all incoming and upcoming trends in almost all developing countries.

Researches in at least some of these areas will be taken up shortly.

iv. System analysis

The tools and techniques of system analysis have also undergone changes. The earlier graphical and grapho-analytical techniques have been replaced by computer-aided analysis. For example, the interest in using equal-area criterion or power circle diagram has declined. The power engineers are using specially constructed software for this purpose e.g. ETAP, EMTP, PSCAD, POWERWORLD etc. Also they are using MATLAB and other programming languages for solving problems which are not covered by the above-mentioned software. Algorithm and program for most of the problems were to be developed as analytical tools could not be availed of from commercial software. There is scope of further development of the programs for analysis and design which will also be taken up in recent future.

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