CHAPTER: VIII

CONCLUSIONS

CHAPTER 8

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8.1 GENERAL:-

In view of the continual growth in power generation, trends towards large unit plant capacity remotely located power plants and necessity of interconnecting them to have maximum benefits from diversity and reserves etc.; the transmission systems have become of greater importance and concern in modern electric power system. Electric utilities all over the world are faced with the pressing need for increasing transmission capacity of their lines to cater to an ever increasing demand for electricity.

The optimization of existing transmission facilities; minimizing right of way as well as losses in the lines are now being recognized as the basic necessities for planning and design exercises. On the other hand, the transmission of bulk power has necessitated refinements of design of transmission systems as well as the search for better alternatives. The most common solution sought for increasing transmission capability of A.C. transmission by enhancement of system voltage. The enhancement of voltage level has by now reached to such an extent that it poses several technical and environmental problems, making it imperative to use prohibitive sizes of transmission structures and corridors. Consequently, the search and improvement of all viable transmission alternatives are now in full swing. Out of the various transmission alternatives, a HPOTS of electric power has attracted considerable attention in the recent past. The literature is replete with several interesting features of this new technology pointing out the advantages accrued from the use of HPOTS, the efficient utilization of right of way and the enhanced power capability are, however, the most striking features of the multi-phase lines. Although a considerable research has been made for investigation of HPOTS, greater efforts are still required to be made for modeling as well as analyzing such systems before they are actually planned in practice. It is, therefore, the prime objective of this thesis to discuss and illustrate at length the mathematical modeling and analysis of HPOTS. This chapter gives a summary of the work carried out in this thesis with a few suggestions for future scope of research and investigation in this area.

8.2 BRIEF REVIEW OF THE WORK DONE :-

Initially, the analytical developments to study various parameters of multi-phase transmission system leading to better understanding and modeling of lines for various system studies have been presented. The expressions for inductance and capacitance, the potential and Maxwell's coefficients describing the capacitance and inductance matrices of multi-phase lines, have been derived covering the transposed and untransposed situations, as well as ground effect and lighting shield wires. Transformation matrices to diagonalise the six-phase line parameters matrices have been developed using eigenvectors. Further, complete line parameters with the effect of ground return included are developed.

Next, a brief account of transformers required for three-phase to multi-phase conversion is presented. Suitable mathematical models of three-phase/six-phase transformers and sequence equivalent diagrams have been discussed on the basis of available literature. The various representations of transmission lines and loads including impedance matrix, ABCD-parameters, equivalent three-phase representations of multi-phase lines; and multi-phase equivalents of three-phase lines etc. are reviewed and consolidated for carrying out steady state and line transient analysis of multi-phase system.

An assessment of the benefits of multi-phase lines in terms of their loadability as constrained by several system performance and operating environment criteria, has been made by applying some of the concepts and constraints reported for the three-phase systems. The basic analytical model for obtaining loadability characteristics is delineated, and the procedure to obtain general and operating loadability curves and loadability dependence on Var supply, is discussed.

Based on the several studies like line compensation, load-flow, fault analysis by simulation on selected test systems, the following salient features regarding the performance of multi-phase (6-phase) system as against those of the conventional three-phase system, have been highlighted.

Evaluation of Line Parameters:-

In this chapter, analytical expressions to evaluate the line parameters of multi-phase (6-phase and 12-phase) transmission systems considering transposed and untransposed line conditions and the effect of ground have been derived. Also a method to obtain multi-phase line parameters with due consideration of presence of earth and lightning shield wires has been presented. Transformation matrices to diagonalize the six-phase and twelve-phase line parameters matrices have been developed using eigenvectors. The Maxwell and potential coefficients, sequence inductances and capacitances six-phase and twelve-phase lines have been discussed. The illustrative calculations carried out for the different conductor configurations and line geometries support the validity of the expressions derived and provide quantitative and comparative values of parameters and certain characteristics of multi-phase lines with the conventional three-phase lines. Based on the computations and the findings of the two case studies, the following conclusions may be drawn:

- Multi-phase systems are found to possess higher inductive and capacitive reactances leading to higher SIL than that of the corresponding conventional TPDCS.

- The effectiveness of transposition (cyclic) on multi-phase lines is only meager since multi phase lines are inherently better balanced circuits than those of their Three-Phase counterparts.

- Multi-phase lines are also characterized by higher and stronger positive sequence parameters with progressively lower values of other sequence parameters.

- The X_0/X_1 ratios for multi-phase lines are higher than those of their lower phase-order alternatives, implying relatively an inferior performance during ground faults in terms of over voltages [12].

- The study of parameters of a 400 KV vertically double-hung, Three-Phase transmission line and its conversion into Six-Phase line reveals that the series impedance matrices (6x6) of both (after eliminating the shield wires of the 2x3-phase and Six-Phase lines) are similar, while; the shunt admittance matrices of both the lines are completely different from each other.

- The symmetrical component transformation of the untransposed lines yields coupling between Zero, Second and Fourth sequences in the Six-Phase system; whereas in the case of TPDCS, coupling between all sequences is present. With the cyclic transposition on Six-Phase line, the impedance matrix is completely diagonalised after transformation; but in the case of TPDC line, a strong coupling exists between zero sequence components of the two circuits, even after transposition.

- The comparison of all configurations reveals that with the Six-Phase newly erected line, there will be a smaller size of tower for an equal amount of power transfer. If we employ the Six-Phase mode of power transmission on an existing Three-Phase Double Circuit line then the SIL is more, and the amount of power that can be transferred, is substantially higher than that of Three-Phase double circuit configuration.

- A comparative study has been made for the existing tower of TPDC 400 KV line employed for the Six-Phase mode of transmission, keeping the phase-to-neutral voltage (i.e. 231 KV) as well as the phase-to-phase voltage (i.e. 400 KV) intact. An attempt has been made to study and compare the effects of the regular hexagonal as well as the uneven-sided hexagonal configurations for Six-Phase mode of transmission on the existing Three-Phase double circuit line, requiring only minimum alterations in the basic tower design.

- The terminal expenses are higher than those of the TPDCS, as HPOTS would require specially built phase shifting transformers at both ends, but the increased cost of these transformers is offset by several factors; viz. the reduced tower size; tower foundation cost; and the right of way cost.

- The comparison of all configurations reveals that with the Six-Phase newly erected line, there will be a smaller size of tower for an equal amount of power transfer. If we employ the Six-Phase mode of power transmission on an existing Three-Phase Double Circuit line then the SIL is more, and the amount of power that can be transferred, is substantially higher than that of Three-Phase double circuit configuration. These features of Six-phase mode of power transmission are eventually eye-catching, in view of the fact that with the same amount of Right of Way, we can transmit more power and alleviate the problem of adverse biological effects.

Modelling of Elements of Multi-phase Transmission Network:-

This chapter has presented an overview of certain transformers required for six-phase conversion from three-phase supply. Mathematical representation of three-phase / multi-phase transformers has been reviewed. Mathematical models of multi-phase transmission lines applicable to any phase order and suitable for balanced as well as unbalanced analysis has been discussed. Recognizing multi-phase transmission lines forming port of a three-phase power system network connected via three-phase / multi-phase interfacing transformers at either end, the attempts to model a multi-phase line as a three-phase network has been discussed.

Similarly the multi-phase equivalent representation of a three-phase line for the analysis of a composite system on multi-phase basis has been considered and dealt in details. In both cases of equivalent representations, phase impedance matrix / ABCD parameter, sequence parameter and equivalent single phase representations have formed the main points of discussions. Similar representations have also been extended to three-phase load and multi-phase lines respectively. The various derivations in the chapter have been substantiated by taking into account the sample systems of chapter II. In this chapter, certain characteristics of multi-phase lines viz. charging current, voltage gain, and voltage regulation characteristics have been brought to light.

The study has revealed that the multi-phase lines are characterized by the lower charging current, a slightly higher voltage rise on an open circuit end, better voltage regulation, higher power transmission capacity and higher steady state stability limit, as against those of their lower phase order counterparts.

Loadability Characteristics:-

Multi-phase transmission lines offer more power transfer for the same performance criteria (voltage drop and stability margin) as compared to three-phase system. The benefit in terms of line loadability increases with increasing phase order. An increase in system strength, series compensation and voltage drop yield increase in like loadability as the phase order increases, whereas decrease in stability margin results in increased line loadability with phase order increase. The shunt compensation has been found to have almost negligible effect on line loadability. A six-phase uprating of a 2x3-phase line yields around 75% benefit in line loadability under same specific performance criteria for six-phase and three-phase modes of operation. Multi-phase lines have better voltage performance and maintain better stability margin especially during heavy loading region. Further, the requirement of minimum Var reserve for multi-phase lines are progressively lower as compared to three-phase lines at all levels of loadings.

The Effectiveness of Series Capacitor in multi-phase transmission line:-

The effectiveness of series capacitor in long distance three-phase has been seen so far, but here, attempt is made for the first time to visualize the effect of series capacitor on multi-phase transmission lines and it is analysed. When series capacitor is inserted in the transmission line the reduction of the transfer impedance of the line will generally less than capacitive reactance of the series capacitor. Normally the stability limit decreases with the shunt compensation. But on a series compensated line it is shown that there can be other possibilities.

It is observed from the Compensation study on both Multi-Phase and TPDCS that the net transfer reactance is not just the arithmetical difference between the total inductive reactance and capacitive reactance of series capacitor but, it (net transfer reactance) depends on Degree of Series Compensation; location of the compensation bank along the line; the line length; and the number of series capacitor banks over which series compensation is distributed. For the longer lines, the resultant transfer reactance will be more due to the line charging effect. In order to account for this discrepancy, the term

"Compensation Efficiency" is introduced to indicate the effectiveness of the series capacitor bank(s) in reducing the transfer impedance. The Compensation Efficiency (K) is defined as the ratio of the net reduction of transfer reactance to the reactance of the series capacitor bank used.

It can be mathematically proved that the Transfer impedance is minimum when the Series Capacitor Bank is located at the center of the line, but the effect of line resistance shifts optimum location of the Capacitor Bank slightly towards the receiving end. The effectiveness of the series compensation decreases with the increasing line length. However, with the higher order of transmission this effectiveness increases for an equal amount of increase in power transfer. It is, however, found that at low degrees of Series Compensation, Compensating Efficiency with Two Capacitor Banks is slightly less than that obtained with a Single Capacitor Bank. This, in fact, is the reason for the requirement of higher MVAR rating for two capacitor banks at one-third points along the line than for one capacitor bank at the mid-point.

It is, however, noticed that beyond the critical shunt compensation value, the compensation efficiency increases, and thereby the power transfer capability also increases. The value of the critical shunt compensation (b_{cr}) is just the value of shunt compensation beyond which the transfer impedance of the line starts decreasing from the value corresponding to zero shunt compensation. The term, "optimum shunt compensation (b_{opt})" It is at this point that the transfer impedance changes the direction of its variation.

The compensation efficiency decreases considerably with the increase in shunt compensation, when the capacitor bank is located in the vicinity of the mid point of the line. However, at higher values of series compensation the effect of shunt compensation tends to increase the compensation efficiency for all positions of the series capacitor bank.

The effect of shunt compensation in reducing the Ferranti over-voltage is predominant only when it is placed at the receiving end of the transmission line. For other locations, the series capacitor itself reduces the power frequency over-voltages considerably.

COMPARATIVE LOAD FLOW STUDY:-

The sample system is taken into consideration with 6 buses, 8 lines respectively. Out of these lines the lines which are three-phase double circuit in nature are transformed into six-phase and the load flow analysis performed on both the network to visualize the effect of six-phase conversion on load flow results. The results obtained are tabulated for the various cases to highlight the effectiveness of the six-phase transformation of existing three-phase double circuit line. Before performing the Load Flow Analysis on a sample system, it is imperative to briefly outline the Mathematical Modelling of the Transmission Lines with a view to providing a quick reference to readers. The Salient Points from the Load-Flow Study are listed below.

1. The voltage magnitude and phase angles of all nodes improve substantially as the TPDC lines are converted to Six-Phase lines maintaining the same line voltages and conductor configuration.

2. Even with the increased loading of 1.67 times (than that of the original system load) on the Sample System (in which Three-Phase Double Circuit Lines are converted into Six-Phase Lines), the benefit of the improved voltage magnitudes and phase angles are retained to an appreciable extent, as evident from the values for P,Q at nodes.

3. This clearly states that the better voltage regulation or MVAR control is obtained by replacing TPDC line by Six-Phase.

4. The real and reactive power loading of most of the lines are reduced. The benefit is relatively more quantitative in reactive power flows.

5. The improvement in line efficiencies means the reduced line loss in the system. The lines 6, 7 & 8 retain marked efficiencies in all cases.

6. The system can transfer more load - a phenomenon that has been checked by increasing the system load (1.67 times the original loading) and the additional generating capacity is provided at node 3 and at node 6. The data and results are

tabulated. It is evident from the results that the system load can be increased without overloading any of the lines, and at the same time maintaining appreciable benefit in voltage regulation and efficiencies.

Fault analysis of the TPDCS and the Six-phase Systems:-

The MATLAB simulation has been done for the GETCO's 400KV TPDCS line and its conversion into Six-Phase. The phase conversion is made on the principle that 2-Three-Phase Supplies are displaced by 180^0 and superimposed on each other to form Six-Phase. The Six-Phase conversion is made by using two 12-terminals Three-Phase transformers. For the simulation of various faults at different locations, two distributed parameters blocks are kept, and line length of an individual block is varied to create fault at the desired location. On the receiving end, the same pair of transformers in mirror fashion is used for Six- phase to Three-Phase conversion.

The graphs of fault currents and phase voltages are obtained for various faults at different locations for the same amount of load on both the systems. The simulation is done with ode15s simulation tool. The graphs for both the systems have been juxtaposed and illustrated. The Conclusive points out of the simulation results and graph are as given below:

- From the graphs, it is observed that the magnitude of fault current is less for the Six-phase system than that for the three phase double circuit system having the same fault resistance, fault type and fault location.
- It is also observed that Three-phase to ground fault is the most severe fault in the case of Three-phase double circuit system, while Four-phase to ground fault is the most severe fault in the case of Six-phase system.
- The Line regulation is good in Six-Phase System compared to that of TPDCS.
- The curves plotted for the load voltages for line-to-ground fault on Mid-point of transmission line show significantly less distortion in the case of the Six-phase system as compared to that of Three-phase double circuit system.

8.3 FUTURE SCOPE FOR FURTHER WORK:-

i) An important component of Multi-Phase system is the transformer employed for phase conversion which requires specially built units for Three-phase/Six-Phase conversion. Therefore, it would be worthwhile to extend the modeling procedure to other types of Three-Phase/Multi-Phase transformer connection schemes covering the details such as, the effects of core structure and saturation, neutral connections, phase shifting feature etc.

ii) The study of power transfer (or line loadability) has been carried out on specific EHV test systems to construct loadability curves and to bring out relative benefits of Multi-Phase systems and their deployment for circuit uprating applications. However, the ultimate loadability benefits have to be modified and dictated by operating criteria in practice. It is also worth-while to examine critical dependence of line loadability on Var supplies by incorporating the effects of load voltage characteristics, transformer taps, line resistance, load modeling, etc.

iii) There seems to be a necessity for developing powerful techniques for analyzing transients on Multi-Phase lines for an extensive simulation of single pole switching, single phase to ground faults, phase to ground faults, phase to phase transients etc. with due consideration to incorporate corona effect, breaker reclosing features with and without resistor pre-insertion, surge arresters etc.

iv) The Simulation of load flow analysis incorporating all real time practical constraints can be done for both Six-Phase and Three-Phase Double Circuit Systems with the help of advanced dedicated soft-wares like, PS-CAD, PFLOW, ETAP etc.

v) New methods for the need-based protection of compensated lines can be developed for the multiphase transmission system.

vi) Innovative algorithm for switching the compensating parameters can also be devised.

PAPERS PRESENTED AT INTERNATIONAL & NATIONAL CONFERENCES

SR	Name of the Conference	Organised By	Duration	Title of the paper presented
1	National Conference on Emerging Technology & Applications ETA-2005	Sarashtra University, Rajkot and Amoghsiddhi Education Society, Sangli (Maharashtra)	1-10-2005 to 2-10-2005	"An Innovative Transmission Alternate: Multi-phase Transmission- The Line Parameters & Comparative Study With Various Conductor Configuration With Three-Phase Double Circuit Counterpart" **Won Best Paper Presentation Award**
2	As Above	As Above	As Above	Effectiveness of Series Capacitor on Multi-phase Lines
3	National Conference on Recent Trends in Power System	Shrinidhi Institute of Science & Technology, Hyderabad	30-11-2005 to 1-12-2005	High Phase Order Transmission System (HPOTS):"A Paradigm to Enhance Power System Capability: A Loadability Study"
4	International Seminar on Power Transmission Research Interests & Challenges	Central Power Research Institute-Bangalore (A Govt of India Society, Ministry of Power)	20-12-2005 to 22-12-2005	The Utility of Series Compensation In High Phase Order Transmission System: A Paradigm to Enhance Power System Capability
5	International Conference on Power System Operation in Deregulated Regime-06	Jointly Organised by: 1) National Power Tr Institute, Ministry of Power, Govt of India 2) Institute of Tech, B.H.U., Varanasi 3)Power Grid Corporation of India	06-03-2006 to 07-03-2006	High Phase Order Transmission System:"A Talisman for the Deregulated Power System"
6	As Above	As Above	As Above	The Role of Series Compensation and Load shedding Transformers in deregulated Power System
7	The 8th IEE International Conference on AC & DC Power Transmission (ACDC-2006)	IEE, IEEE and CIGRE at IEE (IET), Hertfordshire, Savoy Place London (U.K.)	28-03-2006 to 31-03-2006	"A Comparative Study of High Phase order Transmission with Three-Phase Double Circuit Transmission System"
8	National Conference on Emerging Technology & Applications ETA-2006	Sarashtra University, Rajkot and Amoghsiddhi Education Society, Sangli (Maharashtra)	1-10-2006 to 2-10-2006	High Phase Order Transmission :"A Trinket to the Electrical Power Transmission" **Won Best Paper Presentation Award**
9	As Above	As Above	As Above	Mathematical modeling of Three to N-phase Transformer for Multi-Phase Transmission System
10	International Conference on Recent Applications of Computer In Electrical Engg. RACE-2007	Engg College Bikaner & Technically Supported by IEEE	24-3-2007 to 25-3-2007	Talismanic Role of High Phase Order Transmission System : An Innovative Way to Plug on to New Future of Electrical Power Transmission
11	As Above	As Above	As Above	Load Shedding Transformer :A futuristic Option for the Rural Network Power Distribution in India