ABSTRACT

Multi-Phase Transmission System or High Phase Order (HPO) system, that is the use of more than the conventional three phases is an approach to more efficient method of using the existing right-of-way for overhead transmission lines. It had been found that conversion of an existing double circuit three phase system into a six phase system increases the power transfer capability by at least 1.732 times, within the existing right-of-way, with the system voltage remaining same, leading to better efficiency, better voltage regulation, greater stability and greater reliability.

Recently, published methods of reduced phase spacing at high voltage levels (69 KV-230KV) lead to more efficient use of electric energy corridors with High Phase Order (HPO). As little spacing as three feet is quite sufficient between conductors of adjacent phases of 80 KV phase-to-ground six phase system with hexagonal configuration of conductors such that the space location vector diagram and voltage phasor diagram coincide, leading to greater thermal loading and surge impedance loading, unbalanced currents comparable to or better than three phase counter parts, less radio and audible noise. But it requires large investment. In view of the less cost of investment involved, interest centers round conversion of the existing double circuit three phase line into six phase line with phase-to-ground voltage equal to the line voltage of the three phase system leading to increase of power transfer capability to 1.732 times. This leads to an integrated three phase – six phase system.

Allegheny Power System of U.S.A. has converted one of their 138 KV three phase double circuit lines into 138 KV six phase line as an alternative to 230 KV three phase double circuit line. The construction and testing of experimental six phase lines have been carried out by Power Technologies Inc, U.S.A. In view of these developments, the Central Power Research Institute (CPRI), Bangalore, India has undertaken certain preliminary studies which examine a 462 KV six phase transmission line as an alternative to an 800 KV double circuit three phase transmission line, as well as the conversion of certain existing 220 KV and 400 KV double circuit three phase lines to six phase operation.
In view of the familiarity of the three phase symmetrical components of voltages and currents as to their effects, the six phase system is treated as two mutually coupled three phase system and a transformation called Dual Three Phase Transformation (D T P T) is used for the analysis of six phase system. This transformation, despite its mutual coupling between the zero sequence components in the transformed impedance matrix for a completely transposed line is found to be very useful in the analysis of the six phase system, when compared with a six phase symmetrical components method.

In the present work considerable amount of research had been directed towards the analysis of faults with impedances, using both the six phase symmetrical components method and D T P T method. So far, both symmetrical and unsymmetrical fault analysis have been done on six phase transmission systems for short circuit conditions without fault impedances. The symmetrical components method and Dual Three Phase Transformation methods are successfully employed for fault analysis of six phase system with fault impedance. The second method i.e., D T P T is found to be better than the symmetrical components method.

Series faults or open conductor faults arising out of a break in a conductor connecting two power systems or two sections on the same system have not been investigated in detail so far. Since a multi phase line employs several conductors, even at lower voltage levels, the probability of such faults is much greater in multi phase systems than in three phase systems. This work is therefore aimed at developing two methods viz. symmetrical components and D T P T methods to analyze series fault in multi phase systems. Only a couple of cases of open conductor faults on six phase system had been reported in literature employing phase-co-ordinate method. The expression for fault currents in the Dual Three Phase Transformation (D T P T) method agree completely with the phase-co-ordinate method that had been reported in literature, besides conferring some additional benefits.
The Dual Three phase Transformation method had been employed in the analysis of integrated three phase system with six phase lines, using the three phase equivalent of the whole system, if the area of interest lies on three phase part or using the six phase equivalent of the whole system, if the area of interest lies on the six phase part. Certain basic shunt faults that are likely to occur on either three phase or six phase sides have been analysed in this work using symmetrical components and D T P T methods.

In the literature, the analysis of either series fault for a few cases or shunt fault has so far been reported. But there is a possibility of both type of faults occurring simultaneously. This is one of the most difficult problems in the solution of faulted network with this type of simultaneous fault situation. In this work the Dual Three phase Transformation method along with superposition principle is applied for the analysis of simultaneous series and shunt faults on a six phase system. Only certain basic faults that are likely to occur have been analysed.

It was found that, while analyzing six phase system using phase-co-ordinate method, Symmetrical components method and Dual Three Phase Transformation method the ungrounded faults with fault impedance pose some difficulty. Hence in this work a new method of generalised fault analysis is proposed using Millman’s Theorem. Grounded as well as ungrounded faults with and without fault impedances are solved using Millman’s Theorem, to obtain the potential of the fault point. Complete fault analysis had been carried out with the proposed method for all the 120 types of faults grouping them into 13 groups using Dual Three Phase Transformation method and Millman’s Theorem to obtain the potential of the fault point. Once the potential of the fault point is known the fault currents can easily be obtained.

The following salient features were observed, while analysing the faults on six phase system. This will give greater insight into the design of protection schemes for new six phase lines or the conversion of double circuit three - phase lines into six phase
The single line to ground fault on six phase system is equivalent to a five line open conductor fault on other conductors. A shunt fault on certain phases is equivalent to a series fault on the remaining phases. This feature may help in the design of protection scheme in the six phase system. The two phase series fault is the most severe fault on the six phase system. Where as four phase series fault is the least severe fault in the six phase system. In certain cases of faults involving ground, the zero-sequence component of the fault current was found to be absent in spite of it being a grounded fault. Hence it may be noted that if zero sequence currents are used to relay ground faults the protection scheme fails to act in such cases. This point is to be borne in mind while designing the protection scheme for six phase system.

In general the analysis of ungrounded faults is difficult. But the application of Millman’s Theorem to calculate the fault point potential, leads to easy analysis of ungrounded faults.

In the analysis of integrated three phase – six phase systems, it was also observed that a combination of certain shunt faults with ground on six phase side were found to be equivalent to a certain type of fault on the three phase side without ground and vice-versa. This is an interesting feature, that can simplify the protection scheme.

Also, it was found that the use of Dual Three Phase Transformation method not only led to development of simple sequence networks in terms the familiar three phase symmetrical components requiring no phase shifting transformers, but also the results were found to agree fully with the results obtained using phase-co-ordinate method. These D T P T sequence networks lead to greater insight and easier design of a good protection scheme.