Abstract— It is well known that 3-phase Double circuit AC transmission system is efficient for Bulk power transmission system. In this paper the transient stability limit is enhanced for 6-phase transmission system which is obtained by converting 3-phase Double circuit system into 6-phase transmission system. So it is utmost to have full-fledged software for integrated grid operation and “c++” language is used for writing these programs. It is the analysis of load flow and transient stability for three phase fault using 9-bus system. For the considered 9-bus system some inputs values are given in p.u. and load flow analysis is done using Gauss Siedel’s iterative method and the values of voltages, angles, active and reactive power are found at all buses at different times from the fault occurrence time. Then modified Euler’s method is used for the transient stability analysis and swing curves are drawn as output by giving different fault clearing times by which critical clearing angles are found for 3-phase and integrated 3-phase and 6-phase systems. Thus it is proved that integrated 3-phase and 6-phase transmission system exhibits more transient stability than 3-phase Double circuit AC transmission system. This program output consists of critical clearing time and load angle versus time characteristics demarcating stable and unstable regions.

Index Terms— Power flow, transient stability, 3-phase Double circuit AC transmission, 6-phase transmission system Modified Euler’s, Gauss Siedel’s method.

I. INTRODUCTION

Six phase power system is a part of multiphase power system. Six phase systems mainly include 3 phase/6 phase transformers and six phase transmission lines. The concept of 6phase transmission line was introduced by Mr. Barns & Barthold during the year 1972. Six phase transmission lines are more popular due their increased power transfer capability by 1.732 times, maintaining the same conductor configuration, rights of way, better efficiency, better voltage regulation, greater stability and greater reliability. In order to satisfy load growth and relieve transmission grid congestion, new generation and transmission lines construction is happening worldwide [1]. These options are becoming increasingly difficult especially in metropolitan areas due to public opposition for obtaining new right of ways [2]. A report from North American Electric Reliability Council (NERC) [3] has indicated that construction of about 5000 circuit-miles has been delayed over the years. Therefore, alternative methods for increasing power transfer in existing corridors need to be examined. In recent years, high phase order (HPO) systems, line compaction and the use of new conductor technologies like high temperature low sag (HTLS) conductors that are capable of carrying higher current have been evaluated [4],[5]. This paper focuses on high phase (six-phase) transmission system due to the promise it holds for increasing power transfer. By decreasing the phase angles, the conventional three-phase system is converted into high phase order system namely six, nine and twelve phase. For the same voltage and current, the power transfer capability increases with the number of phases. Furthermore, for same line-to-ground voltage, the phase separation is reduced for high phase order systems resulting in a compact tower configuration. The six-phase transformation (three-phase to six-phase) is performed using conventional three-phase double circuit delta-wye and delta-inverted wye transformers connected in parallel [8]. Generation and utilization are conventional three-phase and transmission is high phase order as show in Fig. 1 schematically. A six-phase transmission line was constructed and operated for three years in the state of New York [15].
II. ANALYSIS OF 6-PHASE FAULTS ON THE 3-PHASE DOUBLE CIRCUIT LINE

The above figure shows a 3-phase double circuit line between the nodes (5) & (6). A fault is assumed at the beginning of the transmission line at f1 & f2. Initially for before fault condition Gauss – Seidel’s iterations are to be performed as follows.

**Step 1:** Ybus formation: Initially the shunt and series admittance values are fed to the computer in the input files. The shunt values are the total line charging values at different buses. Since the admittances in parallel can added, simple algebraic addition of all admittance values at a node (or bus) gives the total shunt admittance value at that bus. Similarly the series values of actual admittance between any two buses are also fed to the computers as series values before fault when the whole system is healthy. Then the diagonal elements of Ybus are found by considering algebraic addition of all series and shunt admittances form that node. For finding off-diagonal elements of Ybus, the negative values of actual admittances are considered. By symmetry Yij = Yji. Thus Ybus (9 × 9) matrix before fault is found.

**Step 2:** Gauss –Seidel’s iterations for the base load flow: Using the above matrix, Gauss – Seidel’s iterations are performed and thus all quantities P, Q, V & δ are known at all the buses.

**Step 3:** Change1 is to be considered & induced e.m.f’s behind their transient reactance’s are found. Change1 includes shifting of the generator bus nodes behind their transient reactances for transient stability analysis. Correspondingly admittance values to be fed to Ybus matrix will change. Then these modified admittance values are fed to the computer.

**Step 4:** Change 2: Using Gauss – Seidel’s results find load admittances. For i = (m + 1).....

\[
Y_{ii} = \frac{P_i - jQ_i}{(V_{mi})^2}
\]

**Step 5:** Ybus formation during the fault: From the fig shown above there will be changes in the admittances values as follows since f1 & f2 indicate the 3 phase fault thereby those terminals will be connected to ground. Now the circuit can be analyzed as follows.
Fig 3: Equivalent circuit of the 3 phase double-
Circuit line during the fault between nodes (4) and (7)

As shown in the above figure, $Y_{40} = Y_{45}$ previous value $Y_{60} = (Y_{6f1} + Y_{6g2})$ since admittances in shunt are to be added for resultant admittance. $Y_{46} = 0$; $Y_{67} =$ previous value. Since node number (5) is earthed this can be accomplished by making $5^{th}$ row & $5^{th}$ column elements zero in Ybus (9×9) matrix for a 9-bus problem. For the fault in the middle of the transmission line the fig 2 can be modified and re-drawn as shown above. In the above figure since the 3-phase fault is assumed to occur exactly at the middle of the transmission line, all the values $Y_{5f1}, Y_{5g2}, Y_{6f1}$ & $Y_{6g2}$ will be equal to twice the admittance of each transmission line since the admittance of half of the line is equal to twice the admittance of the total line. Thus the changes in the admittance values will be as follows:

$Y_{56} = 0, Y_{50} = (Y_{5f1} + Y_{5g2})$ (Since admittances in parallel are to be added) $Y_{60} = (Y_{6f1} + Y_{6g2})$ (Since admittance in parallel are to be added) With the above modifications including changes 1 & 2 explained in steps 3 & 4, the Ybus matrix during fault for 3-phase system is formed. Using this (9×9) matrix Gauss-Seidel’s iterations are performed. Then 5$^{th}$ row & 5$^{th}$ column are eliminated which results in matrix of order (8×8).

Step 6: Reduction of $Y_{bus}$: For transient stability analysis the net reactance’s in between the generator nodes are only required. Therefore the $Y_{bus}$ (8×8) matrix during fault will be reduced to (3×3) assuming 2 generator buses and an infinite bus (slack bus). It is the usual practice to consider generator buses only for transient stability analysis. Thus reduced $Y_{bus}$ matrix during fault is formed.

Step 7: To find initial $P_{e2}$ & $P_{e3}$ values for generator buses: The values of the above (3×3) $Y_{bus}$ matrix are used for finding the electrical power outputs of generators 2 & 3. i.e. initial $P_{e2}$ & $P_{e3}$ values.

Step 8: After finding the initial $P_{e2}$ & $P_{e3}$ values, the modified Euler’s steps are used to find the load angles (or) power angles ($\delta_2$ & $\delta_3$) at various instants of time till the circuit breakers of the faulty line are opened.

Step 9: After fault conditions: In the fig. 2, let the circuit breakers CB1, CB2, CB3 and CB4 be switched off at time $t = t_1$. From the time $t_1$ up to the re-closure of the circuit breakers at time ($t_2$) that period is treated as after fault period. During this period, the admittances $Y_{4t}, Y_{6t}$ will have the same values as that of before fault. But since circuit breakers are opened between nodes (5) & (6), it is treated as open circuit. So impedance is infinite, & admittance is zero between 5 & 6 nodes. $Y_{56} = Y_{60} = 0$. With these changes in $Y_{bus}$ elements, $Y_{bus}$ (9×9) matrix is formed during the after fault period. Using these Ybus elements Gauss-Seidel’s iteration procedure is followed to find the latest values of voltages & powers at different buses. The $Y_{bus}$ (9×9) matrix after fault is reduced to $Y_{bus}$ (3×3) by nodal elimination method as two generators and one slack bus are under study. Using this reduced after fault Ybus matrix for 3-phase $P_{e2}$ and $P_{e3}$ values for generators 2 & 3 are found and modified Euler’s method is continued up to the re-closure time $t_2$ seconds. At $t = t_2$ the circuit breakers are re-closed assuming that the fault is temporary and cleared now. Under these healthy conditions $Y_{load}$ matrix of order (9×9) must be used which was found before fault. Using this $Y_{load}$ (9×9) Matrix Gauss–Seidel’s iterations are performed. Then using modified Euler’s method power angle is computed at different intervals of time with $\Delta t = 0.05$ (or) 0.01 sec. up to final time $t_1 = 2$ to 4 Sec. Thus $\delta_2$ values are computed, tabulated and swing curve is drawn [( $\delta_2$ versus time (t)] with an increment of $\Delta t = 0.01$ sec. After finding $t_{cr}$, the critical clearing angle ($\delta_{cr}$) is found from the swing curve corresponding to the time ($t_{cr}$) from the graph as follows.
III. ANALYSIS OF 6-PHASE FAULT ON 6-PHASE LINE

Step 1: Formation of Ybus before fault: 6 phase transmission line using the equivalent 3-winding transformer is shown in the following figure. The 3 winding transformers for getting 6 phase supply from 3 phase supply and vice-versa both at sending end and receiving end are shown as T1 and T2 in the above figure. In the above figure for convenience and reduction of the number of nodes sometimes it will be harder to convert the Y network of T1 & T2 to delta network using star delta transformation by eliminating nodes 10 and 11 in fig. 6. Then the following figure will be obtained. In the above figure the number of nodes is reduced by 2, compared to the previous figure. From the above fig.7. The series admittance values between different nodes as well as shunt admittances are fed to the computer to form Ybus matrix of order (9 × 9) before fault. If more number of nodes are considered as in figure 6. The extra nodes (10) and (11) can be eliminated by nodal elimination method. Thus Ybus is found before fault for 6 phase of order (9×9).

Step 2: Gauss-Seidel’s method can be employed for finding V, δ, P & Q, whichever is unknown using the above bus admittance matrix.

Step 3: Change 1: The generator nodes are shifted behind their transient reactances and new series Y values between the corresponding nodes are fed as follows. This modification is for generator buses only.

Step 4: Change 2: Using Gauss – Seidel’s results in step (2) the load admittances

\[
Y_{li} = \frac{P_i - jQ_i}{|V_{li}|^2} \quad \text{for } i = (m + 1) \ldots \text{To n are calculated as in step 4 of section 2.2 and the matrix Yload 6 phase of order (9 ×9) is found by implementing changes 1 and 2.}
\]

Step 5: Ybus formation during fault: During 6-phase fault at the beginning of the transmission line the fig. 8 will be modified as follows.
In the above figure 8, f₁ & f₂ indicate 6-phase fault at buses (5) & (8). For more clarity the above circuit is redrawn is shown in fig 9. From the above fig 9. The admittance values to be fed to the computer will be as follows. \( Y_{40} = (Y_{45} \text{ previous value } + Y_{48} \text{ previous value}) \) [Since Admittances in parallel are to be added] \( Y_{60} = Y_{65} \text{ previous value} \). 

With the above changes, 3 more shunt admittances \( Y_{40}, Y_{60}, Y_{90} \) are to be fed to the computer in the input file. After that since the nodes (5) & (8) are connected to reference, the elements of 5\(^{th}\) row, 5\(^{th}\) column, 8\(^{th}\) row & 8\(^{th}\) column must be made zero to consider the effect of 6-phase fault i.e. 3-phase fault at buses 5 and 8. Thus \( Y_{\text{bus}} \) of order (9\( \times \)9) is formed and used for Gauss-Seidel’s iterations to find the latest appropriate values of V, δ, P & Q at all buses.

**Step 6:** Reduction of \( Y_{\text{bus}} \): The above (9\( \times \)9) matrix (with fault bus elements zero) is reduced to (3\( \times \)3) by nodal elimination method.

**Step 7:** Calculation of \( P_{e2} \) and \( P_{e3} \): Using the above reduced \( Y_{\text{bus}} \) (3\( \times \)3) matrices during fault for 6 phase using the relation \( P_{en} = R_e \left[ E_n^* \right] \) for \( n = 2 \) & 3, the values of \( P_{e2} \) and \( P_{e3} \) i.e. electrical power outputs of generators 2 & 3 are found.

**Step 8:** Modified Euler’s method to find \( \delta_2 \) & \( \delta_3 \): Using the above values of \( P_{e2} \) & \( P_{e3} \), and modified Euler’s procedure the 1\(^{st}\) estimation and 2\(^{nd}\) estimation of the power angles are performed, with time increments \( \Delta t = 0.01 \) sec in some cases and \( \Delta t = 0.05 \) sec in some other cases. In most of the cases \( \Delta t = 0.01 \) sec is considered for more accuracy, up to time \( t = t_1 \) i.e. up to the opening of the concerned circuit breakers.

**Step 9:** After fault: \( Y_{\text{bus}} \) formation, Gauss – seidel’s & modified Euler’s method at \( t = t_1 \), the 3 phase circuit breaker for the faulty line is opened. Then in that particular local region, some series \( Y_{\text{bus}} \) values will differ. Considering new values of \( Y \) the \( Y_{\text{bus}} \) (9\( \times \)9) after fault matrix for 6-phase is formed. Using this \( Y_{\text{bus}} \) elements Gauss seidel’s iterations are performed & this (9\( \times \)9) matrix is reduced to (3\( \times \)3) and using this reduced \( Y \) matrix \( P_{e2}, P_{e3} \) are found and modified Euler’s method is continued up to \( t = t_2 \) where circuit breakers reclose.

**Step 10:** Modified Euler’s method during re-closure of the circuit breakers: At \( t = t_2 \) sec the circuit breakers reclose. Assuming healthy conditions, using (9\( \times \)9) matrix Gauss-Seidel’s iterations are performed. Then (9\( \times \)9) matrix is reduced to \( Y_{\text{load}} \) (3\( \times \)3) and modified Euler’s steps are performed for finding \( \delta_2 \) and \( \delta_3 \) up to the final time \( t_f = 3 \) seconds (or) 4 seconds. If the 6-phase fault is at the center of the two transmission lines, the fig 8 will be modified as follows.

Then the changes in the admittance values will be as follows: \( Y_{50} = 2Y_{65}, Y_{60} = 2Y_{89}, Y_{80} = 2Y_{65} \) (since \( Y_{65} = Y_{89} \)). \( Y_{60} = 2Y_{65}, Y_{60} = 2Y_{89} \) Where \( Y_{65} \), \( Y_{89} \) represent previous values at present \( Y_{50} = 0 \) \( Y_{80} = 0 \) with the above modifications.
in step (5) the Gauss-seidel’s and modified Euler’s methods are to be continued. Similarly if the 6-phase fault is at the end of the transmission line the nodes 6 & 9 will be connected to reference (or) earth. Correspondingly different admittance values are to be chosen, and then Gauss-Seidel’s and modified Euler’s methods are to be followed.

IV. SYSTEM CONSIDERED

Three phase fault is considered on one of the double circuit lines. Totally 9 cases are delta when the 3-φ Fault occurs on the transmission line between nodes (5) and (6). Generators and Transformers data is

Bus number 1 = slack bus
Bus number 2 & 3 = Generator buses
Bus number from 4 to 9 = Load buses

<table>
<thead>
<tr>
<th>Bus number</th>
<th>Bus type</th>
<th>Voltage in polar form ( V \angle \theta )</th>
<th>Generation</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Swing (or) slack bus</td>
<td>1 ( \angle 0 )</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>PV (or) Generator bus</td>
<td>0.884</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>PV (or) Generator bus</td>
<td>0.7395</td>
<td>2.9</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>PQ (or) Load bus</td>
<td>-</td>
<td>1.4</td>
<td>0.6</td>
</tr>
<tr>
<td>5</td>
<td>PQ (or) Load bus</td>
<td>-</td>
<td>-</td>
<td>2.0</td>
</tr>
<tr>
<td>6</td>
<td>PQ (or) Load bus</td>
<td>-</td>
<td>-</td>
<td>1.2</td>
</tr>
</tbody>
</table>
V. RESULTS

Fig. 13 9 Bus, 3-phase fault, when 1 line is converted into 6-phase at the beginning of the transmission line.

Fig. 14 9 Bus, 3-phase fault, when 5 lines are converted into 6-phase at the beginning of the transmission line.

Fig. 15 9 Bus, 3-phase fault, when 1 line is converted into 6-phase at the Centre of the transmission line.

Fig. 16 9 Bus, 3-phase fault, when 3 lines are converted into 6-phase at the Centre of the transmission line.
Fig.17 9 Bus, 3-phase fault, when 1 line is converted into 6-phase at the End of the transmission line.

Fig.18: 9 Bus, 3-phase fault, when 3 lines are converted into 6-phase at the End of the transmission line.

Fig.19 9 Bus, 3-phase fault, when 1 line is converted into 6-phase at the Centre of the transmission line.

Fig.20 9 Bus, 3-phase fault, when 3 lines are converted into 6-phase at the Centre of the transmission line.
VI. CONCLUSION

In this paper the computer solution of the given problem using Gaussseidel’s and modified Euler’s is found by obtaining different swings curves for generator G2 and generator G3 for 3-phase and 6-phase options, considering the occurrence of a 3-phase fault at the beginning, middle and end of the transmission line between nodes (5) & (6). And the result of each case is indicted in the same graph itself for the relevant case. Result analysis is made comparing different 3-phase and 6-phase option from which it is conclude that the 6-phase option exhibits more transient stability compared to the 3-phase option in any case.

ACKNOWLEDGMENT

The authors would like to acknowledge the help of Dr P.S Subrahmanian for his valuable suggestions and advise for the information and guidance in this research in 3-phase/6-phase transmission lines and thank the Management, the Directors ,the Principal Dr.Panala Krishna Murthy, the HOD Kiran Yaddnapudi and the members of the Department of Electrical & Electronics Engineering (EEE) of Swarna Bharathi Institute of Science and Technology (SBIT), Laqshya Institute of Science & Technology,(LITS) Tanikella, Khammam for their support in executing this work in the Department.

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