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Analysis of Transient Stability in Six Phase Transmission Line Power System

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Abstract

Enhanced power transfer capability through a six-phase converted transmission system is becoming an area of growing interest in the power system industry. However, this conversion will have an impact on the system stability. In this paper, the transient stability of a system is investigated in time domain considering conversion of three-phase double-circuit to the six-phase single-circuit transmission system. All types of fault on the middle of transmission line are simulated using PSCAD/EMTDC. From the simulation results, it has been shown that the system with six-phase single circuit transmission has a better stability limits.

Index terms--*Stability analysis, transient stability analysis, high-phase order transmission, six-phase system, multi-phase system, time domain analysis.*

1. INTRODUCTION

The future growth of power systems will rely more on increasing capability of already existing transmission systems, rather than on building new transmission lines and power stations, for economical and environmental reasons. The external pressure have mounted on the power transmission to find the best solutions about the need to transmit greater amounts of power through long distances with fewer aesthetic and electrical impacts on the environment. The pressures have led to re-examination of basics of the three-phase system. In some applications, for transmitting power over very long distances it may be more economical to convert the EHV ac to EHV dc, transmit the power over two lines, and invert it back to ac at the other end. But the main disadvantage of the dc link is the production of harmonics which requires filtering, and a large amount of reactive power compensation required at both ends of the line. For other applications, it has seemed advantageous to optimize some form of ac. These have renewed interest in techniques to increase the power carrying capacity of existing right-of-ways (ROW) by using the higher order transmission system. Six-phase transmission appears to be the best solution to the need to increase the capability of an existing transmission line and at the same time, responds to the concerns relating to economical and environmental effects. A good deal of research effort applied since early 1970's has proved the economic viability of three to six-phase conversion of an existing three-phase double-circuit line. A brief summary of the principle advantages of six-phase transmission system are:

* Six-phase transmission can provide the same power transfer (thermal or surge impedance) capability as three-phase on smaller ROW, for the same electric field and

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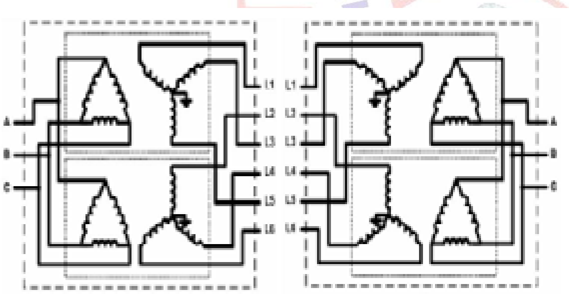
audible noise criteria, with smaller structures and reduced overall cost.

* Conversely, six-phase can provide higher power transfer on a given ROW than three-phase, for the same field and noise criteria.[1]

* Six-phase transmission is compatible with existing systems, since they can be tapped with three-phase connections.

Conversion of an existing three-phase double-circuit overhead transmission line to six-phase single-circuit operation is needed phase conversion transformers to obtain the 60° phase shift between adjacent phases. Three-phase double-circuit transmission line can be easily converted to a six-phase single-circuit transmission line by using two pairs of identical delta-wye three-phase transformers connected at each end of the line as shown in Fig. 1. One of each pair of transformer has reverse polarity to obtain the required 60° phase shift.



(a) (b)

Fig.1 Two pairs of identical delta-wye three-phase transformers. One of each pair of transformer has reverse polarity (a) Sending end (b) Receiving end

The aims of this study is to analysis of transient stability of six phase transmission line for

1) Transient when six phase transmission line charging at time 1.0 second
2) Transient when charged six phase transmission line connected with grid at time 2.0 second.
3) Transient when loss of load

To demonstrate the effects of six-phase conversion, test system has been simulated using PSCAD/EMTDC. From the value of the critical clearing times and simulation results, it has been shown that the test system with a six-phase single-circuit transmission has a better stability.

2. TRANSIENT STABILITY

Transient stability is the ability of a power system to remain in synchronism when subjected to large transient disturbances. These disturbances may include faults on transmission elements, loss of load, loss of generation, or loss of system components such as transformers or transmission lines. The resulting system response involves large excursions of generator rotor angles and is influenced by the nonlinear power-angle relationship. Stability depends on both the initial operating state of the system and the severity of the disturbance. Usually, the system altered so that the post disturbance steady-state operation is differs from that prior to the disturbance. Most power system engineers are familiar with plots of generator rotor angle (δ) versus time (t). Fig. 2 illustrates the behaviour of a synchronous machine for stable and unstable situations. It shows the rotor angle responses for a stable case and for two unstable cases. In the stable case (Case 1), the rotor angle increases to a maximum, then decreases and oscillates with decreasing amplitude until reaches a steady-state. In Case 2, the rotor angle continues to increase steadily until synchronism is lost. This form of instability is referred to as first-swing instability and is caused by insufficient synchronizing torque. In Case 3, the system is stable in the first-swing but becomes unstable as a results of growing oscillations as the end state is approached. This form of instability generally occurs when the post-fault steady-state condition itself is "small-signal" unstable, and not necessarily as a result of the transient disturbance.[2]

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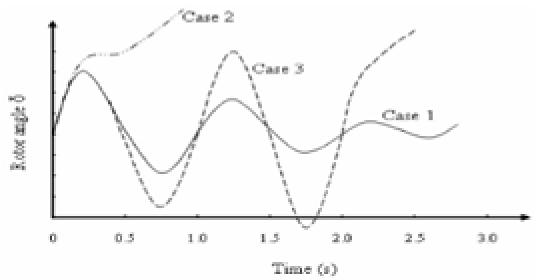

Fig. 2 Rotor angle response to a transient disturbance

In large power systems, transient stability may not always occur as first-swing instability. It could be the result of the superposition of several modes of oscillation causing large excursions of rotor angle beyond the first swing. As far as transient stability is concerned, the most severe switching action is the balanced six-line fault. Two concepts are essential in understanding transient stability known as the swing equation and the power-angle relationship. The swing equation describes the swings of the rotor angle S during disturbances and is given by:

$$\frac{2Hd^2\delta}{\omega_0 dt^2} = \overline{T_m} - \overline{T_e}$$

(1)

H =Inertia constant

δ =Rotor angle

ω_0 =Rated angular velocity

$\overline{T_m}$ =Mechanical torque

$\overline{T_e}$ = Electromagnetic torque

For a system to be transiently stable during a disturbance, it is necessary for the rotor angle (as its behaviour is described by the swing equation) to oscillate around an equilibrium point. If the rotor angle increases indefinitely, the machine is said to be transiently unstable as the machine continues to accelerate and does not reach a new state of equilibrium. In multi-machine systems, such a machine will "pull out of step" and lose synchronism with the rest of the machines. The second concept of transient stability is power-angle relationship which is the relationship between the electrical power of the generator Pe, and the rotor angle of the machine S and is given by:

$$P = \frac{V_1 V_2 \sin\,\delta}{X} \qquad (2)$$

V_1=Phase-to-ground voltage magnitude at the sending end of the line.

V_2= Phase-to-ground voltage magnitude at the receiving end of the line.

δ= Rotor angle

X=Positive sequence impedance of the line

Power flow is a maximum when δ = 90°. If the angle exceeds 90°, the power decreases with increasing angle. System changes which reduce S for the same power enhance the system stability, because there is additional margin for the system to swing without exceeding the 90°. Increasing phase to ground voltage by six-phase conversion increases the voltage, thus generally enhancing system stability in the same manner as system stability is enhanced by any conversion that results in a higher line operating voltage.

3. TRANSIENT STABILITY STUDY

There are two methods of simulation of the transient stability behaviour of conventional three-phase systems currently in vogue. The first method employs alternate computation cycles of the differential and network performance equations. The second method calls for straightforward numerical integration of the swing equations. Both the methods may be extended to six-phase systems; however, for the purpose of this investigation, the first approach is employed as it retains the information regarding bus voltages as a function of

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time. As the transmission system is of particular interest here, equivalent single-phase as well as phase coordinate representations of the network performance are used in the transient stability simulation of the system. A brief account of the two procedures follows.[3]

3.1 EQUIVALENT SINGLE-PHASE PROCEDURE

In this procedure, the six-phase elements of the network are represented by their single-phase equivalent representation. The procedure to derive a positive-sequence network for a composite system either entirely on a six-phase or a three-phase. The stability investigations are carried out as usual by alternate computation cycles of the differential and network performance equations.[3]

3.2 PHASE COORDINATE PROCEDURE

Although the application of the phase coordinate procedure may be questionable for extensive simulations of large systems on account of prohibitive memory and computational costs, its ability to render a complete network status during every step of the integration may be valuable in a few important and complex situations. In addition, the various kinds of fault, especially those involving an unbalanced network along with the disturbances, can be simulated with more ease and flexibility than with other methods.

The procedure is similar to the single-phase method except that the network performance equations are solved in phase coordinates. The swing equations of the machines are written employing only the phase angles. This is because the balanced design of the machine is assumed, implying balanced internally induced emfs. Therefore, there is no advantage in integrating all the internal phase.[3].

4. STUDY SYSTEMS

SIX PHASE TRANSMISSION LINE SIMULATION MODEL IN PSCAD

Conversion of existing double-circuit three-phase overhead transmission line to a six-phase operation needed phase-conversion transformers to obtain the 60° phase shift between adjacent phases. A double-circuit three-phase transmission line can easily converted to a six-phase transmission line by using two pairs of identical delta-star, three-phase transformers connected at each end of the line as shown in Fig. 3. Goudey to Oakdale has been reconfigured from an 115kV double circuit three-phase line to a 93kV six-phase line. [4]The line will be operated with a nominal phase-to-ground voltage of 93 kV. The phase-to-phase voltage will be 93 kV between adjacent phases (60 degrees apart), 161 kV between phases (120 degrees apart), and 186 kV between opposite phases (180 degrees apart). For reconfigured 115kV three phase-double circuits to 93kV six phase lines, here we use two, three phase delta to star with ground 115/161kV transformers at Goudey side and two, three phase star to delta 161/115kV identical transformers at Oakdale side to obtain six phase 93kV transmission line, as shown in figure 3.

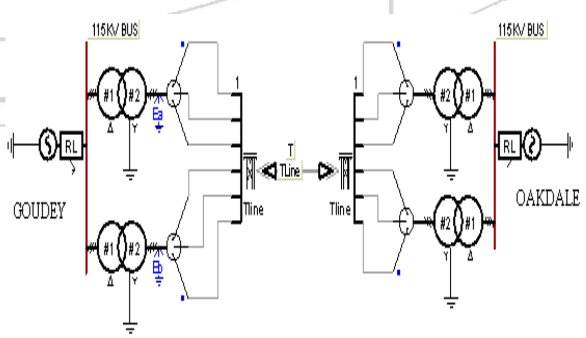

Fig. 3 Conversion of double-circuit three-phase overhead transmission line to a six-phase line

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SIMULATION MODEL

5. ANALYSIS OF SIMULATION RESULTS

Results from the simulations are presented. The transient in six phases are presented for different condition and the results are as per expectation. These disturbances include faults on transmission elements, loss of load, loss of generation, or loss of system components such as transformers or transmission lines. The resulting system response involves large excursions of generator rotor angles and is influenced by the nonlinear power-angle relationship.

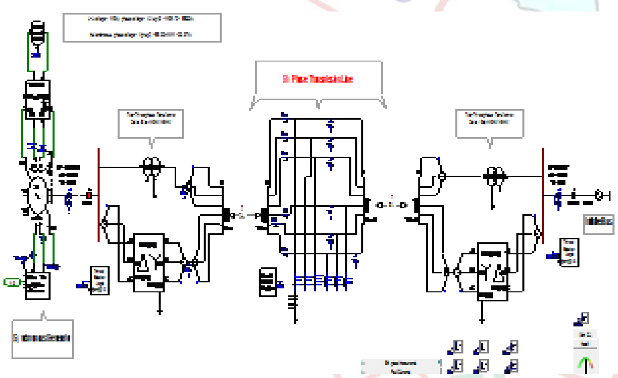

Fig. 4.1a: Simulation Model

5.1 Transient when six phase transmission line charging at time 1.0 second

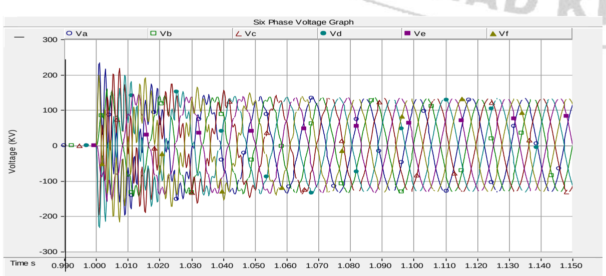

Figure-4.1b: Graph for at the time of line charging at 1.0 seconds uncharged line

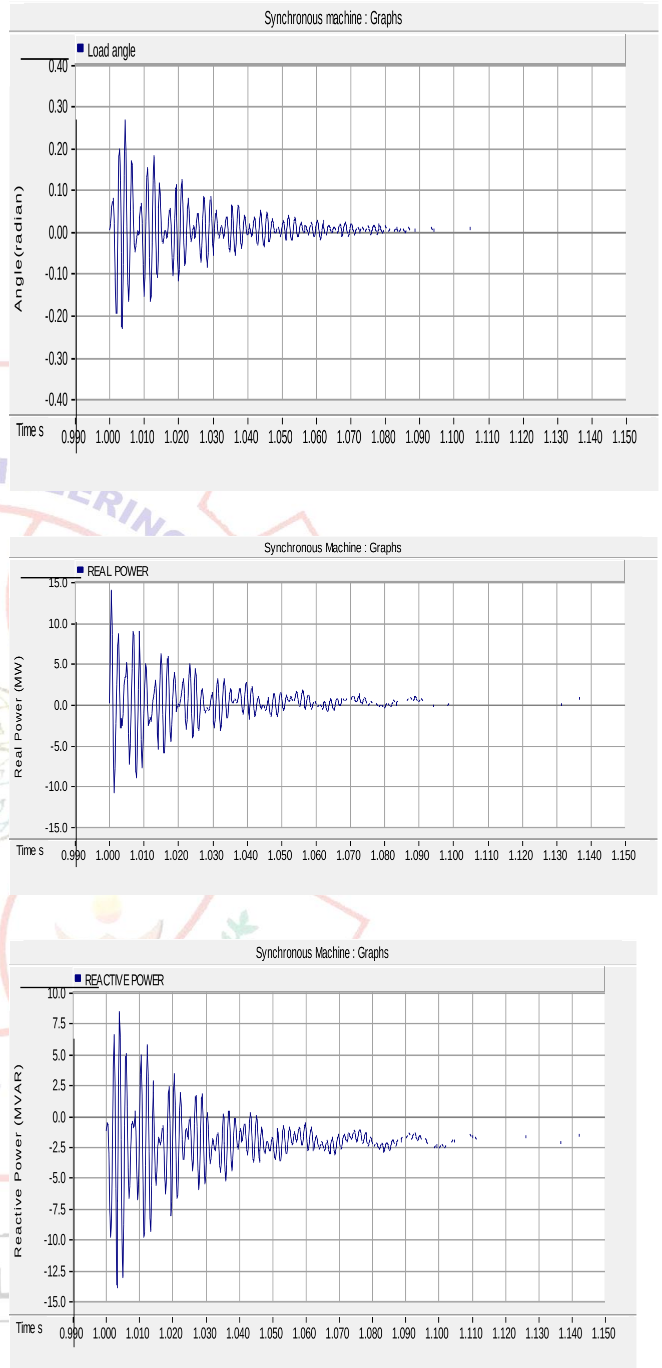

Figure 4.2 load angle, real power, and reactive power graphs.

5.2 Transient when charged six phase transmission line connected with grid at time 2.0 second.

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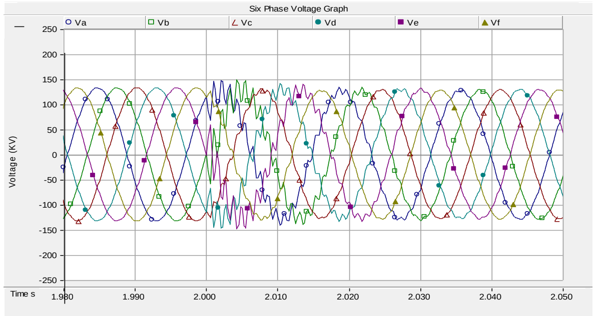
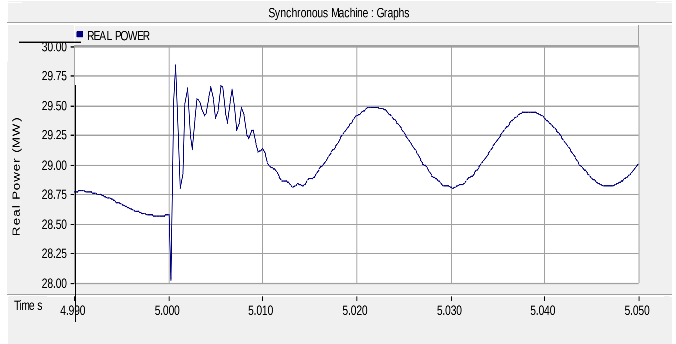
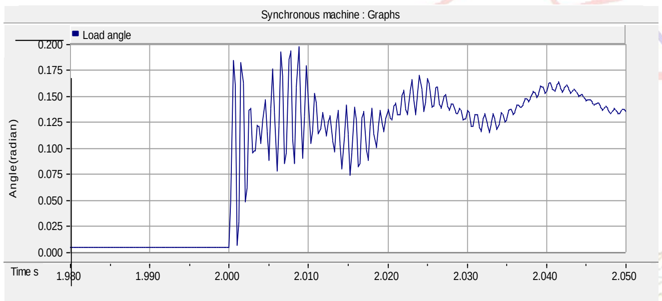
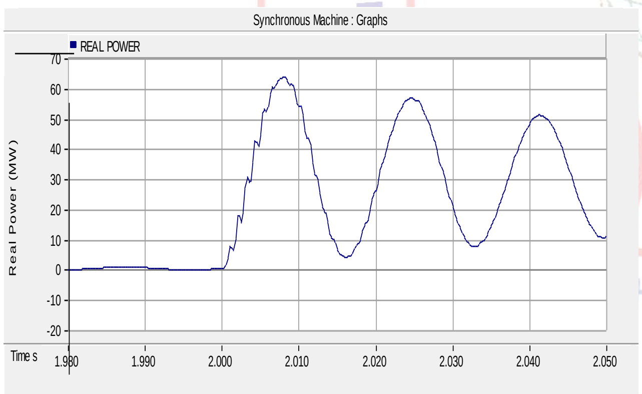


Figure -4.3 six phase voltage graph at 2.0 second







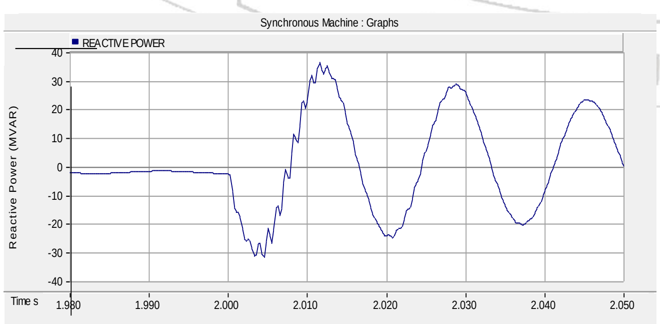


Figure 4.4 load angle, real power and reactive power graphs

5.3 Transient when 20 mw,10 mvar load connected at time 5.0 second

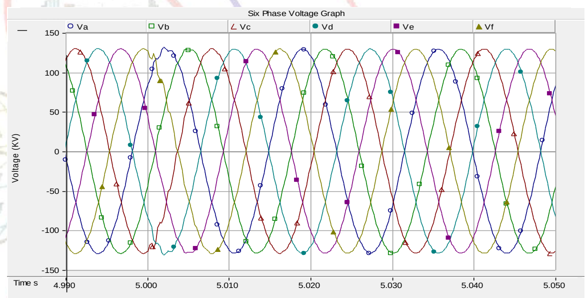
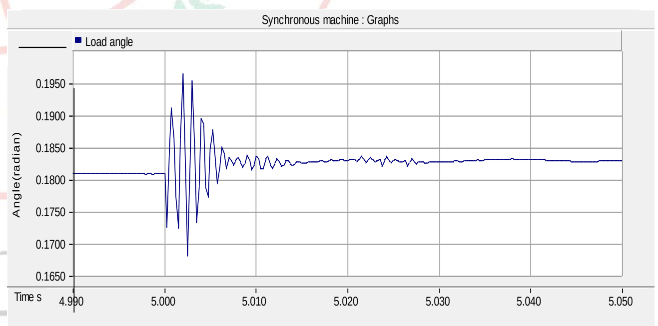


Figure 4.5 Voltage graph



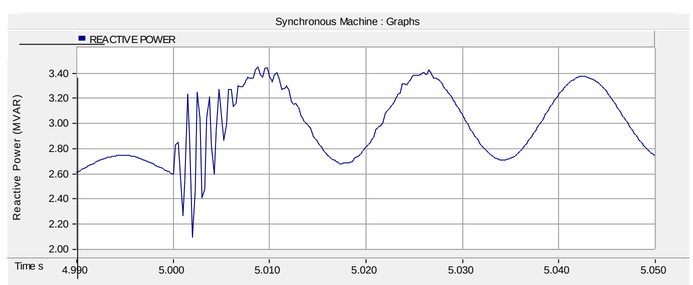


Figure 4.6 load angle graph

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In all the studied cases, the power systems were assumed to be balanced. Transient stability analysis has been performed on the test system in sufficient detail to determine how the six-phase conversion will affect the system stability. Fig.4.2 illustrates the rotor angle swing for the stable condition. The rotor angle will swing and increases to a maximum while the disturbance is applied to the test system and after that disturbance is cleared; the rotor angle then decreases and oscillates with decreasing amplitude until reaches a steady-state. It can be seen that the rotor angle decreased to the stable point because the duration of disturbance which applied to the test system is less than the critical clearing time for that system.

6. CONCLUSION

This paper investigates the transient stability of three- to six-phase conversion of selected transmission line of test system. The investigation is done by monitoring system stability of the test system. This analysis has been conducted by using PSCAD/EMTDC. From the simulation results, it has been shown that test system with six-phase single-circuit transmission has a better stability limits.

7. REFERENCES

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