Investigation on Transient Stability of Six-Phase Transmission System and Proposal for Integrating with Smart Grid

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---ABSTRACT---

Recently, there is a growing interest on the concept of six phase transmission as an alternative to the voltage up gradation of a line, to increase the power transfer capability within the existing rights of way. This paper mainly deals with the transient stability analysis of a 3-phase double circuit line in comparison with that of equivalent 6-phase transmission line. A smart grid is a grid that is capable of delivering electricity from suppliers to consumers via a two-way digital technology, effectively controlling the consumers energy consumption by reducing the cost of generation and transmission and hence to improve the system performance, efficiency and reliability. A framework for cohesive integration of smart grid and six phase transmission technologies facilitates convergence of highly needed standards and implementation of necessary analytical capabilities. This paper critically reviews the reliability impacts of smart grid resources and transient stability of six phase transmission. We observe that an ideal mix of these resources leads to a better stability that eventually accentuates reliability challenges further.

I. INTRODUCTION

power system stability is the ability of an electric power system for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a transient disturbance, with most system variables bounded so that practically the entire system remains intact [1-2].Rotor angle stability refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to a disturbance. Rotor angle stability is divided in to two subcategories, small signal and transients abilities [2-4].Traditionally, the need for increasing power transmission capability and more efficient use of rights-of way space has been accomplished by the use of successively higher system voltages. Constraints on the availability of land and planning permission for overhead transmission lines have renewed interest in techniques to increase the power carrying capacity of existing transmission lines using same available rights –of-way. High phase Order (HPO) transmission is the use of more than the conventional three phases to transmission corridor. The increased interest in HPO Electric Power Transmission over past thirty years can be traced on a CIRGE paper published by L. D. Barthold and H. C. Barnes [5]. Among the HPO, six-phase transmission appears to be the most promising solution to the need to increase the capability of existing transmission lines and at the same time, respond to the concerns related to electromagnetic fields [5], [6]. One of the main advantages of six-phase transmission is that a six-phase line can carry up to73% more electric power than a double circuit three-phase line in the same right-of-way [8].The other alternative to increase the power transmission capability is HVDC transmission. However, a major drawback of HVDC transmission is the huge capital required for installation and operation. And it is economical only if the transmission distance is more than the break even distance. So six-phase is a better option [9]. Whereas the innovation of the transmission grid was driven by technology in the past, the current power industry is being modernized and tends to deal with the challenges more proactively by using state-of-the-art technological advances in the areas of sensing, communications, control,

computing, and information technology [10]–[14]. The shift in the development of transmission grids to be more intelligent has been summarized as "smart grid," as well as several other terminologies such as Intelligent Grid, Grid Wise, Future Grid, etc. The Intelligent Grid program, initiated by the Electric Power Research Institution (EPRI), is to create the technical foundation for a smart power grid that links electricity with communications and computer control to achieve tremendous gains in the enhancements of reliability, capacity, and customer service [15],[16].

II. SMART TRANSMISSION NETWORKS

"Smart grid" is the term generally used to refer to an electrical grid whose function has been transformed from a twentieth century analog technology base to the constant use of digital technology for communications, monitoring (e.g., sensing), computation, and control. In a smart grid, much of the intelligence and situational awareness necessary to understand the state of the grid and to maintain safe, secure, efficient, and reliable operation of the grid reside within the grid's digital information infrastructure itself. The smart transmission network involves enhancement for self monitoring, self healing and the flexibility and certainty of the distributed generator and demand abilities to control the real time information and critical components for smart grid consents. The use of real time measurements as critical component of the smart grid requires tools and techniques such as phasor measurement units (PMU) or synchro phasors as well as state estimation for analysis of stability, reliability and efficiency. Mainly the smart grid in case of transmission system helps us to asset management in HVDC and UHVAC and etc. and in case of system operations self healing grids and etc. Smart grid technology slowly but surely becoming a corner stone in the future power system network.
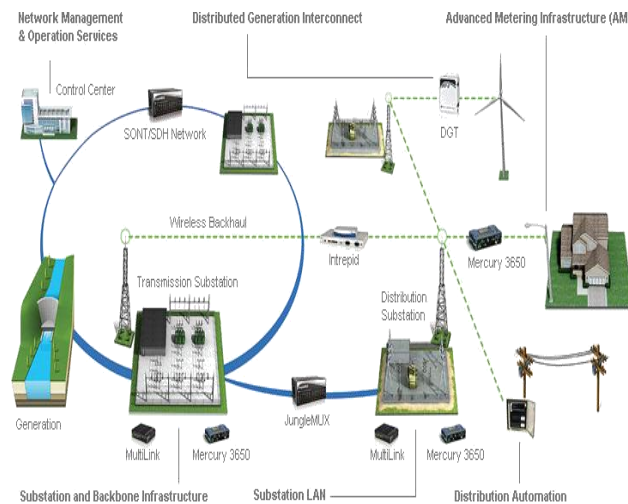

Fig: 1. Smart Transmission Architecture

A. Introduction : This vision of the smart transmission networks is built on   the existing electric transmission infrastructure. However, the emergence of new technologies, including advanced materials, power electronics, sensing, communication, signal processing, and computing will increase the utilization, efficiency, quality, and security of existing systems and enable the development of a new architecture for transmission networks.

B. High-Efficiency and High-Quality Transmission Networks :

In the concept of smart transmission networks, ultrahigh-Voltage, high-capacity transmission corridors can link major regional interconnections. It is thus possible to balance electric supply and demand on a national basis. Within each regional interconnection, long-distance transmission is accomplished by using controllable high-capacity ac and dc facilities. Underground cables are widely used when overhead lines are not practical, mostly in urban and underwater areas. Advanced conductors, including high-temperature composite conductors for overhead transmission and high-temperature superconducting cables, are widely used for electricity transmission. These conductors have the properties of greater current-carrying capacity, lower voltage drops, reduced line losses, lighter weight, and greater controllability. In addition, new transmission line configurations, e.g., 6- or 12-phase transmission line configurations, allow for greater power transmission in a particular right-of-way with reduced electromagnetic fields due to greater phase cancellation [17]

C.*Flexible Controllability, Improved Transmission Reliability and Asset Utilization Through The Use Of Advanced Power Electronics* :In a smart transmission network, flexible and reliable transmission capabilities can be facilitated by the advanced Flexible AC Transmission Systems (FACTS), high-voltage dc (HVDC) devices, and other power electronics-based devices. FACTS devices (including traditional large-scale FACTS and new distributed FACTS devices [18]–[20]) are optimally placed in the transmission network to provide a flexible control of the transmission network and increase power transfer levels without new transmission lines. These devices also improve the dynamic performance and stability of the transmission network. Through the utilization of FACTS technologies, advanced power flow control, etc., the future smart transmission grids should be able to maximally relieve transmission congestions, and there fully support deregulation and enable competitive power markets. In addition, with the trend of increasing penetration of large scale renewable/alternative energy resources, the future smart transmission grids should be able to enable full integration of these resources. HVDC lines are widely used to provide an economic and controllable alternative to ac lines for long distance and high-capacity power transmission and integration of large wind farms. Power electronics-based fault current limiters or current limiting conductors [19], [21] may achieve maximum utilization of line and system capacity, increased reliability, and improved system operation under contingencies. Solid-state transformers are used to replace traditional electromagnetic transformers to provide flexible and efficient transformation between different voltage levels [22].

D.*Self –Healing and Robust Electricity Transmission :*Smart transmission networks will extensively integrate advanced sensing, signal processing, and communication technologies to monitor operating conditions of transmission lines, transformers, and circuit breakers in real time [24], [25].A cost-effective distributed power line condition monitoring system [26], based on a distributed power line wireless sensor net in which each distributed intelligent sensor module incorporates with advanced signal processing and communication functions, is able to continuously measure line parameters and monitor line status in the immediate vicinity of the sensor that are critical for line operation and utilization, including measurement of overhead conductor sags, estimation of conductor temperature profile, estimation of line dynamic thermal capacity, detection of vegetation in proximity to the power line, detection of ice on lines, detection of galloping lines, estimation of mechanical strength of towers, prediction of incipient failure of insulators and towers, identification of the critical span limiting line capacity, and identification of the fault location of the line.

E.Advanced Transmission Facility Maintenance : In the smart transmission networks, live-line maintenancecan be used to clean and deice conductors, clean and lubricate moving parts that open and close, replace spacer/dampers, disconnect/connect breakers, tighten or replace bolts, and install sensors and measuring devices. Advanced maintenance and power line condition monitoring technologies allow for prioritized equipment ranking, condition based maintenance, prevention programs, smart equipment replacement programs, and right-of-way maintenance. This reduces catastrophic failures and maintenance costs, and improves the overall reliability of the transmission system [27].

F. Extreme Event Facility Hardening System : An extreme event facility hardening system is able to identify potential extreme contingencies that are not readily identify able from a single cause, develop various extreme event scenarios (e.g., floods, extreme weather, etc.), develop modular equipment designs for lines and novel system configuration to manage failures, and enable rapid system restoration under catastrophic events [27].

III. TRANSIENT STABILITY ANALYSIS OF 3-PHASE/6-PHASE SYSTEM

Stability studies provides information related to the capability of a power system to remain in synchronism during the disturbance resulting the loss of generating or transmission facilities ,sudden or sustained load changes, or movement faults. Specifically these studies provide the change in the voltages, currents, powers, speed & torques of the machines of the power systems, as well as the changes in system voltages and power flows, during immediately following a disturbance. The degree of the stability of a power system is an important factor in the planning of the new facilities. In order to provide the reliability required by the dependence on continuous electric service, it is necessary that power systems be designed to be stable under any conceivable disturbance. According to the disturbance occurred in the power system, the stability may classify in to three types:

[1] Steady state stability
[2] Transient stability
[3] Dynamic stability

Steady state stability refers to the ability of the power system to regain synchronism after small disturbances, such as gradual power changes. Dynamic stability is an extension of the steady state stability. The dynamic stability is concerned with small disturbances lasting for a long time. With the inclusion of automatic control devices. Dynamic stability can be significantly improved through the use of the power system stabilizers. Dynamic system study has to be carried out for 5-10 sec and sometimes up to 30 sec. Transient stability studies deals with the effect of the large, sudden disturbances such as the occurrences of a fault, the sudden outage of a line or the sudden application or removal of loads. Seven essential factors affecting the stability.

- Prime mover input torque
- Inertia of the prime mover and generator.
- Inertia of motor and shaft load.
- Shaft load output torque.
- Internal voltage of synchronous generator.
- Internal voltage of synchronous generator.
- Reactance of the system including generator, line and motor factors.
- Internal voltage of synchronous motor.

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-wye three-phase transformers connected at each end of the line as shown in Fig. 2. One of each pair of transformer has reverse polarity to obtain the required 60° phase shift. [29].
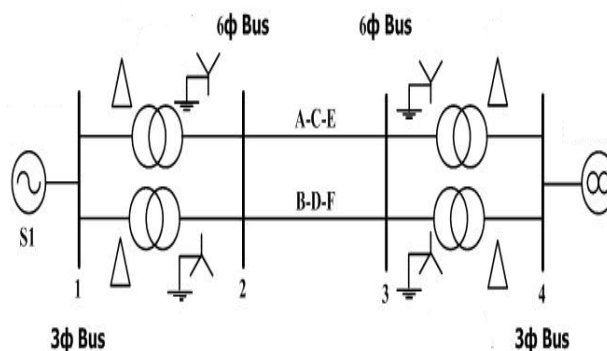

Fig.2. One-line diagram of converted double-circuit three phase transmission line to six-phase line.

For the conversion of 6-phase from the 3-phase double circuit line, the following changes and calculations are to be made: In 3-phase double circuit line the two winding transformer is replaced by 3 winding transformer and the values of the equivalent reactance of the 3-winding transformer for 6phase are found by conducting short circuit tests on the set of 3- windings of the 3-winding transformer. The transmission line of 6-phase line will be proved as 90% of that of the 3phase double circuit line, when the same 3-phase double circuit line is converted in to 6-phase line without altering the transmission towers and using the same corridors and same rights of way. There are 120 possible fault combinations in a six-phase system. And there are 23 combinations with distinct fault levels and phase interconnections [30].
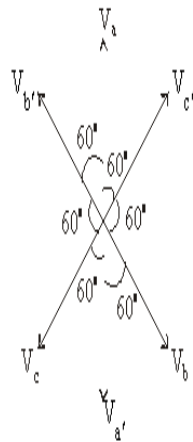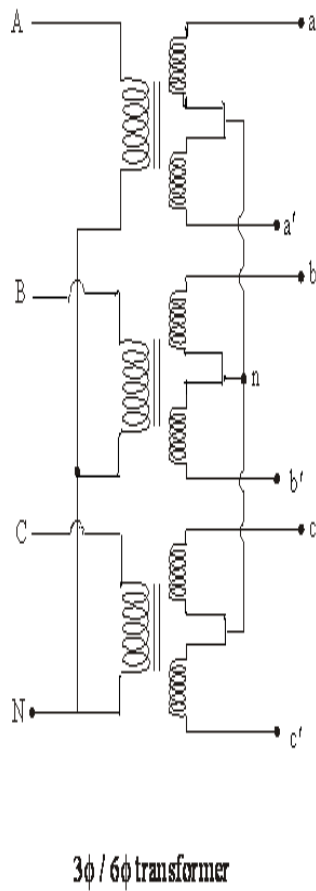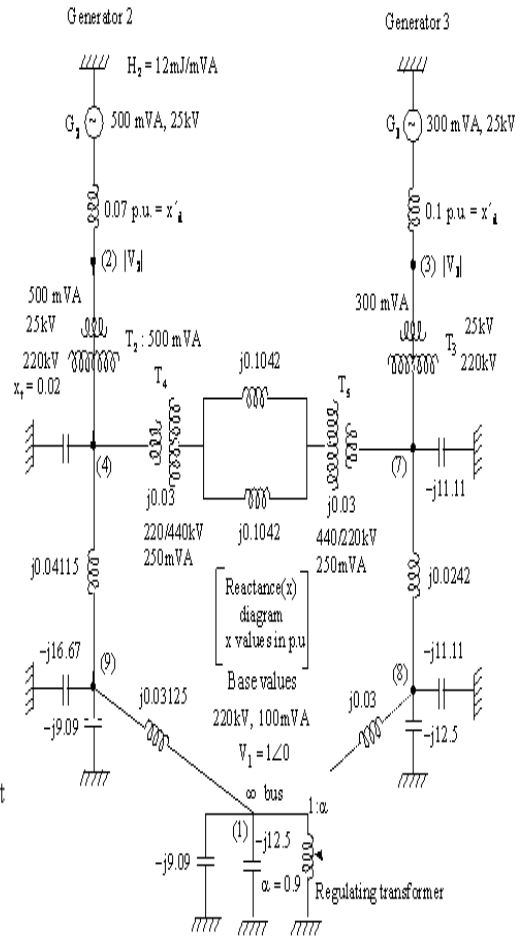
Fig.3.Six phase Vector diagrams

Fig. 4: 9 bus single line diagram with one slack bus,
Bus number 1 = slack bus
Bus number 2 & 3 = Generator buses
Bus number from 4 to 9 = Load buses

Vector diagrams showing phase and line voltages in six phase systems Phase and line voltage relations: Consider V line between V_a and V_c. Then from the above fig:

$$\mathbf{V}_{line} = \mathbf{V}_a - \mathbf{V}_c' = |\mathbf{V_a}| = |\mathbf{V_1'}| = \mathbf{V}_{ph}$$

From equilateral triangle M N K
Since MN = KN = V_{ph} and the line voltage
$V_{line} = V_L = V_{ph}$
□ $V_L = V_{ph}$ for 6 phase system

A simple three-phase consisting of two generators, five transformers including one regulating transformer and five transmission lines resulting in a 9 bus system shown in fig 4, Is considered. Different symmetrical and unsymmetrical faults at Bus five are assumed and the transient stability of the system is analysed with three phase double circuit lines and the equivalent converted six-phase lines of that system [31].

RESULTS OF 3-PHASE/6-PHASE SYSTEM FOR SYMMETRICAL &UNSYMMETRICAL FAULTS

Table.1   Results showing t$_{cr}$, δ_{cr} & (δ_{cr} - δ_0) for SLG fault cases. where δ_0 = initial load angle.

S.No	Fault	Type of Switching	Gen	Line	t$_{cr}$ sec's	(δ_{cr}- δ_o) Ele.Deg
1	SLG	Single pole	G2	Three-phase	0.25	24.6
2	SLG	Single pole	G2	Three/Six-phase	0.32	35.8(more)
3	SLG	Single pole	G3	Three-phase	0.28	30.4
4	SLG	Single pole	G3	Three/Six-phase	0.35	41.6(more)
5	SLG	Three pole	G2	Three-phase	0.22	17.8
6	SLG	Three pole	G2	Three/Six-phase	0.31	33.4(more)
7	SLG	Three pole	G3	Three-phase	0.26	24.8
8	SLG	Three pole	G3	Three/Six-phase	0.34	40.4(more)

Table.2. p.u. values of Voltages and loads at different buses based on 220KV, 100MVA.

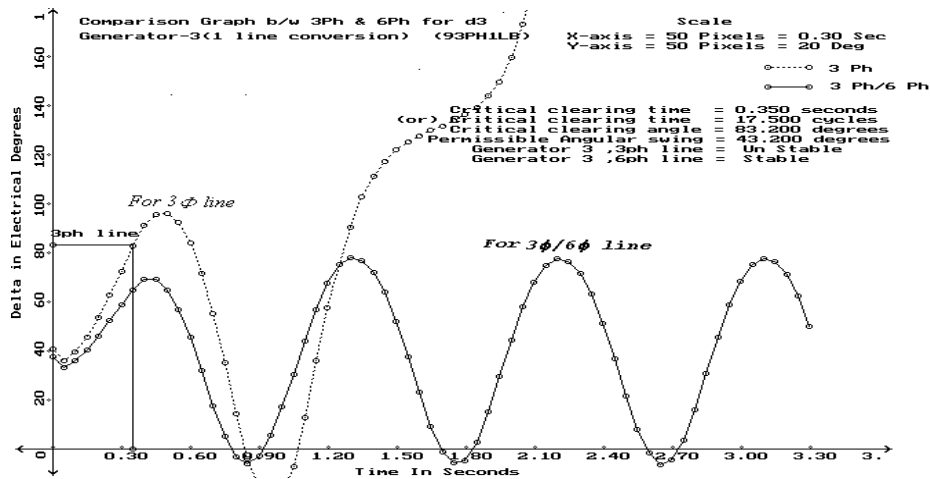| Bus No	Bus type	Voltage in polar form $V\angle\delta$	Generation		Load	
			P$_g$	Q$_g$	P$_L$	Q$_L$
1	Swing (or) slack bus	1	-	-		
2	PV (or) Generator bus	0.884	3	-		
3	PV (or) Generator bus	0.7395	2.9	-		
4	PQ (or) Load bus	-	-	-	1.4	0.6
5	PQ (or) Load bus	-	-	-	2.0	0.8
6	PQ (or) Load bus	-	-	-	1.2	0.5
7	PQ (or) Load bus	-	-	-	1.1	0.4
8	PQ (or) Load bus	-	-	-	0.5	0.2
9	PQ (or) Load bus	-	-	-	0.4	0.1

Fig.5. 9 Bus, 3- phase fault, when 1 line is converted In to 6 -phase at the beginning of the transmission line
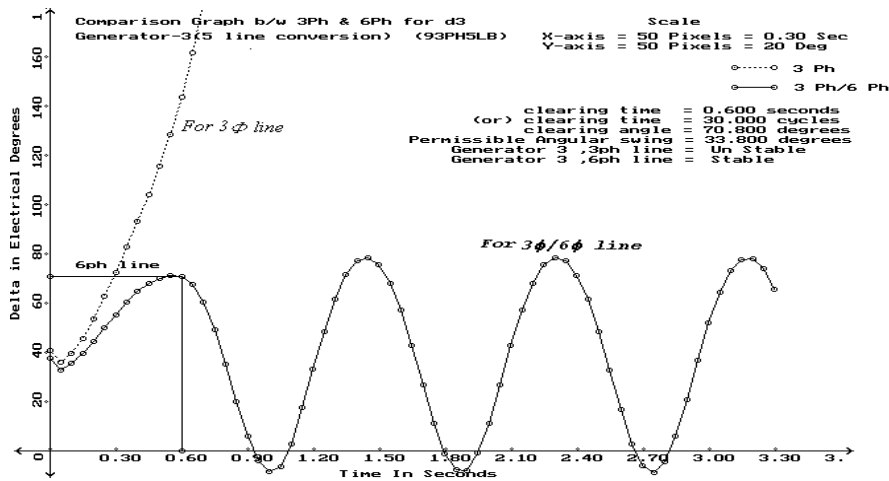

Fig.6.   9 Bus, 3- phase fault, when 5 lines are converted In to 6- phase at the beginning of the transmission line.
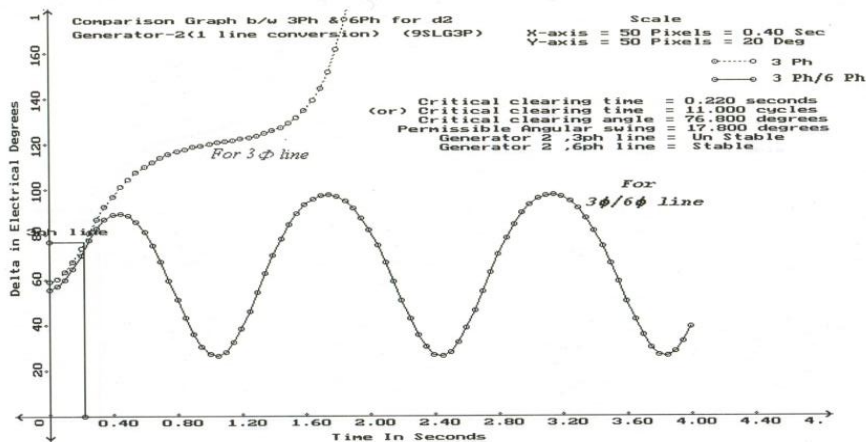

Fig.7. comparison graph between 3-phase line and 3-phase/6-phase line for 1-line of δ of generator- 2 for 1-line conversion for critical clearing time 0.22sec for SLG fault

IV. CONCLUSION

The proposal of integration of smart grid and six phase transmission network for monitoring and optimizing the electric transmission system with more transient stability provides the solution for some of the main problems faced by the existing grid system, such as wastage of energy, power theft, and manual billing system, and transmission line fault, power transfer capability. In future, if we plan to implement this design and validate it in our transmission system along with all these new architectural components, it can be used for optimizing the energy consumption. This method will improve the power transfer capability along with better transient stability, less radio interference etc, mentioned .The integration of smart grid and six-phase definitely improves the reliability of transmission of power reducing the power interruptions and better efficiency, stability etc.

V. ACKNOWLEDGEMENTS

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