2011 International Conference on Signal, Image Processing and Applications
With workshop of ICEEA 2011
IPCSIT vol.21 (2011) © (2011) IACSIT Press, Singapore

Modelling and Voltage Stability Enhancement of IEEE 14 Bus System Using "Sen" Transformer

M.Arun Bhaskar, M.Mahesh, Dr.S.S.Dash, M.Jagadeesh Kumar, C.Subramani

EEE Department, Velammal Engineering College, Chennai, Tamilnadu, India

m.arunbhaskar@gmail.com, maheshmatu@gmail.com

Abstract. The Paper illustrates the use of MAT LAB package for the modeling of standard IEEE 14 bus system. The dynamic behavior of the system is learned by testing the basic system under large and small disturbances. The stability margins associated with different configurations of the system are observed. To show the effect of controller on the stability margins under these disturbances, SEN transformer is added, modeled and tested.

Keywords: voltage stability, "Sen" transformer, IEEE 14 bus system, modelling, simulation.

1. Introduction

A. Voltage Stability

Voltage stability refers to ''the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition'' (IEEE-CIGRE, 2004). If voltage stability exists, the voltage and power of the system will be controllable at all times. In general, the inability of the system to supply the required demand leads to voltage instability (voltage collapse).

The nature of voltage instability phenomena can be either fast (short-term, with voltage collapse in the order of fractions of a second to a few seconds) or slow (long-term, with voltage collapse in minutes to hours) (IEEE-CIGRE, 2004). Short-term voltage stability problems are usually associated with the rapid response of voltage controllers (e.g., generators' automatic voltage regulator [AVR]) and power electronic converters, such as those encountered in flexible AC transmission system or FACTS controllers and high voltage DC (HVDC) links. In the case of voltage regulators, voltage instability is usually related to inappropriate tuning of the system controllers. Voltage stability in converters, on the other hand, is associated with commutation issues in the electronic switches that make up the converters, particularly when these converters are connected to ''weak'' AC systems, i.e., systems with poor reactive power support.

2. Introduction to Sen Transformer

Electric power flow through an AC transmission line is a function of the line impedance, the magnitudes of the sending-end voltage (**Vs**) and the receiving-end voltage (**Vr**), and the phase angle (_) between these voltages. Figure 9-1 shows a simple transmission line represented with only a reactance (*X*) and the related expressions for active and reactive power flows at the receiving end of the line.

Power flow control parameters (voltage magnitude, its phase angle, and line reactance) can be regulated with the use of the following, now considered conventional, equipment:

1. Voltage regulating transformer (VRT), shunt or parallel-connected switched inductor/ capacitor, static var compensator (SVC), or static synchronous compensator (STATCOM) for voltage regulation

2. Phase angle regulator (PAR) or phase shifting transformer (PST) for phase angle regulation

3. Thyristor-controlled series capacitor (TCSC) for series reactance regulation.

By regulating any one of the power flow control parameters using one of the above conventional solutions, both the active and reactive power flows in the transmission line are affected simultaneously.

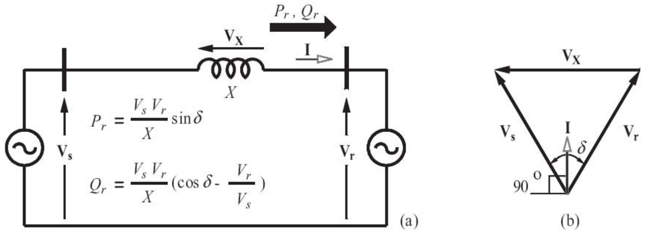

Fig 1. (a) Power transmission system (b) Phasor diagram

Consider that the point of compensation in the transmission line is at its sending end. Assuming that there are no changes in the transmission line's impedance and the voltage at the receiving end, a power flow controller (PFC) can control the active and reactive power flows (*Pr* and *Or*) to be a particular pair of values by modifying the sending-end voltage to a specific magnitude and phase angle. This can be accomplished by connecting a compensating voltage in series with the line using a shunt–series power converter. The shunt–series-type converters have been installed in several locations to be used as unified power flow controllers (UPFCs). A ±160 MVA-rated UPFC demonstrated for the first time that the active and reactive power flows in a transmission line could be regulated independently while maintaining a fixed line voltage at the point of compensation.

2.1 Working of Sen Transformer

A. Voltage Regulator

The VRT is an autotransformer, shown in Figure, that provides three-phase, bipolar compensating voltages (Vs_sA, Vs_sB, and Vs_sC). The uncompensated transmission line's three-phase sending-end voltages (VsA, VsB, and VsC) are regulated at Vs_A, Vs_B, and Vs_C when the compensating voltage is connected in series with the line at the point of compensation. Since the compensating voltage is a fraction of the line voltage, the rating of the autotransformer is only a fraction of the transmitted power. As shown in Figure the VRT operates as an autotransformer. The exciter unit consists of a three-phase (A, B, and C), Y-connected primary windings that are connected in shunt with the line. The three-phase primary windings are excited from the three-phase line voltages (VsA, VsB, and VsC). A three-phase, bipolar compensatingvoltages (Vs_sA, Vs_sB, and Vs_sC) that are either in phase or out of phase with the corresponding phase-to-neutral voltage are generated from the induced secondary voltages.

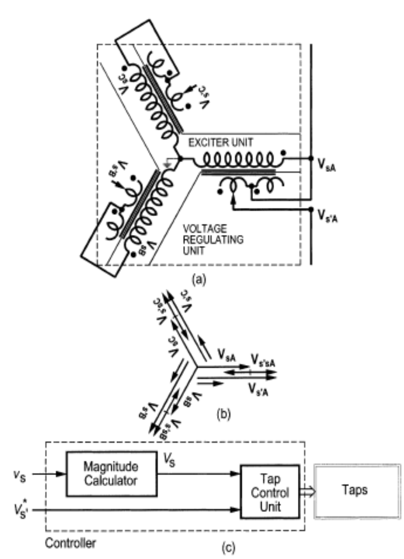

Fig 2. (a) Voltage regulator circuit, (b) Phasor diagram, (c) Controller

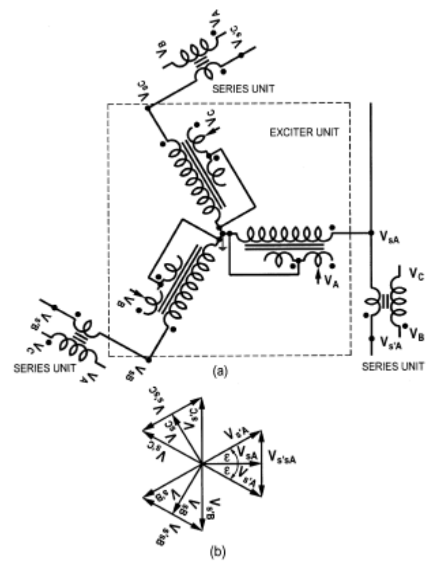

Fig 3. (a) Phase angle regulator circuit, (b) Phasor diagram

B. Phase *Angle Regulator*

A PAR connects a voltage in series with the transmission line and in quadrature with the phase-to-neutral voltage of the transmission line as shown in Fig.3 The series-connected compensating voltage introduces a phase shift whose magnitude (for small change) in radians varies with the magnitude of the compensating voltage in per units where the phase-to-neutral voltage of the transmission line is the base voltage. In a typical configuration, a PAR consists of two transformers as shown in Fig.3 The first transformer (exciter unit) is called a regulating transformer and is connected in shunt with the line. Its primary windings are excited from the line voltage ( ), and a three-phase bipolar voltage is induced in the secondary windings. With the use of taps, a compensating voltage ( ) with variable magnitude and in quadrature with the line voltage is generated from the phase-to-phase voltage of the induced voltage of the regulating transformer. For series connection of this voltage, an electrical isolation is necessary. The second transformer (series unit) is called a series transformer and is excited from the phase-to-phase voltage of the regulating transformer.

The induced voltage of the series transformer is connected in series with the line.If the series transformer is a step-down transformer, the primary windings of the series transformer as well as the secondary windings of the regulating transformer are high-voltage-rated and low-current-rated so that the taps on the secondary side of the regulating transformer can operate at a low current and can ride through a high fault current. Please note that a PAR can be realized with a single-core transformer as well. In this case, the taps are always subject to carry high line current as well as even higher fault current.

2.2. Modeling of Sen Transformer

A digital computer simulation model of the ST has been developed using mat lab. The model consists of two subsystems: the electrical subsystem and the tap-selection algorithm subsystem.

A. Electrical System

The electrical system is comprised of two ac systems connected by a three phase transmission line. The ST is connected at the sending end of the transmission line. Table I gives the parameters for both the ST and the network.

1) Electrical Network Model: The ac sources at both sending and receiving ends are modeled as infinite sources with the same magnitude but at a phase difference of 20 (the receiving end voltage lags the sending end voltage). The transmission line is modeled as lumped series impedance.

2) ST Model: The ST is a specially designed transformer with multiple windings having multiple tap positions in the secondary. The model for such a transformer is not available in mat lab. Therefore, nine single-phase transformers, each have on-load tap changing capability have been used to model the ST. Use single-phase transformers, inter-phase. Mutual flux linkage and thus mutual inductance has not been considered, which may cause some discrepancies in the results. These nine single-phase transformers are modeled with a small resistance and leakage reactance as shown in Table I. Output voltages of three transformers (contributing from phase , and) are added in series and then fed to one phase of the transmission line. The nine outputs (*aa, ab, ac, ba, bb, bc, ca, cb,* and *cc*) from the tap-selection algorithm supply the value of tap setting to all nine transformer Tap terminals. Should these outputs undergo any changes; the transformers readjust their tap positions and produce the required compensating voltages.

3) Tap Changer Model: In a practical transformer, tap changing is performed through a tap selector, where a resistor or inductor is used in parallel with the tap positions to limit the current through a shorting winding segment between two consecutive taps. In Fig. 2, an example of tap-changing operation has been shown along with the equivalent mat lab model for each position of the tap selector. Although, practical transformers with on load tap changers (OLTC), such as the ones from Reinhausen [8] use taps with voltage difference in the range of 0.02 p.u. to 0.067 p.u., in this model a voltage difference of 0.1 p.u. between taps has been assumed for theclarity of simulation. The time required to move the tap selector between adjacent tap positions is 2 s [8]. In order to move the tap selector from its initial position, terminal E (0.2 p.u.) to its final position, terminal C (0.1 p.u.), the following four steps of approximately 0.5 s each are performed.

3. Testing

A. Modeling of IEEE *14 Bus System*

A single line diagram of the IEEE 14-bus standard system extracted from [1] is shown in figure 4. it consists of five synchronous machines with IEEE type-1 exciters, three of which are synchronous compensators used only for reactive power support. There are 11 loads in the system totalling 259 mw and 81.3 mvar. The dynamic data for the generators exciters was selected from [2].

The IEEE 14-BUS was studied using the Mat lab programs to obtain the system P-V curves and perform time domain and eigenvalue analyses to study the general performance of the system. Sen Transformer controllers is added to the system study their effect in the system and their interactions. The model details are discussed in the following sections. First, the synchronous generator modelling is done and then the load modelling is done.

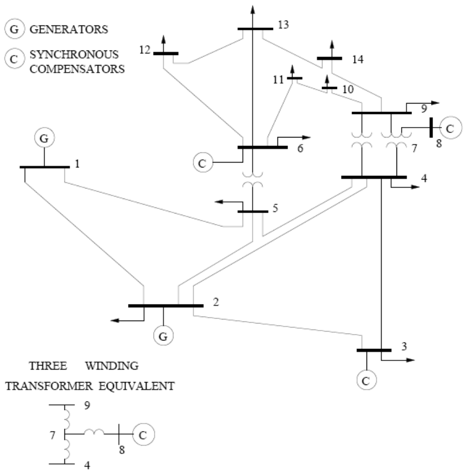

Fig4. IEEE 14 Bus Systems

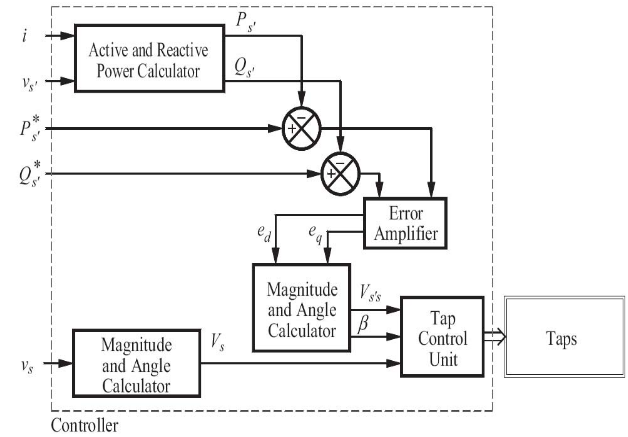

Fig5. Block diagram modelling

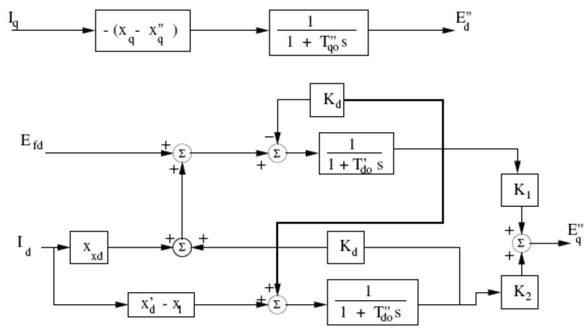
Fig6. Block diagram for the sub transient machine mode

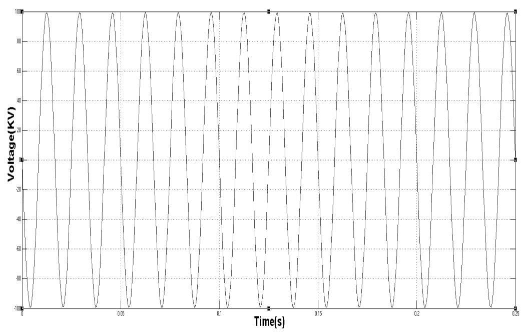

Fig7 Voltage during normal condition

4. Simulation and Results

A. Base Test Performance

Newton Raphson Load Flow is performed for a standard IEEE 14 bus system and the bus voltages of all the 14 buses are found out. Now, the loading at any of the bus is increased gradually and the bus voltages are calculated each time. When the loading at the 6^{th} bus is increased from 11 MW to 95 MW, the bus voltage at the 14^{th} bus dropped below the stipulated value (ie 0.9 PU). Thus it is found out to be the weak bus and the Sen Transformer has to be connected at that bus to improve the stability of the system.

Voltage at 14^{th} bus during normal condition = 99 KV

Voltage at 14^{th} bus during overload condition = 85.5 KV

B. Effect of Sen Transformer

A Sen Transformer is modeled and added to the 14^{th} bus of the Base system. During overload condition the bus voltage falls below 90 KV which is abnormal. Now the bus voltage is calculated after connecting the Sen Transformer at the 14^{th} bus.

Voltage at the 14^{th} bus after connecting Sen Transformer during overload condition = 97 KV

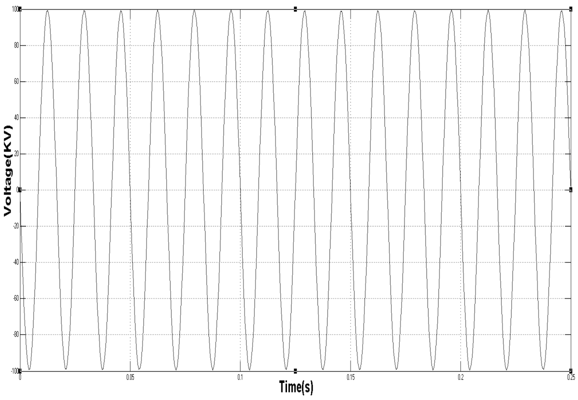

Fig 8 Voltage during overload condition

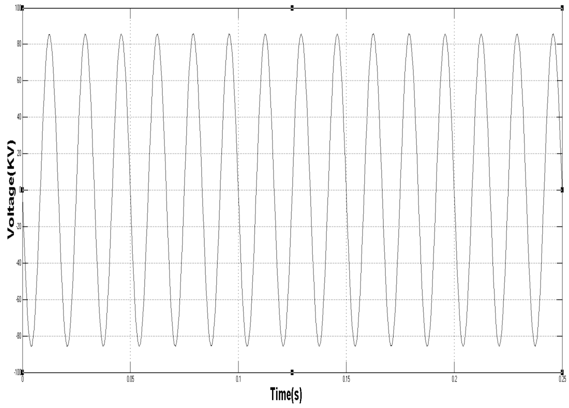

Fig 9 Voltage at 14th bus after connecting Sen Transformer

5. Conclusion

The modeling of standard IEEE 14 bus system has been done using mat lab package .the dynamic behavior of the system was learned by testing the basic system under small disturbances the stability margins associated with different configurations of the system were observed. . as part of the analysis to increase stability margins of the system sen transformer was added ,modeled and tested to show the effect of controller on the stability margins under both small and large disturbances. In conclusion significant improvement in voltage is shown as by the stimulation of IEEE bus test system.

6. References

[1] C. A. Ca˜nizares and Z. T. Faur, “Analysis of SVC and TCSC Controllers in Voltage Collapse,” IEEE Trans. on Power Systems, vol. 14, no. 1, February 1999, pp. 158–165.

[2] C. A. Ca˜nizares. “Power Flow and Transient Stability Models of FACTS Con trollers for Voltage and Angle Stability Studies”. In Proc. of IEEE/PES Winter Meeting, Singapore, January 2000.

[3] G. Hingorani and L. Gyugi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. IEEE Press, 1999.

[4] C. A. Ca˜nizares, UWPFLOW: Continuation and Direct Methods to Locate Fold Bifurcation in AC/DC/FACTS Power Systems. University of Waterloo, November 1999. Available at http://www.power.uwaterloo.ca.

[5] Power System Toolbox Version 2.0: Load Flow Tutorial and Functions. Cherry Tree Scientific Software, RR-5 Colborne, Ontario K0K 1S0, 1991-1999.

[6] K. K. Sen and M. L. Sen, Comparison of the ‘Sen’ Transformer with the Unified Power Flow Controller, IEEE Trans. Power Delivery, vol. 18, no. 3, pp. 1523−1533, Oct. 2003.

[7] K. K. Sen and M. L. Sen, Introducing the Family of ‘Sen’ Transformers: A set of Power Flow Controlling Transformers, IEEE Trans. Power Delivery, vol. 18, no. 1, pp. 149−157, Jan. 2003.

[8] K. K. Sen and A. J. Keri, Comparison of Field Results and Digital Simulation Results of Voltage-Sourced Converter-Based FACTS Controllers, IEEE Trans. Power Delivery, vol. 18, no. 1, pp. 300−306, Jan. 2003.

[9] N. G. Hingorani and L. Gyugyi, Understanding FACTS- Concept and Technology of Flexible AC Transmission Systems. Piscataway, NJ: IEEE Press, 2000.

[10] B. A. Renz, A. Keri, A. S. Mehraban, C. Schauder, E. Stacey, L. Kovalsky, L. Gyugyi, and A. Edris, “AEP unified power flow controller performance,” IEEE Trans. Power Del., vol. 14, no. 4, pp. 1374–1381, Oct. 1999.

[11] “Load Tap Changer, Type RMV-A,” Reinhausen Manufacturing, instruction manual, TL 800