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Research Paper

POWER SYSTEM TRANSIENT STABILITY IMPROVEMENT OF TWO MACHINE SYSTEM USING FUZZY LOGIC CONTROLLED STATCOM

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A static synchronous compensator is one of the FACTS devices used to improve the transient stability of the power system. Flexible AC Transmission System (FACTS) devices are found to be very effective in a transmission network for better utilization of its existing facilities without sacrificing the desired stability margin. The effect of STATCOM for improving the stability of the two machine power system at during fault condition is investigated. In this paper a Mamdani based Fuzzy logic controller is designed, and Simulation results show that STATCOM is effective in midpoint voltage regulation on transmission line. The study is thereby simulated using the MATLAB/SIMULINK software.

Keywords: Transient stability, FACTS, STATCOM, Fuzzy logic controller

INTRODUCTION

Modern electric power system is facing many challenges due to day by day increasing complexity in their operation and structure. In the recent past, one of the problems that got wide attention is the power system instability. With the lack of new generation and transmission facilities and over exploitation of the existing facilities geared by increase in load demand make these types of problems more imminent in modern power systems. Demand of electrical power is continuously rising at a very high rate due to rapid industrial development (Hingorani and Gyungi, 2000). To meet this demand, it is essential to raise the transmitted power along with the existing transmission facilities. The need for the power flow control in electrical power systems is thus evident. With the increased loading of transmission lines, the problem of transient stability after a major fault can become a transmission power limiting factor. The Power system should adapt to momentary system conditions, in other words, power system should be flexible. In an ac power system, the electrical generation and load must balance at all times up to some extent, the power

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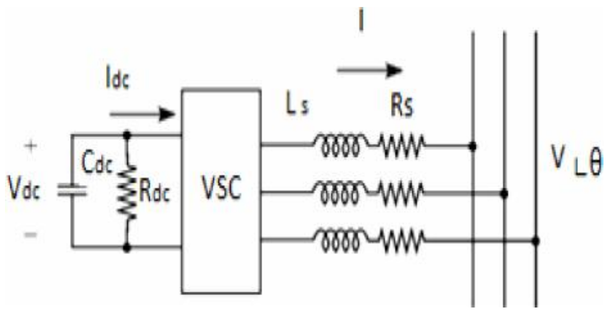
system is self regulating. If generation is less than load, the voltage and frequency drop, and thereby the load goes down to equal the generation minus transmission losses. But there are only a few percent margins for such a self Regulation. Hence there is chance of system collapse. Generator excitation controller with only excitation control can improve transient stability for minor faults but it is not sufficient to maintain stability of system for large faults occur near to generator terminals (Cong and Wang, 2002).

Thus, this requires a review of traditional methods and the creation of new concepts that emphasize a more efficient use of already existing power system resources without reduction in system stability and security. In the late 1980s, the Electric Power Research Institute (EPRI) introduced a new approach to solve the problem of designing and operating power systems the proposed concept is known as Flexible AC Transmission Systems (FACTS). The two main objectives of FACTS are to increase the transmission capacity and control power flow over designated transmission routes. FACTS are defined by the IEEE as a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability.

STATCOM CONTROLLER

A static synchronous compensator is one of the FACTS device operated on principle of reactive power compensation can use to improve the transient stability of the system by increasing (decreasing) the power transfer capability when the machine angle increases (decreases) (Laszlo Gyugi, 1994). Static synchronous compensator's three modes, i.e., capacitive mode, inductive mode and no load mode regulates voltage in transmission system. When Converter a.c. output voltage (Vc) > transmission system voltage (Vs), STATCOM considered to be in Capacitive mode and when Vs > Vc, STATCOM considered to be in inductive mode and in No-Load mode Vs = Vc, no reactive Power exchange takes place (Trainber *et al.*, 1994). STATCOM mainly comprise of step down transformer with leakage reactance, three phase GTO voltage source inverter and a dc capacitor voltage (Ekanayake and Jenkins, 1996). Figure 1 shows equivalent circuit diagram of STATCOM system (Yoon and Kin, 1996).

Figure 1: STATCOM's Basic Circuit Diagram



Voltage across capacitor, i.e., Vdc is given by the following equation,

$$C\frac{dv_{dc}}{dt}+Gv_{dc}=mk[\sin(\sim+\sim)][I_D+\cos(\sim+\sim)]I_Q \qquad ...(1)$$

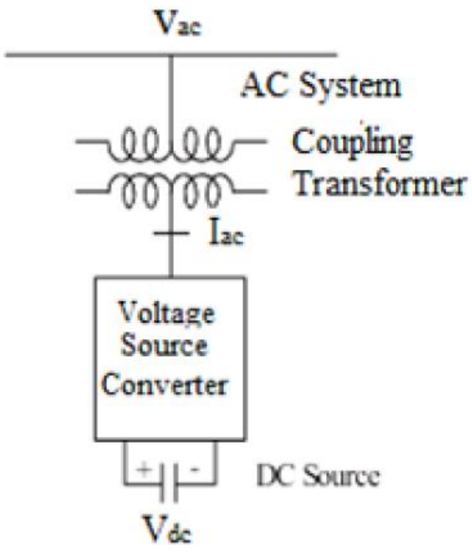
where *G* is conductance across the capacitor that represented losses in the capacitor while á and m are control variables of inverter which affected the magnitude and phase angle of the voltage injected by the inverter (Padiyar and Kulkarni, 1996). In STATCOM different technologies used dependent upon the power ratings of STATCOM. For higher power STATCOMs GTO based technologies are used while for lower power STATCOMs IGBT based technologies used (Nicolas Lechevin and Rajagopalan, 1998). In this paper GTO based technologies used. In GTO based static synchronous compensator m is normally kept constant and angle ~ is varied to control reactive power (Padiyar and Kulkarni, 1996). Amount of real power generated or absorbed by STATCOM depends upon the size of capacitor.

As compare to SVC, STATCOM provides a number of performance advantages for reactive power control applications because of its greater reactive current output capability at depressed voltage, faster response, better control stability, lower harmonics and small size, etc. (Chun Li Ohrang and Jiang Wang, 1998; and Moadders and Gole, 1999). In This paper a Mamdani based Fuzzy logic controller is designed. The inputs to the Fuzzy logic controller are the alternator speed and its derivative and output is firing angle ~ of the voltage source converter. The proposed controller is tested on a two machine power system under Matlab Simulink Environment.

OPERATING PRINCIPLE OF STATCOM

STATCOM is made up of a coupling transformer, a VSC and a dc energy storage device. STATCOM is capable of exchanging reactive power with the transmission line because of its small energy storage device, i.e., small dc capacitor, if this dc capacitor is replaced with dc storage battery or other dc voltage source, the controller can exchange real and reactive power with the transmission system, extending its region of operation from two to four quadrants. A functional model of a STATCOM is shown in Figure 2.

Figure 2: Functional Model of STATCOM



The relationship between fundamental component of the converter ac output voltage and Voltage across dc capacitor is given as

$$V_{out} = kV_{dc} \quad ...(2)$$

where k is coefficient which depends upon on the converter configuration, number of switching pulses and the converter controls. The fundamental component of the converter output voltage, i.e., V_{out} can be controlled by varying the dc voltage across capacitor which can be done by changing the phase angle ~ of the operation of the converter switches relative to the phase of the ac system bus voltage. The direction of flow of reactive power whether it is from coupling transformer to the system or from system to the coupling transformer depends upon the difference between the converter output voltage and the ac system bus voltage. The real power flowing into the converter supplies the converter losses due to switching and charges the dc capacitor to a satisfactory dc voltage level. The capacitor is charged and discharged during the course of each switching cycle but in steady state, the average capacitor voltage remains constant. If that were not the case, there would be real power flowing into or out of the converter, and the capacitor would gain or lose charge each cycle. In steady state, all of the power from the ac system is used to replenish the losses due to switching.

The STATCOM's ability to absorb/supply real power depends on the size of dc capacitor and the real power losses due to switching. Whenever the dc capacitor and the losses are relatively small. The amount of real power transfer is also relatively small. This implies that the STATCOM's output ac current Iac, has to be approximately + 900 with respect to ac system voltage at its line terminals. Varying the amplitude of the converter three-phase output voltage Vout controls the reactive power generation/absorption of the STATCOM. If the amplitude of the converter output voltage Vout is increased above the amplitude of the ac system bus voltage Vac then the ac current Iac, flows through the transformer reactance from the converter to the ac system generating reactive power. In this case, the ac system draws capacitive current that leads by an angle of 900 the ac system voltage, assuming that the converter losses are equal to zero. The ac current flows from the ac system to the voltage-sourced converter if the amplitude of the converter output voltage is decreased below that of the ac system, and consequently the converter absorbs reactive power. For an inductive operation, the current lags the ac voltage by an angle of 90°.

Assuming again that the converter losses are neglected. If the amplitudes of the ac system and converter output voltages are equal, there will be no ac current flow in/out of the converter and hence there will be no reactive power generation/absorption the ac current magnitude can be calculated using the following equation

$$I_{ac} = \frac{V_{out} - V_{ac}}{X} \qquad ...(3)$$

Assuming that the ac current flows from the converter to the *ac* system. V_{out} and V_{ac} are the magnitudes of the converter output voltage and ac system voltage respectively, while X represents the coupling transformer leakage reactance. The corresponding reactive power exchanged can be expressed as follows:

$$Q = \frac{V_{out}^2 - V_{out} - V_{ac}\cos\sim}{X} \qquad ...(4)$$

V-I CHARACTERISTICS OF STATCOM

When the STATCOM is worked in voltage regulation mode, It implements the V-I Characteristics as shown in Figure 3. The V-I characteristics are depicted by the following equation:

$$V = V_{ref} + X_s.I \qquad ...(5)$$

where,

V = Positive sequence voltage

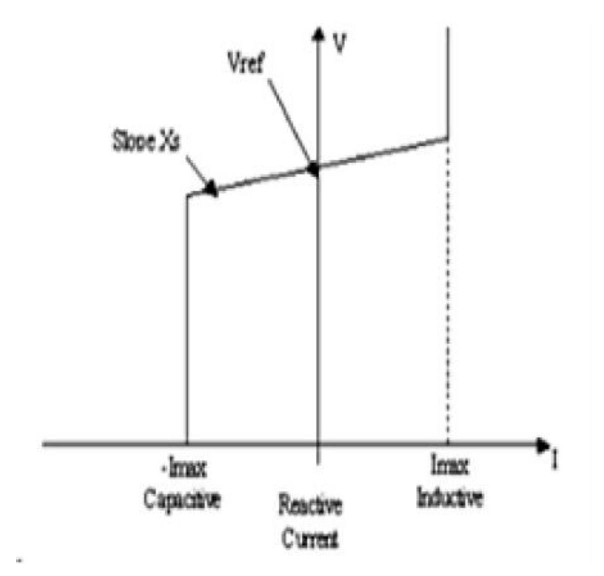
I = Reactive current (Pu/P_{norm})

($I > 0$ indicates an inductive current and $I < 0$ indicates capacitive current)

Xs = Slope (usually between 1% and 5%)

P_{norm} = Converter rating in MVA

Figure 3: V-I Characteristics of STATCOM

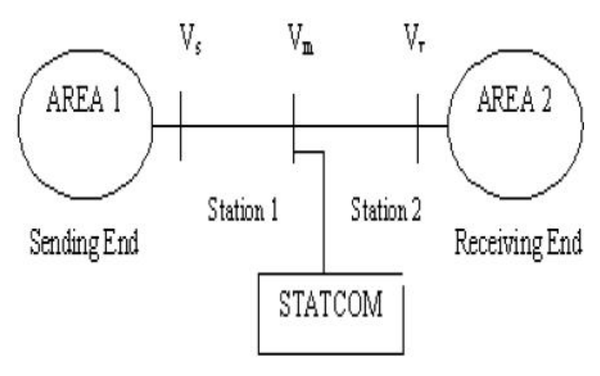


TWO MACHINE SYSTEM

Fig 4 shows single line diagram of two area system (area 1 and area 2). Area 1 (1000 MW hydraulic generation plant) connected to area 2 (5000 MW hydraulic generation plant) through 500 kV, 700 km transmission line.

Both plants fed to a load center, modelled by a 5000 MW resistive load. System is initialized so that line carries 950 MW which is close to its surge impedance loading. In order to maintain system stability Static synchronous compensator of 200 MVA is connected at midpoint of transmission line. By connecting it at midpoint the power transfers capability of system increases significantly (Yixin Ni and Mak, 1999; and Chen *et al.*, 2000).

Figure 4: Single Line Diagram of Two Area Interconnected System



FUZZY LOGIC CONTROLLER

Fuzzy modeling is the method of describing the characteristics of a system using Fuzzy inference rules. The method has a distinguishing feature in that it can express linguistically complex non-linear system. It is however, very hand to identify the rules and tune the membership functions of the reasoning. Fuzzy Controllers are normally built with Fuzzy rules. These Fuzzy rules are obtained either from domain experts or by observing the people who are currently doing the control.

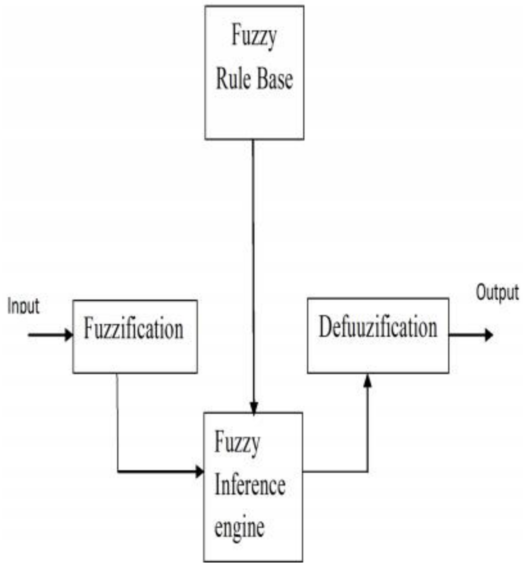
The membership functions for the Fuzzy sets will be derive from the information available from the domain experts and/or observed control actions. The building of such rules and membership functions require tuning. That is, performance of the controller must be measured and the membership functions and rules adjusted based upon the performance. This process will be time consuming.

The basic configuration of Fuzzy logic control based as shown in Figure 5. Consists of four main parts, i.e.

- Fuzzification,
- Rule base,
- Inference Engine, and
- Defuzzification

In Analytical approaches, Modelling and Control of Power Network requires

Figure 5: A Fuzzy System



mathematical equations/models. As power system models are highly non linear, number of assumptions need to be made before deriving mathematical equations (Pranesh Rao and Crow, 2000). Fuzzy Logic is one option by which one can get rid from above problem because Fuzzy logic is technique which deals with human reasoning that can be programmed in to Fuzzy logic language, i.e., is membership function, rules interpretation (Farsangi and Sang , 2002).

Function of fuzzification is mapping of input of Fuzzy logic, i.e., is crisp value in to Fuzzy variables by using membership functions while function of Fuzzy logic engine to infer the proper control actions based on given Fuzzy rules. Under defuzzification, control actions translated into crisp values by using normalized membership functions (Cong and Wang, 2002; and Liu *et al.*, 2003).

In this paper defuzzification of output signal is done by using centroid method. Fuzzy based Controller has been designed by taking generator speed and its derivative as input while angle alpha as output. The Fuzzy membership functions of these variables are as shown in Table 1.

Table 1: Fuzzy Rules

μ dw/dt	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	PM	PS	NB	NM	NS	Z	PM
NM	PS	NM	NM	NB	Z	Z	PS
NS	PM	NS	NS	Z	NM	PS	NS
Z	PB	Z	Z	Z	NM	PS	NM
PS	Z	Z	PM	NS	NS	PM	NS
PM	Z	PM	PM	PS	PB	PM	NS
PB	PM	PS	PM	PS	PM	PB	NS

The logic is that when frequency is high and its rising fast, the system is in critical condition because the input mechanical power of generators is more than output electrical power. Therefore the STATCOM should inject big capacitive current into the network hence alpha should be small (Amit Jain and Aman Behal, 2004). By this loaction the transmittable power capacity of the line on which STATCOM installed will be increased and the transient stability will be improved. Other conditions can be analyzed in a similar way.

SIMULATION

Simulink Model of two machines (M1 and M2) system,Each machine equipped with a Governor, excitation system and Power system stabilizer. These components are included in Turbine and Regulator 1 and Turbine and Regulator 2. Both machine connected through a 500 kv, 700 km transmission line. Resistive load of 5000 MW connected on Machine M2 side. GTO based STATCOM having rating of 200 MVA connected at midpoint of transmission line.

Given simulation model run for under discrete mode with sample time (Ts) set at 20 × 10^{-6}sec.

SIMULATION RESULTS

System Without Statcom

A three phase fault having clearing time of 0.1 sec is given at 0.2 sec. System installed without STATCOM becomes unstable on the fault time as shown by Figures 6 and 7.

Figure 6: Deviation of Rotor Angle with Time (Under Fault)

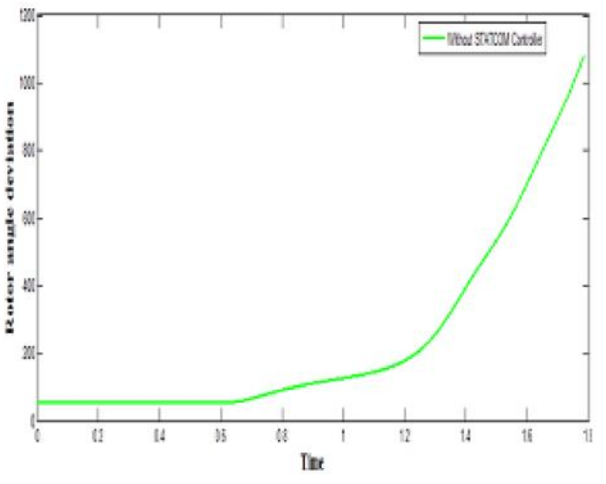
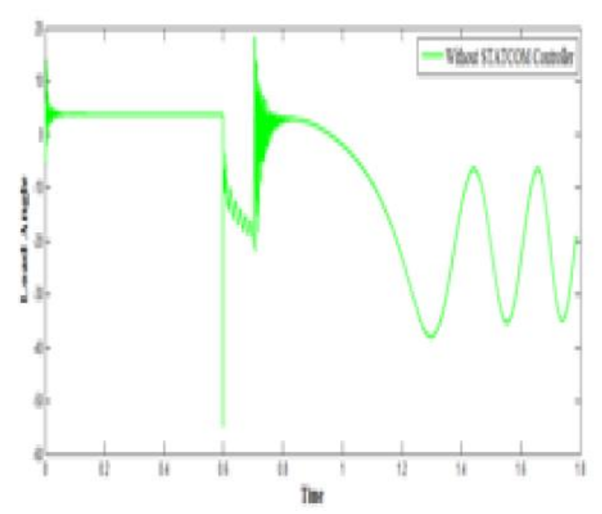


Figure 7: Load Angle with Time (Under Fault)



System Installed with Fuzzy Based Statcom Controller

Now system is installed with Fuzzy based STATCOM Controller and fault having clearing time of 0.1 sec is given during time period of 0.2 sec to 0.3 sec as shown in the Figures 8 and 9.

Figure 8: Rotor Angle Deviation with Time (After Clearing Fault)

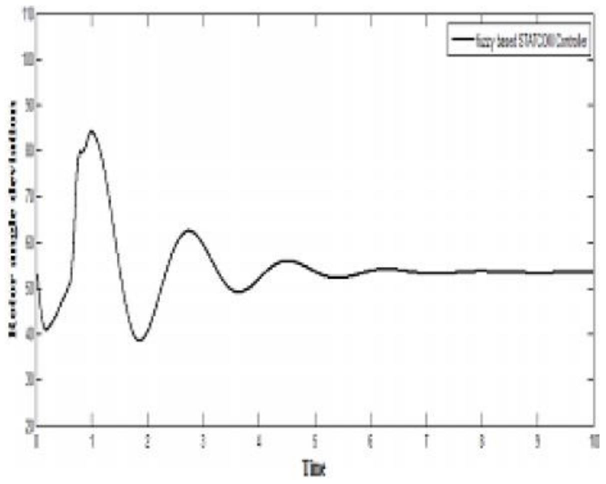
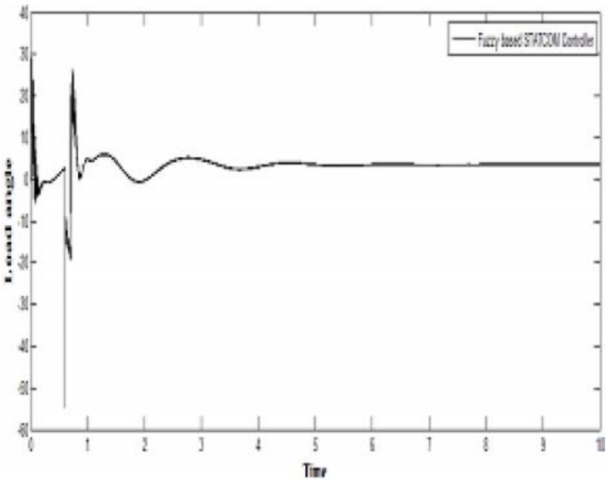


Figure 9: Load Angle with Time (After Clearing Fault)



The Figure10 shows that the voltage under fault conditions. When the three phase fault occurred at the transmission line, the system voltage gets unbalanced. Due to unbalance of the voltage, Transient stability, random variations of voltage magnitudes, mainly due to loads, and involving speed variations. To avoid these problems by installing the STATCOM at the midpoint of transmission line, the voltage will be get balanced and as possible to improve the transient stability and the system becomes stable as shown in Figure 11.

Figure 10: Three Phase Fault Voltage

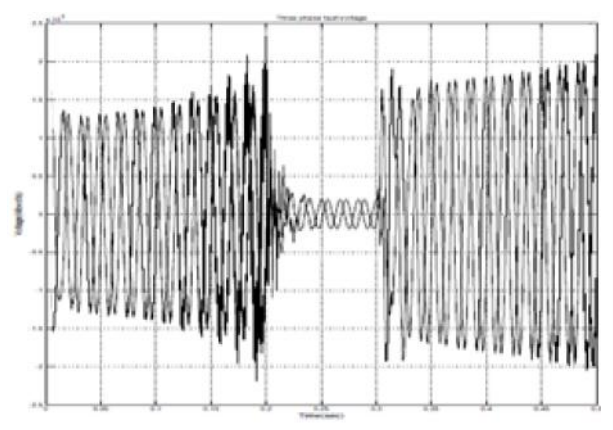
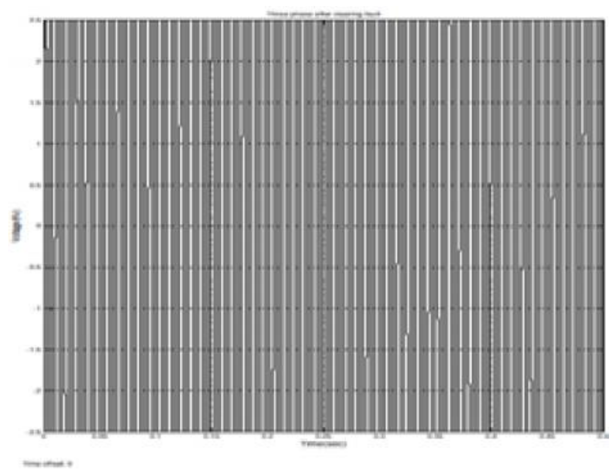


Figure 11: Three Phase Clearing Fault Voltage



CONCLUSION

In This Paper, Mamdani based Fuzzy logic controller is successfully designed to control the STATCOM for improving transient stability of the power system. Controller inputs are chosen carefully to provide better damping to the system and its range are determined by the simulation results of fuzzification process. Simulation results indicate that Fuzzy based STATCOM controller provides better transient stability and Simulation results indicated that the Fuzzy based STATCOM controller installed with two machine system provides better damping characteristics and provides improved transient stability.

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APPENDIX

Data for various components used in Matlab Simulink model of Figure 6 are as follows:

Generator Parameters

M1 = 1000 MVA,

M2 = 5000 MVA

V =13.8 KV, f = 60 Hz, Xd = 1.305, Xd' = 0.296,

Xd'' = 0.252, Xq = 0.474, Xq'' = 0.243,

X = 0.18, H = 3.7

Transformer Parameters

T1 = 1000 MVA, T2 = 5000 MVA

13.8/500 KV, Rm = Lm = 500 ohm

Transmission Line Parameters per km

$R_1 = 0.01755\ \Omega$, $R_0 = 0.2758\ \Omega$, $L_1 = 0.8737$ mH, $L_0 = 3.22$ mH, $C_1 = 13.33$ nF, $C_2 = 8.297$ nF.

STATCOM: 500 KV, 200 MVA, Vref = 1 V, Ts = 20×10^{-6}

Cp = Cm = 5000×10^{-6}

Science writers are Padiyar and Kulkarni (1996).