Impact of PSS and STATCOM on Dynamic Parameters of Power System Based on Neuro-fuzzy Controllers

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***Abstract*—This paper studies the impact of leveraging both static synchronous compensator (STATCOM) and power system stabilizer (PSS) on multi-machine power systems. Considering a standard IEEE 9-bus test power network, the classic and intelligent controllers are applied and analyzed to achieve a desirable system performance. Simulated tests show the usefulness of STATCOM on network power quality in terms voltage profile. In addition, it can significantly improve the damping oscillations of synchronous generator under normal and abnormal network conditions. The PSS also contributes to improving the synchronous generator parameters. It is also observed that using intelligent controllers with STATCOM and PSS leads to a better performance relative to the classic controllers.**

Keywords—STATCOM; PSS; power quality improvement; classic and intelligent controller

I. INTRODUCTION

With the increase in population and community development in the field of technology, the need for electrical energy consumption and more are also welcome [1]. But despite the increasing need for electrical energy and consumption of this clean energy, the mission of the network managers and manufacturers and distributors of electrical energy, is to deliver the energy in the highest quality [2]. In other words, with the increase in consumption and the need for electrical power, network must has high reliability and suitable forward looking to the time of the may be required [3,4]. Thus, in order to achieve such goals should have comprehensive information and studies on power network to make quite professional and accurate decisions in necessary times. In normal working conditions of the power system, various parameters in the delivery of electrical energy with a high level of quality are important. That can mention to bus voltage level, the loss of active network, freeing capacity increase of network load, etc., so that in order to deliver the energy in the desired level to the subscriber parameters should be located as standard [5].

In critical situations of network such as sudden withdrawal of large loads, symmetrical and asymmetrical short circuit faults, etc., there will be more difficult and complex situation. At first we must prevent from network instability (increase in power angle and the frequency oscillation amplitude) and after fixing the error and preventing a crisis, parameters such as Voltage fluctuations, the frequency and power angle can be destroyed or returned to the desired level [6]. In the production and transport, which are the two major networks part, and in order to improve the network in both normal and abnormal conditions of the network, FACTS devices were the most important devices that have been studied in several researches [7,8]. It can be mention to have dealt with the placement and amount of reactive power injection into the network devices [9,10] and FACTS devices controller [11,12], to reduce active power losses and raising the voltage. A review of the studies on the use of FACTS devices, shows their significant influence both in normal conditions and in conditions of transient network. Parallel FACTS devices such as STATCOM and SVC [13,14] in the supply of reactive power, intense voltage drop compensation and sustained improvement in severe transients and FACTS devices such as TCSC and SSSC series of dynamic stability improvements had significant and positive impact [15,16]. But while the FACTS device (series and parallel), given that a large-sized power switches (high power) and advanced manufacturing technology, in many cases were not economical. As a result, their most important influence in maintaining stability and power quality parameters improvement, is associated with their high costs of construction and installation. This makes it difficult for experts and network administrators to decide about construction and installation projects related to them. In traditional networks, even in today's networks with advanced equipment and control systems, the power system stabilizer (PSS) element is undeniable and very effective. Although this equipment is used in production units with synchronous generators, but a significant portion of the risks to the network eliminates or significantly reduced. In this context, have been many studies on the impact of PSS on power oscillation damping and frequency [17,18]. However, this equipment as well as other power network controllable equipment had various classic and nonlinear controller in some studies [19,20]. A significant part of the criteria for decision making in implementing the action plans, is obtained from the

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results of computer comparison simulations, in which one of the main characteristics of this article, is a comparison being studied as well as the equipment used and the type of control system analysis and comparative study was carried out and the intelligent controller used in this study was neuro-fuzzy controller optimized by ANFIS is done in MATLB software.

In this article, the 9-bus and 3-mashine power system as a test network in order to analyze the effect of STATCOM and PSS selected. Also in order to compare these two important equipment, at first the network was in a normal work situation and production units based on load studies have defined production. Then the network as a result of a three-phase short circuit fault faced severe voltage drop, swinging in frequency and power angle in generating units.

In order to evaluate the influence of each controller is used to control the equipment in each of the above scenarios, the (PI) classic controller and intelligent neuro-fuzzy in this paper is used. Presentation of this article is as follows: In the second part, the mathematical model is studied, including standard network matrix model in different modes, synchronous generator model, PSS and STATCOM model and etc. is offered. In the third part, the studied network and considering the mentioned scenarios simulated in MATLAB software. Finally, in section IV, according to the results in reviews, comparisons and conclusions will be made.

II. POWER SYSTEM MODEL

In order to analyze the issue in different scenarios and situations should be determined a mathematical model of the problem efficiently and fairly. The mathematical model of the standard network, synchronous generator, STATCOM, PSS, etc. are provided in this section.

A. IEEE 9-Bus Standard Network

The 9-Bus IEEE standard network, consisting of 3 generators, 3 PQ sets and 6 transmission line as shown in Fig. 1 which data lines, loads and generators in [21] is given. Since all scenarios and the effectiveness of different devices evaluations is done on the this network, the network must therefore be simulated with all its equipment so in terms of computation time, access to various parameters such as voltage, current, and apply different handlers for different devices simply happen. So the reduced-level admittance matrix method for the networks immolation is chosen. Generally in this method only the buses that are injected power into the network, are in the network's original equations. In other words, if we assume that the network equations generally are as:

$$\begin{bmatrix} I_1 \\ \vdots \\ I_9 \end{bmatrix} = \begin{bmatrix} Y_{11} & \cdots & Y_{19} \\ \vdots & \vdots & \vdots \\ Y_{91} & \cdots & Y_{99} \end{bmatrix} \begin{bmatrix} V_1 \\ \vdots \\ V_9 \end{bmatrix} \tag{1}$$

where column vector representing the current injection I buses, Y matrix represent admittance matrix and V vector is voltage in phasor mode network buses, only (1) to (3) buses are due to the presence of synchronous generator on this buses, are able to inject power (according to Fig.1) and the rest of the bus current is zero. Then (1) can be written only for buses which are able to inject power.

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = Y_{reduced} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \tag{2}$$

To solve this equations, 4-level Ranjcutay method is used by assuming to have initial condition of the buses current (based on load), buses voltage can be achieved in the first step (the first sampling time). After obtaining the buses voltage, generators equations are solved based on these voltages and calculate currents to get in the next phase voltages. This process continues until the last stage of solving these equations. It should be noted that this method for the short-circuit fault occurs in the network is also responsive and only admittance matrix in this situation will change.

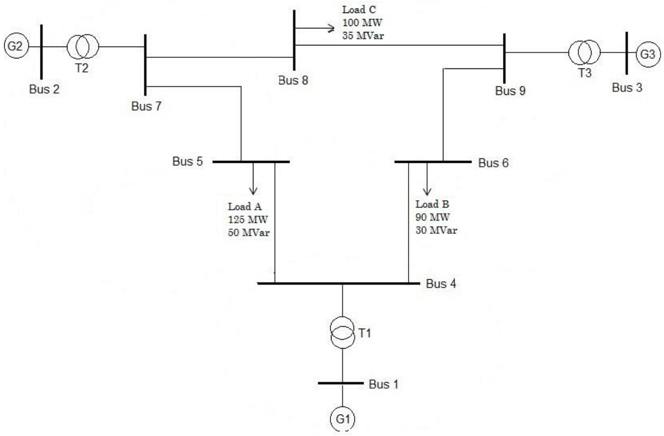


Fig. 1. One-line diagram of 9 Bus-IEEE standard network

B. Power System Stabilizer

The power system stabilizer (PSS) is widely used in existing power systems in order to contribute to the damping the low frequency oscillations [22,23]. A practical PSS must be robust over a wide range of operating conditions and capable of damping the oscillation modes in power system [24]. A PSS model is viewed as an additional control block to enhance system stability. A PSS contains three blocks [25]: the rest block, the washout filter and the phase-compensation. Some commonly used input signals are rotor speed deviation, accelerating power, and frequency deviation [26,27]. A common structure for PSS is reported in Fig. 2 [28].

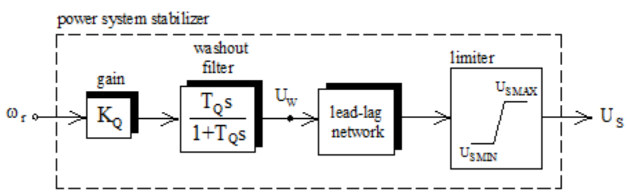


Fig. 2. One-line diagram of 9 Bus-IEEE standard network

C. Static synchronous compensator

A STATCOM is capable of injecting independently controllable reactive power into the system. It provide continuously variable reactive power at its point of connection with the grid [29]. STATCOM uses VSCs with capacitors connected on dc side. The configuration of a STATCOM connected to bus M of a transmission line is shown in Fig. 3. Basically it consists of a step-down transformer (SDT) with a leakage reactance X_{SDT}, a three phase voltage source converter (VSC) and a dc capacitor. The STATCOM is assumed to be based on pulse width modulation converters. The operation of STATCOM is fundamentally different from that of conventional SVC.

Two control signals are M (modulation ratio defined by PWM) and ϕ (phase angle defined by PWM). The dc capacitor (C_{DC}) has the function of establishing an energy balance between the input and output during the dynamic change of the var output. The reference signal Q_{REF} and P_{REF} can control the amplitude and phase angle of output voltage, respectively [30,31]. In general, a STATCOM system can be divided into three key parts: the converter power stage, the passive components and the control system [32,33].

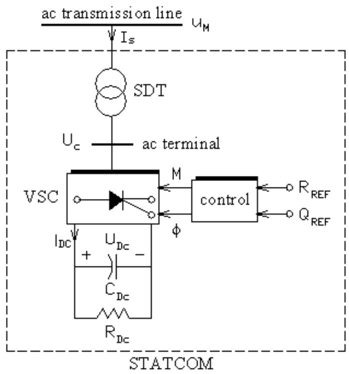
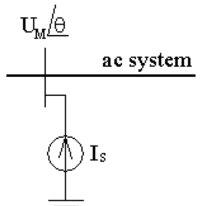
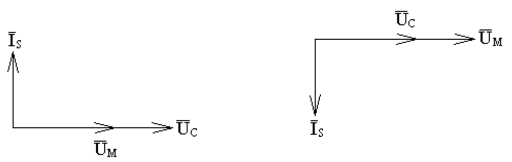


Fig. 3. Schematic diagram of an STATCOM

The principle of STATCOM operation is illustrated in Fig. 4. The voltage of STATCOM is synchronized with voltage of the line to which the STATCOM system is connected. That is the STATCOM current does not change the angle of the voltage at bus M.



(a) Mathematical model of STATCOM



(b) Power exchange operation

Fig. 4. The STATCOM principle diagram

D. Classic and Smart Controller

Since one of the purposes of this article is to compare the effects of classical and smart controllers on the performance of the equipment so PD and PI controllers as classical controllers and neuro-fuzzy controller as smart controller were chosen. The PI controller for STATCOM control and the PD controller is intended to control the PSS. In designing (coefficients selection) PD and PI controller, which has been mentioned in different ways in different references. In this paper genetic algorithm is used to select the optimal controller coefficients of these two classic controller. For designing the (training) suitable neuro-fuzzy controller, the results obtained from classical optimization controllers were used. As a result of this article, power system control in different states, by the PSS and STATCOM will be conducted. This equipment also will be controlled by the (PI) classic controller and neuro-fuzzy intelligent controller to make the desired goals will be accessible in the power system. Therefore, when the STATCOM placed in the network studied, bus voltage control target is the connection STATCOM to the network and as a result, according to the reactive current injection voltage control, STATCOM is determined by each controller. Also in the case, which PSS placed on the PV generator, the purpose of oscillation damping power and the rotor speed (frequency), the difference between the actual speed of the rotor and its reference value (speed error rate) as the control parameter placed in each classical and intelligent controllers and thus the stimulation flow of synchronous generator will be determined by the output of each controller.

III. Simulation Results

To investigate the impact of various devices and controllers on the network according to the study and mathematical models presented in the previous section, different scenarios are simulated in MATLAB.

In this part network works normally and based on the results of load flow (as the initial conditions) the network is simulated. The results of the network simulation in the initial state (without STATCOM and PSS) is given in the Figs. 5 and 6. With regard to the Fig. 5, 5 bus voltage is lower than all buses voltage in the network, so the STATCOM is placed at the 5bus. Also in this section the PI controller is used, to control STSTCOM to achieve the desired voltage (1.02 pu) at 5 bus, that the optimal ratio controller (K_P=92.2 and K_I=9.1) are obtained using a genetic algorithm (GA).

In this section simulate the network in a case of a three-phase short circuit fault for 200ms (10 cycles according to the frequency of 50Hz) happened on the line between buses 5 and 7 (closer tobus5). The results of this simulation without the presence of STATCOM and PSS are shown in the Figs. 7 and 8.

As shown in Fig. 7, when the three-phase voltage short-circuit error all the buses has been a sharp drop and after the error was fixed voltage buses were not recovered. The bus voltage error 5 and 7, which were nearer to the error have had dropped more than others buses. In Fig. 8 it can be seen that the angular velocity fluctuations of Synchronous generators at the time of an error increased and after it fixed, the time is spent for damping of oscillations.

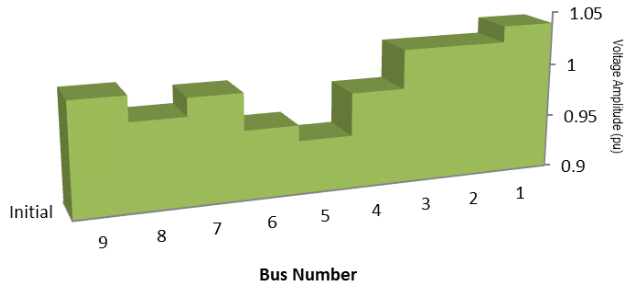


Fig. 5. Voltage buses in the initial state (without the presence of PSS and STATCOM)

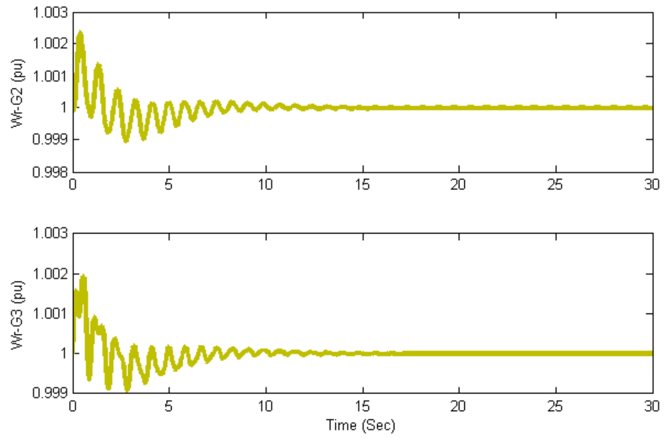


Fig. 6. Angular velocity of generator 2 and 3 according to time (without PSS and STATCOM and the controller)

Then the STATCOM is placed on the5bus again. The controller in this case, as in the previous section, is the PI controller, with coefficients optimized by genetic algorithms. The results of the simulation of STATCOMon5bus, and in the presence of a short circuit fault is provided in the Figs. 9 and 10. As shown in Fig. 9, because of the presence of STATCOM at 5bus and reactive power injection to the network in this bus, all buses voltage than transient state without STATCOM consist of less drop and buses have the ability to restore the voltage. Also in Fig. 10 observed that with the presence of STATCOM, not only fluctuations in angular velocity generator have been dramatically reduced, but also the damping of fluctuations happened sooner rather than when STATCOM was not connected to the network. Next time, instead of placing STATCOM in bus (5), according to different controllers (PD optimization and fuzzy control) [34], we will place PSS in generators 2 and 3 and compare the results. This results were compared in Figs. 11, 12 and 13.

As shown in Fig. 11, with the presence of PSS, the buses voltage during and after the error has not changed much and voltages in addition to a sharp drop in the voltage level during the error, was not reached to an acceptable level after the error. Also in Fig. 12 observed that in the presence of optimized classic controllers, the impact of STATCOM in damping of oscillations in the angular velocity of the synchronous generators have been better than PSS. The results in Fig. 13 shows that with the presence of intelligent controller such as fuzzy control, PSS would been better than STATCOM in terms of damping the frequency oscillations.

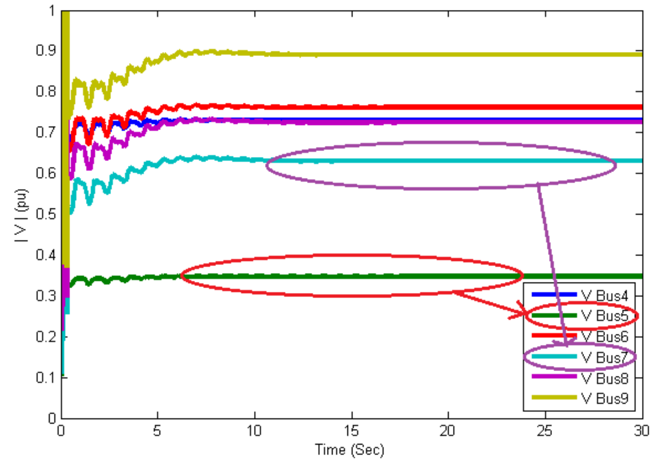


Fig. 7. The buses voltage in the presence of three-phase short circuit fault according to time (without PSS and STATCOM)

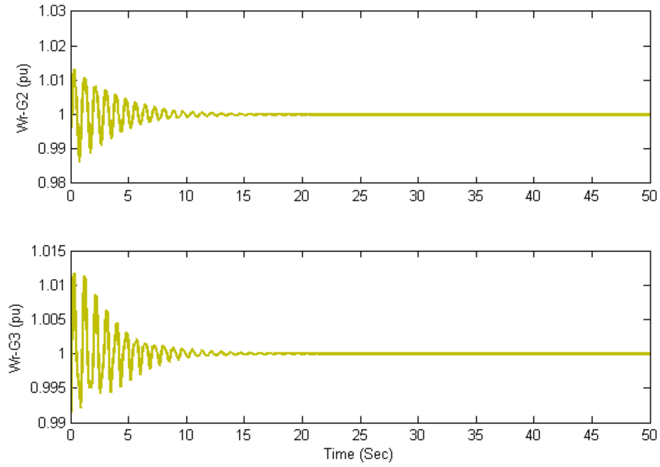


Fig. 8. rotor angular velocity of generator (2) and (3) in the presence of three-phase short circuit fault according to time (without PSS and STATCOM)

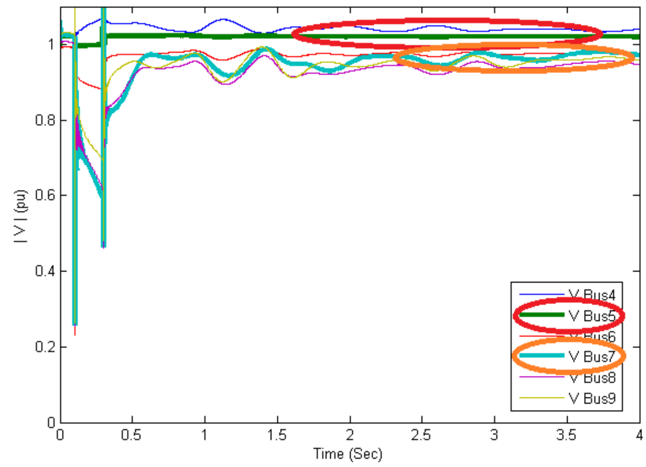


Fig. 9. The buses voltage in the presence of three-phase short circuit fault according to time (with STATCOM)

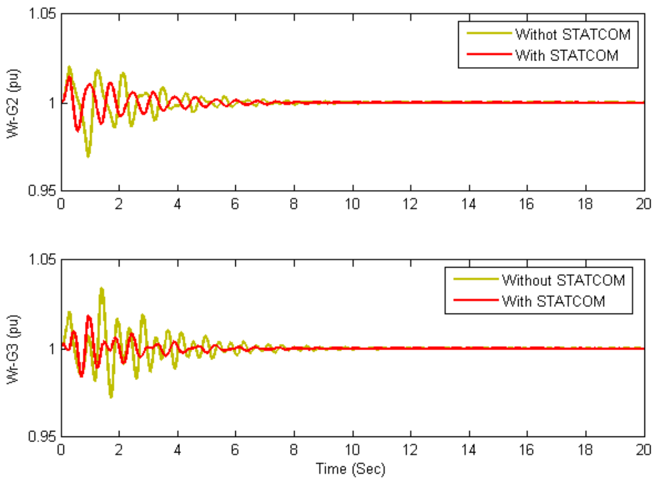


Fig. 10. rotor angular velocity of generator (2) and(3) in the presence of three-phase short circuit fault according to time (with STATCOM)

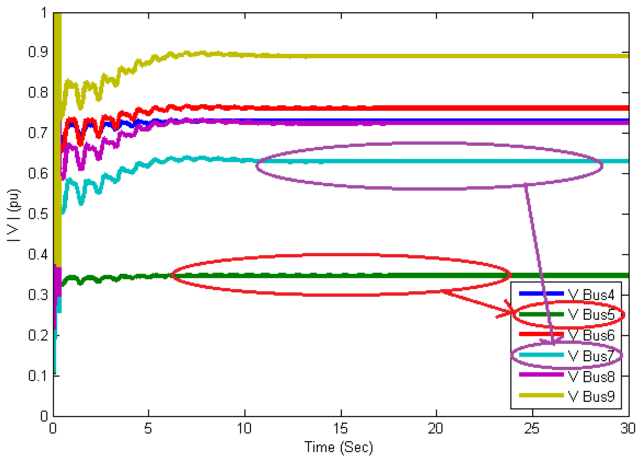


Fig. 11. The buses voltage in the presence of three-phase short circuit fault according to time (based on optimized PD controller for PSS)

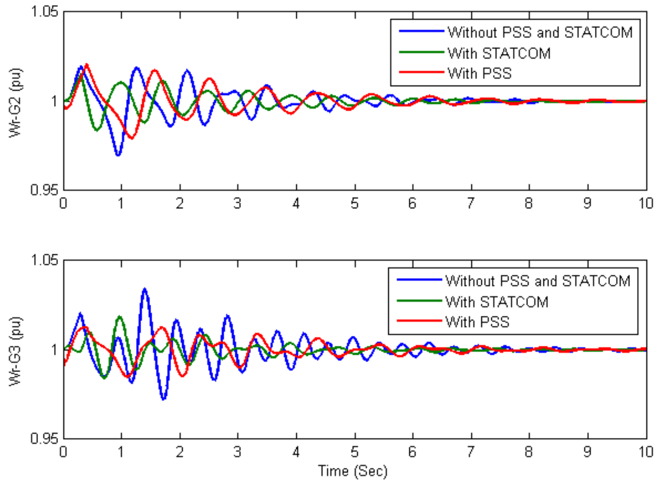


Fig. 12. rotor angular velocity of generator (2) and (3) in the presence of three-phase short circuit fault according to time (based on optimized PD controller for PSS)

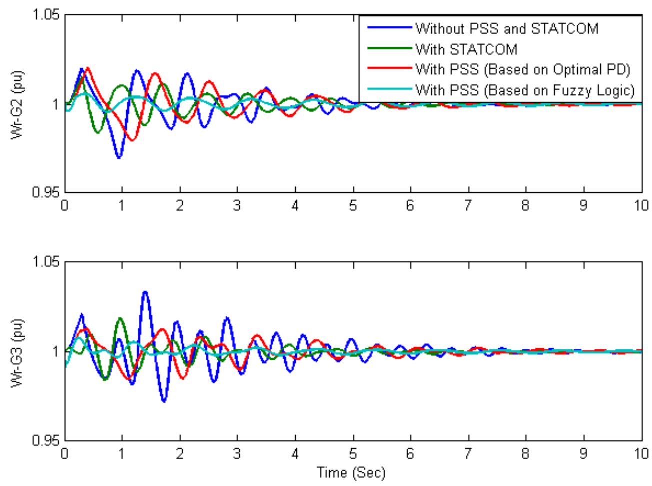


Fig. 13. rotor angular velocity of generator (2) and (3) in the presence of three-phase short circuit fault according to time (based on optimized PD controller for PSS)

IV. Conclusion

In this paper, STATCOM and PSS as crucial elements in improving the power quality of the power network were studied and compared. In order to enhance the quality of the analysis and comparison and having an accurate analysis, 9 Bus-IEEE standard network was chosen as the test network. Also to consider all aspects of a typical power system, two completely different scenarios is chosen in the simulation, including the impact of mentioned devices in normal working mode and when the error occurs.

The results of the simulation in two different scenarios showed that STATCOM in both working mode network (normal and error), has been able to improve the power quality. In other words, in the normal working mode network, because of reactive power injection in to the network, STATCOM is able to improve the level of voltage, reduce active power loss and release the lines capacity, etc.

In case of error, it had the ability to improve angular velocity of synchronous generators fluctuations and also voltage recovery and stability. However, the PSS never been a big impact in buses voltage stability improvement both in normal working mode and error mode of network. It has been effective only in reducing the damping of the oscillations frequency. It should be noted that according to the study results, it can be concluded that the type of controller used, have had a great influence in the PSS control and achieving the desired objectives. It is caused because with the presence of the fuzzy controller, damping of oscillations had better condition by PSS than that PSS works with optimized PD controller.

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