Voltage profile Improvement Using Static Synchronous Compensator STATCOM

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Abstract—*Static synchronous compensator (STATCOM) is a regulating device used in AC transmission systems as a source or a sink of reactive power. The most widely utilization of the STATCOM is in enhancing the voltage stability of the transmission line. A voltage regulator is a FACTs device used to adjust the voltage disturbance by injecting a controllable voltage into the system. This paper implement Nruro-Fuzzy controller to control the STATCOM to improve the voltage profile of the power network. The STATCOM controller has simulated for some types of abnormal conditions. The simulation results show improves the system voltage profile. The performance of compensator with its new controller was very close to the nominal value, which was 98% of the busbar voltage.*

Keywords— FACTS, STATCOM,VSI, d-q theory, park transformation, FLC, Sinusoidal Pulse Width Modulation (SPWM).

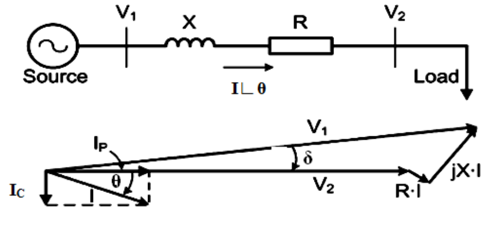
I. INTRODUCTION

Power quality is defined of electrical limits that permit the part of the equipment to use function in its intended manner without loss of the performance or life expectancy. The electrical device like generator, transformer, motor, computer, printer, communication equipment, or a house machines. All of these devices react negatively to the power quality, depending on the severity of the problems. Reactive power unable to be transmitted when large load angle even with essential the magnitude of voltage gradient [1]. Instability of Voltage may cause partial or complete interruption in the power system. Static Synchronous Compensator is a voltage source inverter (VSI) based on shunt device generally used in transmission system to enhance the compensator and power quality. The advantage of STATCOM is that, it has a very advanced power electronics based control that can efficiently regulate the injection current into the transmission bus [2]. The second advantage is that, it has different applications, e.g. i. controlling the voltage of distribution bus against sag/swell conditions. ii. Suppressing the harmonics content in line currents iii. Modified poor load power factor, and compensating the reactive power of the transmission line and the load [3]. STATCOM with an energy source on the DC side, it is advisable to control the magnitude and phase angle of the injected voltage by the VSC in order to control the active power and reactive power output. A shunt compensator enables to mitigate voltage fluctuations at the point of common coupling (PCC) [4].

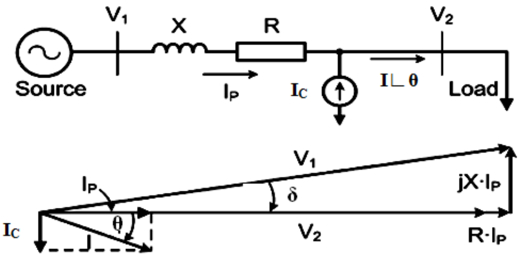
II. COMPENSATION AND VOLTAGE REGULATION

The principle and theoretical effects of shunt reactive power compensation in AC system for voltage regulation are shown in figure 1. This includes a source (V_1), a power line and a typical inductive load. Figure 1a, shows the system without compensation and it is related to the phasor diagram. From the phasor diagram, the angle of the line current has related to the side of the load, this means that active current (I_P) is in phase with (V_2) the load voltage. Since assumed the load is inductive and requires reactive power for suitable operation and hence, the source must supply it; thus increasing the current from the generator and through power lines. If reactive power is supplied near the load, the line current can reduce power losses and improve voltage regulation at the load terminals [5]. This can be done in three ways: **1)** with a capacitor [6]; **2)** with a voltage source inverter [7]; or **3)** with a current source inverter [8]. In figure1b, a current-source device is used to compensate the reactive component of the load current by inject/absorb current (I_C) to/from system. As a result, the system voltage regulation is improved and the reactive current component from the source is reduced or almost eliminated. If the load needs leading compensation, then an inductor would be required. In addition, a current source or a voltage source can be used for inductive shunt compensation.

The STATCOM is providing voltage support under large system disturbances during which the voltage excursions would be well outside of the linear operating range of the compensator. The main advantage of using voltage or current-source Var generators (instead of inductors or capacitors) is that the reactive power generated is independent of the voltage at the point of connection as shown in figure 2 [9].



a Without Reactive Compensation



b Compensation with a Current Source

Fig.1: Principles of Shunt Compensation

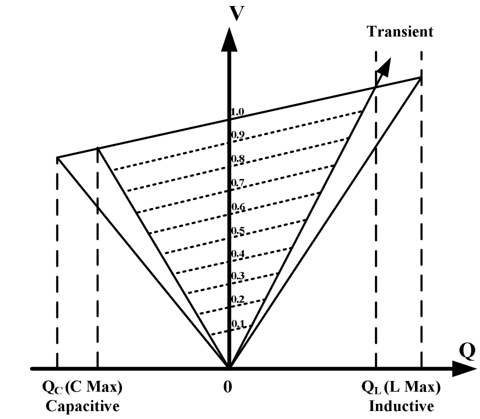


Fig.2: Q-V characteristics of the STATCOM

The STATCOM connected between the source and load as shown in figure 3.

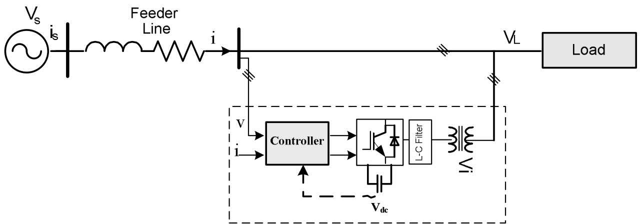


Fig.3:Fundamental connection of STATCOM

III. MEASURING LINE VOLTAGE AND REACTIVE POWER

For measuring line voltage and reactive power, d-q theory has been used. D-q theory is based on time-domain, and it is valid for operation in different state (steady or transient state), also this theory can applied for generic voltage and current waveforms, this will simply allow to control the reactive power in real time. Another advantage of this theory is the simplicity of the calculations, which include algebraic calculation and simply to separating the mean value and alternated value respectively when calculated the components of power system [10]. The d-q theory implements by transformation to quadrant coordination known "park transformation" from a stationary reference coordinates abc to dq rotating coordinates[11].The transform applied to time-domain voltages in the natural frame (i.e. v_a, v_b and v_c) is as follows:

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(\emptyset) & \cos(\emptyset-\frac{2\pi}{3}) & \cos(\emptyset+\frac{2\pi}{3}) \\ -\sin(\emptyset) & -\sin(\emptyset-\frac{2\pi}{3}) & -sin(\emptyset+\frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(\emptyset) & \cos(\emptyset-\frac{2\pi}{3}) & \cos(\emptyset+\frac{2\pi}{3}) \\ -\sin(\emptyset) & -\sin(\emptyset-\frac{2\pi}{3}) & -sin(\emptyset+\frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (2)$$

$$\emptyset = (\omega t + \theta) \quad (3)$$

Where $\emptyset$ is the angle between the rotating and fixed coordinate system at any time and θ the phase shift of the voltage. Then the compensated active power and reactive power calculated by:

$$p = V_d I_d + V_q I_q \quad (4)$$

$$q = V_d I_q - V_q I_d \quad (5)$$

The resultant voltage is:

$$\boldsymbol{v} = \sqrt{\boldsymbol{v_d}^2 + \boldsymbol{v_q}^2} \quad (6)$$

IV. CONTROL SCHEME OF STATCOM

Block diagram of the STATCOM control system is shown in Figure 4. The three phase line voltages are sensed then filtered to eliminate high frequency noise and the quadrature voltage components (vd and vq) the are calculated by park transformations. The measured voltage is calculated and works as a feedback for the closed loop control system. The measured voltage is compared with the reference voltage of the busbar (set point) v_{ref} to generate error signals v_{erorr}. This error signal is processed in controller where:

$$V_{error} = v + V_{ref} \quad (7)$$

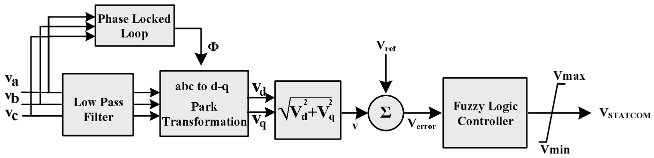


Fig.4: Block diagram for STATCOM control system

V. FUZZUY CONTROL SYSTEM

Fuzzy logic control are suitable for approximate reasoning, especially for the system that have mathematical model is difficult to derive. Fuzzy system controllers perform an important role in different practical applications. There are many inference mechanism systems in fuzzy logic control which Takagi-Sugeno type is chosen in this paper. To tune the membership functions of the Takagi-Sugeno (TS fuzz-like-PI controller), Artificial Neural Network (ANN) will be used in this paper. The TS fuzzy controller have a highly non-linear variable gain controller. it makes wide differences of the gain of the controller. The selection of controller parameters may lead to an adequate system response or instability [12]. First the controller build using mamdani-type then transfer it to TS fuzzy type to get a better system response by using Neuro-Fuzzy control to adjust the parameters of fuzzy and rules by employing ANN learning algorithm. Since it integrates the qualitative of fuzzy approach with the capabilities of adaptive learning of ANN, this system can trained without need great expert knowledge that usually required for the mamdani fuzzy logic [13]. Results, the fuzzy rule base is reduced.

The membership parameters of the output and input functions are determined through the training step. The designed Fuzzy system consists of five layers, each one have parameters no need to tune or have parameters need to tune during the training stage. The output of five layers that emulate the fuzzy design steps is given in reference [14] for more details. The objective of the learning algorithm is to set the parameters of the membership functions for output and input so that the output of adaptive fuzzy matching the training data. Gradient Descent-GD and Lease Squares Estimate-LSE (hybrid learning) applied for identify the parameters of network. The use of GD method updates the antecedent membership function parameters. In this work The input universe of discourse is split into 5 gaussian membership function with 50% overlapping, therefore, for two inputs (error and Δerror), 25-control rule resultant linear functions required to be determined as shown in Figure 5. To tune the rules using adaptive fuzzy, two group of data are generated. Two vectors of input data: V_{error} and ΔV_{error} the output m the modulation index. Figure6 shows the validation test of Fuzzy logic system. To perform the procedure the GUI of ANFIS file included in the MATLAB/FUZZY Logic Toolbox is used.

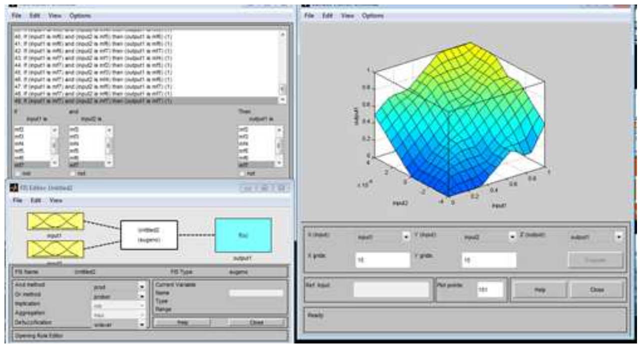


Fig.5: Fuzzy logic validation test and surface

VI. SIMULATION STUDY

system consists of feeder with two branches changeable load. the STATCOM system installed in busbar 2 (BB2) to compensate the voltage in BB2. the test start by change the load and measure the load voltage at BB2 without compensation as shown in figure 10. From the result it can be notice that the drop voltage increased proportionally with increasing the load, the maximum drop was 0.94 pu between 0.6 and 0.8 sec. Figure 11 shows the action of STATCOM to compensate the load voltage where the voltage at BB2 was restored and mitigate the drop voltage from 0.94 to 0.985 pu, this compensation done by inject compensated voltage $V_{STATCOM}$ with respect to phase voltage as shown in Figure 12. Figure 13 shows the p-v curve, it can notice that the voltage with STATCOM more stable and enhanced the stability margin. To investigate the performance of the adaptive controller for step change of the load condition, a PI controller is used for the sake of comparison. Figure 14 shows the results of the system response to step change in rms of the line voltage. From the results, it is clear that the Fuzzy controller has a smoother in response and faster than the PI controller to reach the steady state.

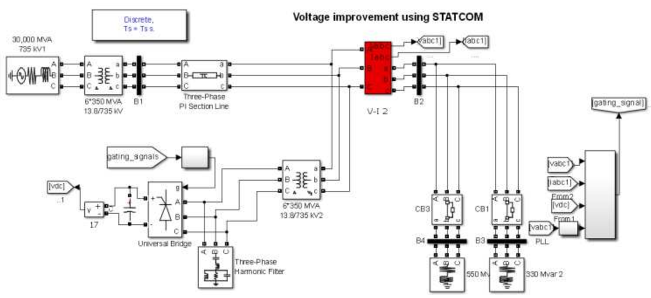


Fig.6: System model for simulation

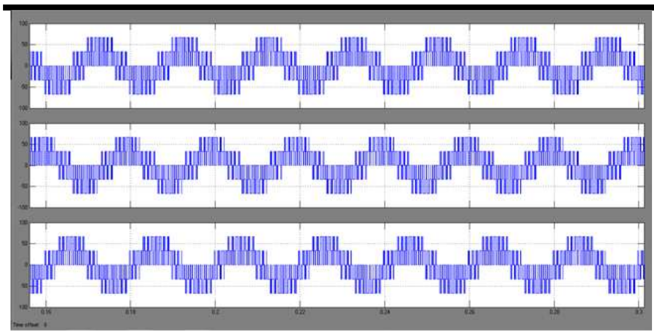


Fig.7: The 3-ph phase waveforms output of the inverter

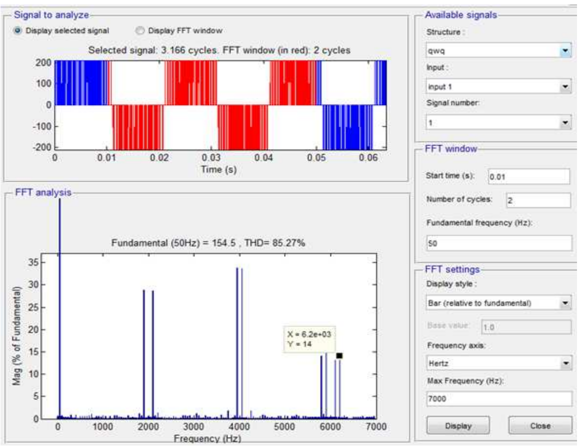


Fig.8: Fourier analysis of inverter output

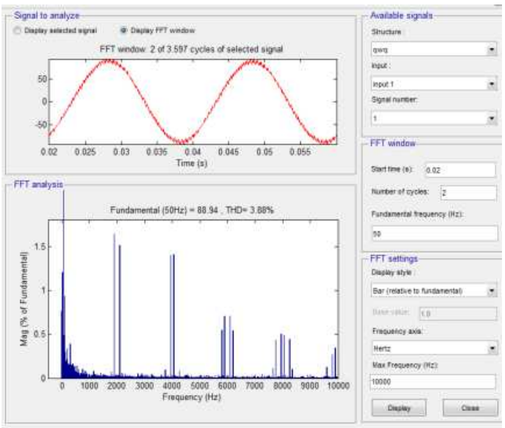


Fig.9: Fourier analysis of line current after STATCOM voltage injected

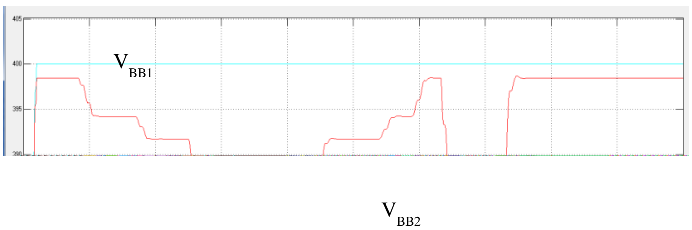


Fig.10: The BB2 voltage without compensation

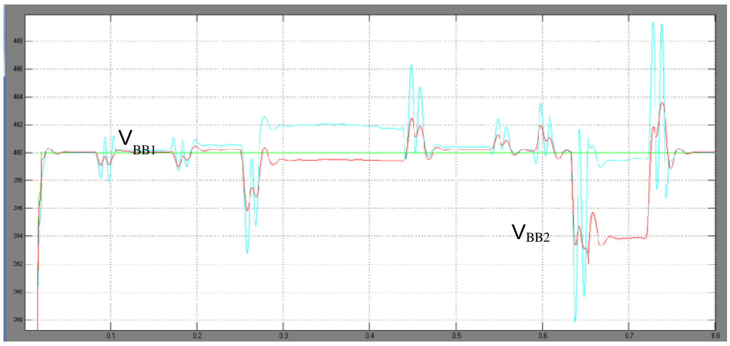


Fig.11: The BB2 voltage with compensation

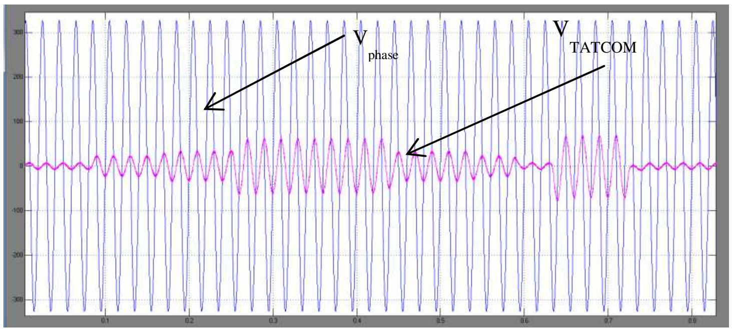


Fig.12: The injected compensated voltage $V_{STATCOM}$ versus phase voltage

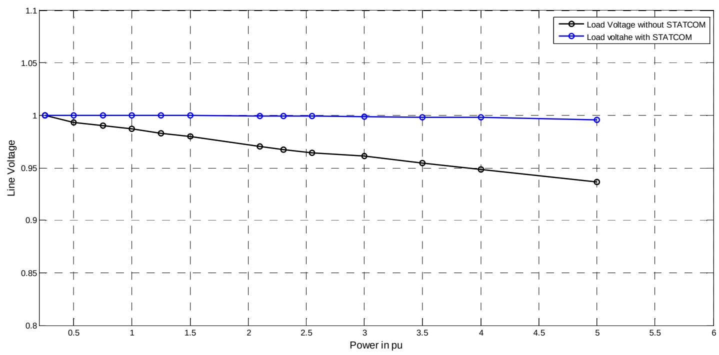


Fig.13: P-V curve of the system

VII. CONCLUSION

In this paper, a STATCOM based three phase PWM with adaptive controller has been integrated in the load bus, and some abnormal conditions have been studied through simulation. The results of simulation have shown the STATCOM with adaptive controller improve the voltage profile of distribution system through the abnormal conditions. The model of STATCOM is developed with the required controller and components to prove its performance in fast regulation at load voltage. The of simulation compared with and without compensation. Also the simulation results of STATCOM show the ability to restore the load voltage for increased the load with satisfactory performance. The STATCOM performance with the controller was very close to the nominal value of the busbar voltage (within 98%). In these tests the conventional PI controller has been used for the seek of comparison. Also controller algorithm is used to control the STATCOM for voltage profile improvement. The Neuro-Fuzzy System was tuned the algorithm off-line. The rules determine by training the error and change of error for voltage for initiating the process. The computation time was small, this important notice for implementation in real time. Simulation results show the adaptive controller provide an good performance for the operation of STATCOM. Nero-Fuzzy controller is used to control the STATCOM for voltage profile improvement. the results show that the used controller smoother and fast response compared with the conventional PI controller.

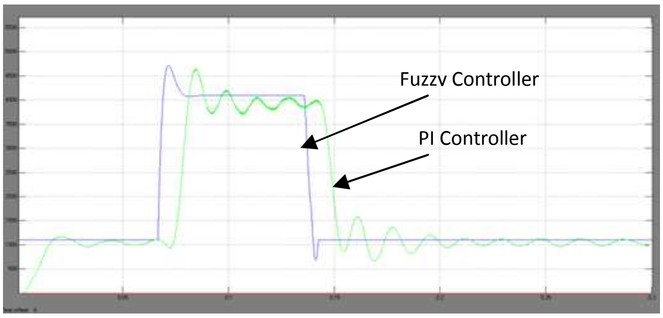


Fig.14: The line voltage versus injected compensated voltage

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