Reactive Power Compensation enhanced Power System Stability using STATCOM

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Abstract. The paper mainly deals with the essential necessity of reactive power management for voltage stability along with efficient operation required to meet suitable power factor and reducing losses in a given network. Hence a reliable power system has to be exercised on managing reactive power both during generation as well as off-taking process in the grid helping to maintain a decent quality of electrical equipment due to escalating load requirements. Static synchronous compensators (STATCOMs) are deployed across power networks for voltage regulations and as VAR compensators. This article reviews the integration of STATCOMs into distribution grids in general and power quality enhancements during adverse situation of power delivery. STATCOMs are able to continuously transfer reactive power from different sources of supply directly into the loads, which could alleviate both active and reactive energy demands on the grid. The article presents results of reactive power compensation for improvement of voltage profile of a network and also open the scope of integration of renewable energy sources for better power delivery.

Keywords: Reactive Power, Compensation, STATCOM, Voltage Profile, Stability, PWM, Converters

1 Introduction

With the rise of global energy demand and concurrent reduction in fossil fuel use, electric power systems are under greater pressure than ever. This may cause lower reliability as well has poor quality power supply to consumer. Prompted by rapid development, financial constraints and increasing environmental concerns, the current energy crisis has led to a re-examination of conventional patterns in energy consumption as well as push towards more reliable networks but such effort always introduce some challenges in power system stability. By the installation of advance power electronics based devices, enables more integrated and stable network than traditional facilities but also incorporate renewable generating facilities such as solar or wind**[1]**. Microgrids that can host distributed energy resources are now seen by experts as a workaround solution for these problems resulting in enhanced and cleaner of the grid. The newer Flexible AC Transmission System (FACTS) has dissolved those issues and made more dynamic power system, reliable and efficacious energy network. FACTS technology has been used for high-performance power delivery, demand management, energy security, stable power conversion and power quality improvement**[2]**. Static VAR Compensator (SVC), Thyristor controlled Series Capacitor or Reactor (TCSC and TCSR), Thyristor Switched Series Capacitor (TSSC) or Static Synchronous Compensators (STATCOM) are well recognized FACTs devices ensure improved power transmission, continuous, stable and optimized power delivery. Integration of FACTS technology with renewable power sources and distributed generation (DG) opens up a new frontier in the realm of energy efficiency, while maximizing security and reliability of entire energy systems**[3]**. Extensive research shows that STATCOM plays key role during integration of DG units with the grid**[4]**. They help in providing dynamic VAR compensation which is important part of producing or maintaining the required voltage profile during eventuality on grid. STATCOM is better in overall to provide dynamic VAR support because SVC's have limited range of operation**[5]**. While in the case of SVCs, which are limited to controlling bus voltage only, on the other hand STATCOM can regulate the output current at its nominal value making it more reliable and adaptive for voltage control**[6]**. STATCOMs installed on the Point of Common Coupling (PCC) provides well acclaimed performance and improve the voltage stability during disturbances, which allows a higher penetration level of DG units connected to the grid**[7]**.A lot of research articles can be found on optimal positioning of STATCOM in distribution system along with their optimal size for achieving a cost effective solution for a improved power delivery[8],[9].

In this article it is emphasized to show the control strategy of STATCOM circuit. This paper explains the scheme of converting mains voltage into DQ components to estimate the mains current and inverter reactive current implementing a PI controller. The PI controller also computes the direct axis current based on the DC link voltage, giving feedback for accurate current extraction in the DQ frame. The subsequent DQ components are then converted back to the ABC frame to produce PWM signals for the inverter's IGBT. The discussion has been utilized in power line measurements at the Point of Common Coupling (PCC) to obtain sine and cosine parameters of the grid for an appropriate power supply assessment and recovery. The transformation of the grid to an alpha-beta frame is achieved using Matlab's transform functions, with further computation done in the DQ framework. A Phase-Locked Loop (PLL) circuit, integrating a harmonic oscillator and PI controller, arrests the sine and cosine components to guarantee a detailed synchronization and control. Complete simulation study shows the performance control of the grid connected STATCOM during different loading conditions.

2 Structure and problem formulation

STATCOM is a parallel-connected FACT device. Since this article is focusing of voltage profile control of bus through reactive power compensation, a typical diagram likes Figure 1 can be put up for presenting STATCOM connection to grid with controller and renewable sources attached to it. Basic circuit topology of the proposed reactive power compensator comes with a STATCOM interfacing at Common Point of Coupling (PCC) connected to grid along with RL type non-linear AC load. Controlled reactive power given in Equation 1 will be delivered to the load by STATCOM. STATCOM is connected in parallel with a fixed capacitor and load. The voltage profile at the corresponding bus is regulated through Equation 2 considering a reference voltage which can be determined through Equation 3. PWM technique has been applied for generating gate signal to have rapid switching of IGBTs. According to the Figure 1 instantaneous voltage of STATCOM and current can be computed as per Equation 4. In this article calculation of three phase voltage and current have been computed using Park's transformation and then represented with d-q-0 axis transformation by the Equations (5) and (6) respectively.

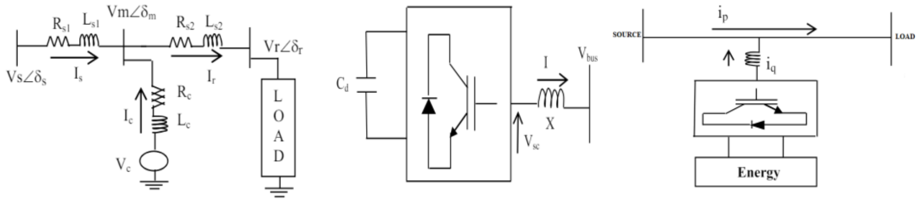

Figure 1. Connection diagram and control circuit of STATCOM

$$Q = \frac{V_c \times V_{bus}}{X}\cos\delta - \frac{V_{bus^2}}{X} \tag{1}$$

$$V \cong E[1 - \frac{Q_l - Q_c}{S_{SC}}] \tag{2}$$

$$V_{ref} = V - X_s * I \tag{3}$$

$$\left(R_c + L_c \frac{d}{dt}\right) i_c = V_m - V_c$$
where, $i_c = [(i_a \ \ i_b \ \ i_c)]^T$ and $V_m = (V_{ma} \ \ V_{mb} \ \ V_{mc})^T$ (4)

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = T \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}, \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = T \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{5}$$

$$T = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \tag{6}$$

3 STATCOM model and control strategy

Voltage swell, voltage dip or sag, interruption in power flow or power quality disturbance due to transients, harmonics or unbalance are the most common issues in quality power delivery that disturbs a referred voltage profile on a network. Hence, there should be a well-trained control strategy so as to take care of problems distressing power system network. The Simulink model for the proposed STATCOM position and connections have been shown with line diagram by the Figure 2. The Figure 3 has been used as proposed STATCOM model for this work. A phase-locked (PLL) is a control circuit that produces a phase based input signal. It is generated according to the mains voltage to obtain the sine and cosine values of the mains voltage waveform. Sine and cosine values are needed to find the direct and quadrature components of other parameters in the circuit. PLL input is provided by the PCC itself. First, the α-β coordinate system is calculated as a grid in the ABC coordinate system. Then, sine and cosine values are extracted with the help of resonators.

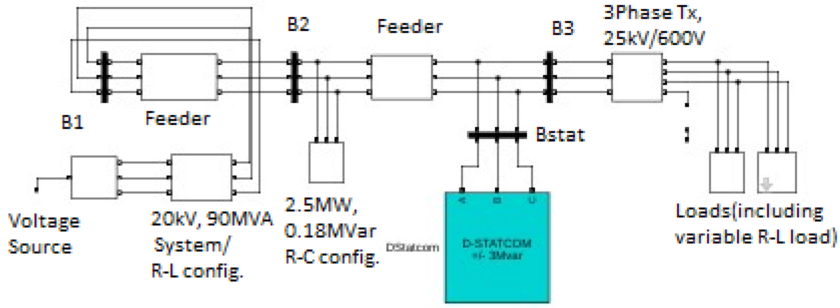

Figure 2. Fundamental line diagram of STATCOM position and connections

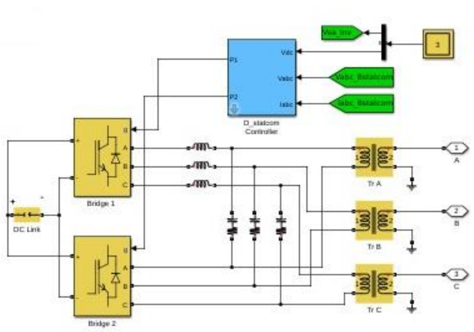

Figure 3. Proposed STATCOM Simulink model connected to grid

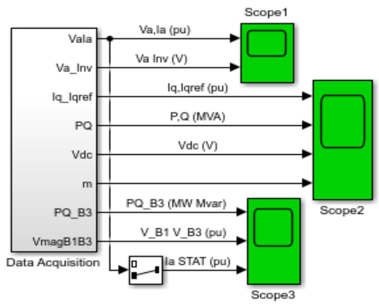

Figure 4. Data acquisition from grid with and without STATCOM

The current type of control is done in the D-Q frame. The input and output signals are first transformed into D-Q frames and then developed to generate control signals in the D-Q frames. To facilitate calculation, the signal is converted into D-Q frames. In the ABC framework, the active as well as reactive power of each level must be discovered independently and acted upon, making the cycle even larger. The mains voltage and current are first converted to the alpha-beta control system by removing the sine and cosine elements. Then change has been made by the alpha-beta frame to the D-Q frame. To simplify the calculation, the inverter voltage and current are also changed from the ABC pole to the D-Q pole.

4 Results and analysis

A three-phase STATCOM Matlab/Simulink model has been shown in Figure 3 and a data acquisition system for displaying required output has been shown in Figure 4. A programmed AC voltage source has been connected to the network. The load and STATCOM are connected to the grid via a common connection. There is a variable nonlinear load also that has both resistance and inductance. A power inverter connected to the PCC provides current to deliver reactive power to the load. There are IGBT switches in the inverter and the PWM signal given to the IGBT switches is produced by a controller circuit. To generate a PWM signal, some parameters of the main circuit has been measured. There is a series inductance between the grid and the inverter to reduce the harmonics produced by STATCOM. The measurements obtained from this Simulink model are reflected through a data acquisition system by Figure 4. In the simulation period, first the variable load remains constant and the response of STATCOM has been observed during step changes in supply voltage. It is ensured that the variable load modulation is disabled and Ton=0.14 and Toff= 1. The controlled voltage supply block is applied to control 20kV equivalent voltage. Voltage is programmed first at 1.059 pu for the STATCOM to float initially setting bus voltage B3=1 pu and reference voltage, Vref =1pu. Then another three steps has been exercised at t= 0.18s, t=0.25s and t=0.3s bringing the source voltage to increase successively by a factor of 5%, decrease it by a same factor and finally restore it back to base value of 1.059pu. The phase A voltage,V_A and current, I_A wave shapes of the STATCOM along with its controller signals are shown in Figure 5 obtained from scope1 & 2 given in Figure 4.

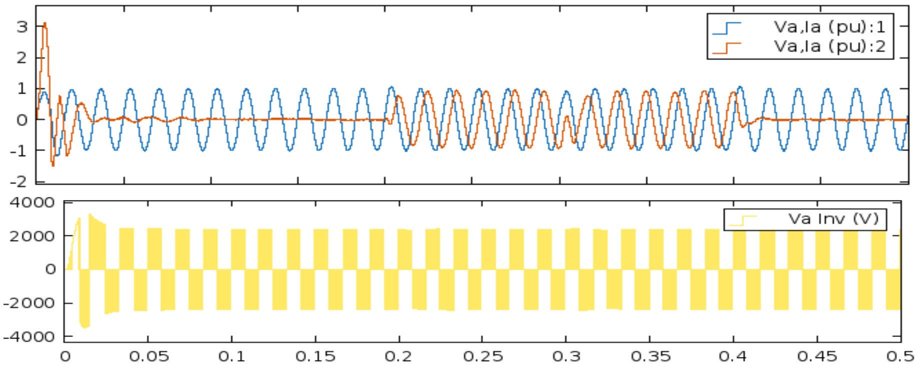

Figure 5. Voltage and current waveform for phase A during simulation

It is only lasting about a transient for 0.14s, which the steady state sets in. The phase A voltage, V_A and current, I_A wave shapes of the STATCOM along with its controller signals are shown in Figure 5 obtained from scope1 & 2 given in Figure 4. Initially the input voltage even is not large enough to activate STATCOM. The STATCOM did not absorb power nor supply power to the grid. A rise of 5% in the source voltage is seen at t = 0.18s. The STATCOM and therefore is feeding reactive power into the network of Q=+2.5 MVAR has been shown in Figure 6 obtained through scope2 to balance this increase in voltage.

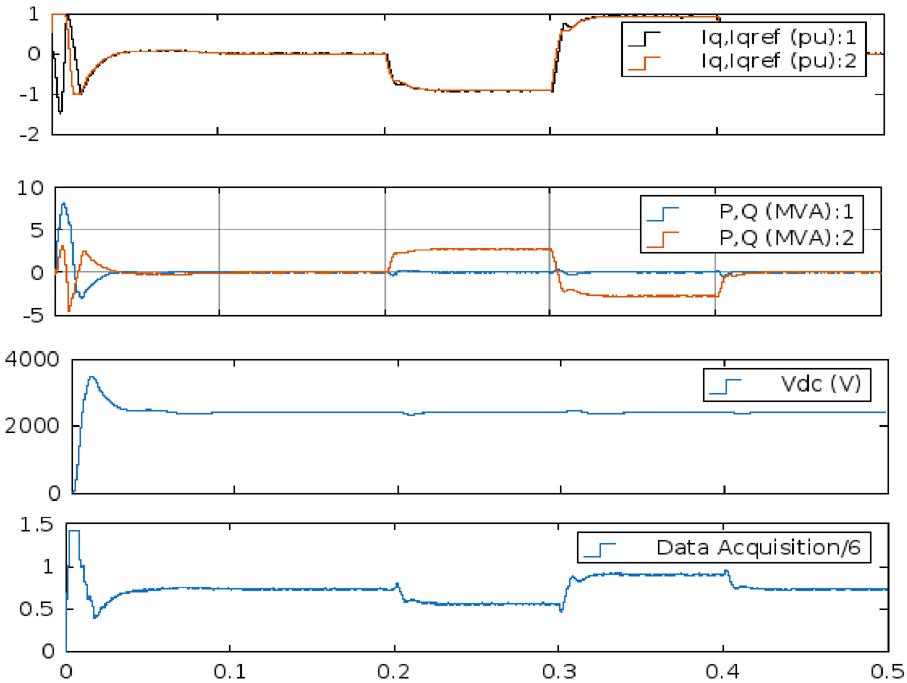

Figure 6. Reactive power compensation during voltage profile variation.

The voltage of the source is reduced by corresponding reactive power, Q=0 at time t=0.28s. STATCOM has to supply reactive power for keeping 1 pu voltage by notching reactive power, Q from +2.6 MVAR's to -2,7MVA and it can be observed that once STATCOM alters its operation from inductive mode to capacitive mode, PWM inverter modulation index is also surged from 0.55 to 0.8 which is shown in Figure 7 traced by scope2. The retreating of reactive power may be of one cycle event as obtained by STATCOM. During the simulation for voltage profile testing, it is observed that P and Q variations at bus B3) as well as voltages in buses B1 and B3 plotted in Figure 6 by scope2. It is seen that voltage level varies from 0.95 pu to 1.03 pu which reveals $\pm\mathbf{4}\%$ variation in bus voltage without using STATCOM. Later changing the type of operation earlier to regulation of voltage in STATCOM Controller, a voltage variation in bus B3 as shown in Figure 7 traced by scope3 is much less as $\pm\mathbf{0.69}\%$. The STATCOM injects a 5-Hz modulated reactive current that compensates voltage.

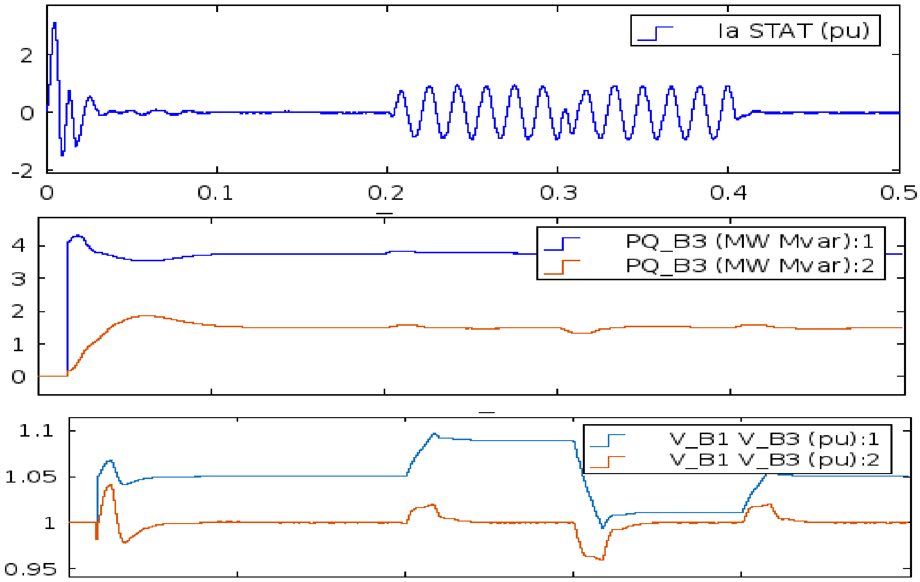

Figure 7. Voltage profile compensation of bus1 and bus 3

5 Conclusion

This research paper explains the basic principles of STATCOM operation with an improved control method. The article verifies an effective control scheme for a STATCOM circuit by transforming mains voltage into DQ components for precise current estimation and inverter control. The incorporation of a PI controller for direct axis current computation and the conversion back to the ABC frame for PWM signal production confirms precise inverter operation. The practice of power line measurements at the PCC, along with alpha-beta to DQ conversions and PLL-based synchronization, proves a pivotal mechanism for consistent power supply assessment and control. The design has been verified by simulation in the Matlab/Simulink platform. Simulation results prove the effectiveness of the reactive power compensation performance of the model. The comprehensive simulation results authenticate the STATCOM's robust performance under several loading conditions. This article also discusses how STATCOM can be integrated with renewable energy sources for achieving benefits in distribution system. In general, three-phase STATCOM plays an important role by providing reactive power support, improving voltage stability, improving power quality, improving efficiency and stability of the power system.

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