Compensation of Reactive Power Using STATCOM in Distribution Network

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Abstract—Voltage disturbances are the most important power quality problem faced by many industrial and domestic users. This paper analyzes the voltage sag and swells mitigation using STATCOM (Static Synchronous Compensator) at distribution system. The voltage source converter (VSC) is used with DC link capacitor as a STATCOM. Sinusoidal pulse width modulation (SPWM) based Control strategy using dq0 transformation is proposed for STATCOM Controller to mitigate the issue related to voltage disturbances and tested in MATLAB/SIMULINK software. Simulation results are shows the effectiveness of proposed control strategy.

Keywords—Reactive Power; Voltage Sag; Voltage Swell; STATCOM; Distribution System; SPWM technique; dq0 transformation.

I. INTRODUCTION

The majority of power consumption has been drawn in reactive loads such as fans and pumps etc. These loads draw lagging power factor currents in the distribution systems. These excessive reactive power demand increases feeder losses and reduces the active power flow capability of distribution system which also affects the voltage profile.

Voltage sag and swell is the most important power quality problems faced by many industrials and domestic users. It contributes more than 80% power quality (PQ) problems that exist in distribution system. According to definition, Voltage sag is the RMS reduction in the AC voltage at power frequency from half of a cycle to a few seconds duration. Similarly, Voltage Swell is the RMS increase in the AC voltage at power frequency from half cycles to a few seconds[1]. Voltage sag and swell are not tolerated by sensitive equipment used in modern industrial plants, such as process controllers, programmable logic controllers (PLC), adjustable speed drives (ASD), and robotics. It has been reported that high intensity discharge lamps used for industrial illumination get extinguished at voltage sags of 20% and industrial equipment like PLC and ASD are about 10%[5].

In this paper, STATCOM is based on three phase voltage source converter. STATCOM produce capacitive and inductive reactive power internally. By controlling the gate pulses of inverter switches, this voltage source can modify the compensating reactive power and making voltage profile smooth. So, in case of voltage sag by injecting reactive power and in case of voltage swell by absorbing reactive power, we can improve the voltage profile[4].

STATCOM maintain constant voltage at PCC by controlling the amount of reactive power injected into or absorbed from the distribution system. In this paper SPWM based typical PCC voltage control strategy of STATCOM is demonstrated and where the controller is implemented with the use of dq0 coordinate system signals. This voltage control operation of a STATCOM is demonstrated with MATLAB/SIMULINK software with simulation results.

II. CONFIGURATION & PRINCIPLE OPERATION OF STATCOM

![Fig1. Single line diagram of STATCOM in Distribution System][2]

When STATCOM used in low voltage distribution system, it is identified as Distribution STATCOM (DSTATCOM). In general STATCOM is used to generate or absorb reactive power. The STATCOM is a three-phase and shunt connected power electronics based device.
It is connected near the load at the distribution systems. The major components of a STATCOM are shown in Figure 1. It consists of a dc capacitor, three-phase inverter (IGBT, thyristor) module, ac filter, coupling transformer. The basic single line diagram of the STATCOM in distribution system is the voltage sourced inverter that converts an input dc voltage into a three phase output voltage at fundamental frequency.

According to Fig 1, the controller of the STATCOM is used to operate the inverter in such a way that the phase angle between the inverter voltage $V_i$ and the system voltage $V_s$ is dynamically adjusted so that the STATCOM generates or absorbs the desired VAR at the point of connection (PCC). The phase of the output voltage of the inverter $V_i$ is controlled in the same way as the distribution system voltage $V_s$. Figure 2 shows the three basic operation modes of the STATCOM output current, I, which varies depending upon $V_i$. If $V_i$ is equal to $V_s$, the reactive power is zero and the STATCOM does not generate or absorb reactive power. When $V_i$ is greater than $V_s$, the STATCOM 'sees' an inductive reactance connected at its terminal. Hence, the system 'sees' the STATCOM as a capacitive reactance. Then the current flows from the ac system to the STATCOM, resulting in the device absorbing inductive reactive power.

III. SYSTEM CONFIGURATION

In this paper, the modeling of STATCOM controller is based on the SPWM technique. Figure 3 shows the simplified system diagram of a STATCOM, comprising of a DC link capacitor, IGBT based VSC, coupling Inductor and control strategy.
A three-phase voltage source converter (VSC) is realized using six IGBTs (insulated gate bipolar transistors) switches with anti-parallel diodes. It converts the DC voltages across storage devices into a set of three phase AC output voltages. It could be 3-phase 3-wire or 3-phase 4-wire VSC. VSC may be two level converter, three level converters or multilevel converter. An energy storage device is to supply the required energy to the VSC via a DC link capacitor for the generation of injected voltages. Three phase loads may be an unbalance load or a nonlinear load.

For reducing ripples in compensating currents, interfacing inductors are used at AC side of VSC. A LC filter is connected to the system in parallel with the load to reduced harmonics and matches inverter output impedance to inverter to share current. The compensator is use to reduce switching ripples in the PCC voltage injected by switching of STATCOM. Coupling transformer is used to couple the output voltage of VSC with system. These voltages are coupled with AC system through the reactance of coupling transformer.

The STATCOM is operated for the compensation of lagging power factor balanced load to correct the power factor at source side or to regulate the voltage at PCC. As per the voltage level, STATCOM injects or absorb reactive currents to regulate the PCC voltage at the desired reference value of the voltage and the source currents may be leading or lagging currents depending on the reference value of PCC voltage.

IV. CONTROL STRATEGY

For reactive power compensation, a STATCOM exchange the reactive power with distribution system as per the level of system voltages, so by doing so we can protect the voltage sensitive load. Basic function of the STATCOM control block is sense the fault; computation of voltage; generation of trigger pulses to SPWM based DC-AC inverter and termination of trigger pulses when the event has passed.

Fig. 4 shows the control algorithm of STATCOM controller. For extracting gate pules for VSC, first of all measure the PCC voltages ($V_a$, $V_b$, and $V_c$), PCC currents ($I_{sa}$, $I_{sb}$ and $I_{sc}$) and DC bus voltage ($V_{dc}$) of the STATCOM. PLL (phase locked loop) is use to continue track the fundamental frequency quantity in distorted condition and which can also extract the phase angle $\theta$ of fundamental voltage, which is mainly use to synchronization of VSC to system.

Fig3. Block diagram of distribution system with STATCOM [8]

The STATCOM protects the utility distribution system from voltage sags and/or flicker caused by rapidly varying reactive current demand by unbalanced load. STATCOM also be applied to utilities with weak grid knots or fluctuating reactive loads. In utility applications, a STATCOM provides leading or lagging reactive power to achieve system stability.

Fig4. Schematic diagram of STATCOM controller to reactive power compensation using SPWM technique [9]
As shown in figure 4, the control strategy applied for STATCOM consist of two control loops. An outer voltage regulation loop consist AC voltage measurement block which measure the system voltage $V_{ac}$ and compare with one reference value $V_{acRef}$. Output of error single is applied to the AC voltage regulator (PI controller) which generate the reference current $I_{qRef}$ for inner current loop. Outer regulation loop also consist the DC voltage measurement block, which measure the DC input voltage of VSC. $V_{dc}$ is compare with the some $V_{dcRef}$ value output of error signal is applied to the DC voltage regulator which generate the reference current $I_{dRef}$ for inner current loop. Where $I_d = $ Direct axis current (current in phase with voltage which controls the active power flow) $I_q = $ Quadrature axis current (current in quadrature with voltage which controls the reactive power flow).

An inner current regulation loop consisting AC current measurement block, which measure the system current using PLL block we extract $\theta$, by these $\theta$ and $I_a$, $I_b$, $I_c$ current, we can transformed $I_a$, $I_b$, $I_c$ to $I_d$, $I_q$ using dqo transformation (park transformation). These $I_d$ and $I_q$ compare with $I_{dRef}$ and $I_{qRef}$ respectively and output of these error signal is passing through the current regulators which consist the two separate PI controller which tuned to till the desired response is not get. PI controller is use due to it have low steady state error. Output of the PI controllers in current regulator is treated as $V_d$ and $V_q$. then using the inverse dq0 transformation (inverse park transformation) we gate $V_a$, $V_b$, and $V_c$ applying to PWM modulator where comparing the these modulating signal $V_u$, $V_b$, and $V_c$ with any carrier frequency signal, we get gate pulse for VSC switches.

The inner current loop is responsible for power quality issues like low THD and good power factor, whereas the outer voltage loop balance the power flow in the distribution system. Synchronous reference frame control is also called dq0 control which transforms the grid voltage and current into d-q frame. This transformed voltage detects the phase and frequency of grid whereas transformed current control the grid power. Thus the control variable becomes dc values hence filtering and controlling becomes easier.

V. MATLAB MODELLING OF STATCOM

In this section, the performance of STATCOM is studied with the SPWM based algorithm. The DC bus voltage of STATCOM is selected 800V nominal and its rated capacity is 100Ah for the system line voltage of 415V.

![Fig5. Simulation of STATCOM for reactive power compensation at distribution level](image)

The VSC is connected to the network through the AC inductor of 1.5mH. For self-supporting DC bus of STATCOM, a capacitor of 1000µF is used. Initially considered linear reactive load is 3-single phase load 20KW. The PCC line voltage is considered 440 V. The simulation results are taken for the above mentioned load conditions.

![Fig6. Subsystem for STATCOM Controller](image)

As shown in figure 6 the statcom controller consist the two loop, one is outer voltage or power contro loop and second is inner current control loop.

![Fig7. Subsystem for power regulator](image)
In this power regulator block mainly sense the voltage and current at grid and form this using p-q theory calculation gives corresponding active power P and reactive power Q. This active power P and reactive power Q is separately compare with it’s per unit system value and this two error signals are gives to two separate PI controllers. Output of these two PI controllers is obtaining reference value of I_d current (I_{dref}) and reference value of I_q current (I_{qref}).

As shown figure 8, this current regulator block is mainly use for getting triggering pulses for inverter switches. Here we take inverter output current as reference and convert to I_d and I_q respectively and output of this error signal is give in to PI controller, which is generate the modulating signal. These modulating signals are converted back into three phase signal and compared with high frequency carrier signal which generates series of gating signal for inverter switches.

![Image](image.png)

**Fig8. Subsystem for current regulator**

**VI. RESULTS ANALYSIS**

In this section we analyzing simulation result for two different cases.

**Case1: Voltage Sag**

When distribution system voltage (400V) is less than the nominal voltage (415 V), which is applied at t=1.5 sec. the similarly the PCC voltage is fall from 440V to 415 V at t=1.5 sec. control change such that V_PCC is 440V by supplying the reactive power by STATCOM. Actually before fall in voltage STATCOM absorb the reactive power at t <1.5 sec with voltage fall STATCOM supplying reactive power. From figure 9 we can easily show that by supplying reactive power, it maintains the PCC voltage constant. There is nothing doing with active power and 800V dc is constant.

![Image](image.png)

**Fig9. Waveform of system voltage, PCC voltage, reactive power, active power, and DC input voltage w.r.t. time in sec at Sag condition.**

**Case2: Voltage Swell**

When distribution system voltage (440V) is more than the nominal voltage (415 V) which is applied after t=1.5 s. the similarly the PCC voltage is rise from 440V to 460 V at t=1.5 sec. control change such that V_PCC is 440V by absorbing the reactive power by STATCOM. Actually before rise in voltage STATCOM supplying the reactive power at t <1.5 sec, with voltage rise at t >1.5 sec STATCOM absorbing the reactive power. We easily show that reactive power is absorb and maintain the PCC voltage maintain constant. There is nothing do with active power and 800V dc is constant.

![Image](image.png)

**Fig10. Waveform of system voltage, PCC voltage, reactive power, active power, and DC input voltage w.r.t. time in sec at Swell condition**
VII. CONCLUSION

From above simulation of STATCOM is carried out with SPWM control technique for voltage sag and voltage swell mitigation. The DC bus voltage of STATCOM has been regulated to its reference value. The algorithm and STATCOM has been found very effective for voltage sag and voltage swell condition. It has been observed that STATCOM is capable to regulate the PCC voltage at reference voltage with compensation of reactive power demanded by load. This shows that no voltage disturbance on the distribution system during the transition of voltage due to unbalanced load. From these we concluded that STATCOM has a huge scope in improving power quality levels in distribution system.

REFERENCES