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Compensation of Reactive Power by Using STACOM under Dynamic Voltage SAGS



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Abstract:
This paper introduces a new reactive current reference generator, which employs a current set point instead of the usual reactive power set point. Paper presents a complete control scheme intended for synchronous compensators operating under these abnormal network conditions. In particular, this control scheme introduces two contributions: a novel reactive current reference generator and a new voltage support control loop. The generator has as main feature the capacity to supply the required reactive current even when the voltage drops in amplitude during the voltage sag.

Key words: ***FACTS technology, PQ improvement, Control Strategies, voltage sags.***

INTRODUCTION

Power quality determines the fitness of electrical power to consumer devices. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life. The term is used to describe electric power that drives an electrical load and the load's ability to function properly. Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all.

There are many ways in which electric power can be of poor quality and many more causes of such poor quality power. Centralized power generation systems are facing the twin constraints of shortage of fossil fuel and the need to reduce emissions. Long transmission lines are one of the main causes for electrical power losses. Therefore, emphasis has increased on distributed generation (DG) networks with integration of renewable energy systems into the grid, which lead to energy efficiency and reduction in emissions.

Smart control devices like STATCOM (Shunt Active Power Filter), DVR (Series Active Power Filter) and UPQC (Combination of series and shunt Active Power Filter) are the latest development of interfacing devices between distribution supply (grid) and consumer appliances to overcome voltage/current disturbances and improve the power quality by compensating the reactive and harmonic power generated or absorbed by the load. This paper deals with a technical survey on the research and development of PQ problems related to solar and wind energy integrated to the grid and the impact of poor PQ.
Reactive power compensation is an important issue in distribution system. If the reactive current increases, the system losses also increase. Various methods have been applied to mitigate voltage sags. For voltage sag mitigation we generally use capacitor banks, parallel

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feeders etc. But the power quality problems are not completely solved by using these devices.

A STATCOM is a voltage source converter (VSC)-based power electronic device. Usually, this device is supported by short-term energy stored in a dc capacitor.

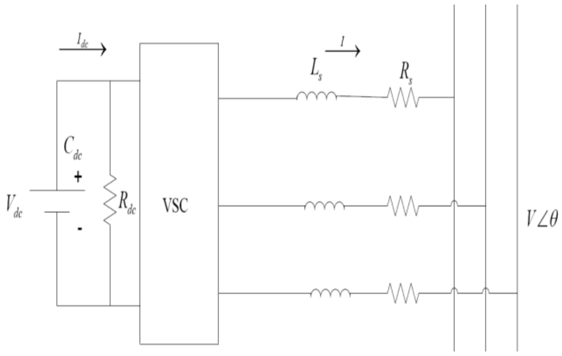

Fig 1: STATCOM equivalent circuit

The STATCOM filters load current such that it meets the specifications for utility connection. If properly utilized, this device can cancel the following:
The effect of poor load power factor such that the current drawn from the source has a near unity power factor;
• The effect of harmonic contents in loads such that current drawn from the source is sinusoidal;
• The effect of unbalanced loads such that the current drawn from the source is balanced;
• The dc offset in loads such that the current drawn from the source has no offset.

STATCOM (STATic COMpensator)

The following features followed by STATCOM:
• This device is connected to the line as a shunt mode.
• This device is based on voltage source inverter (VSI).
• In this device there are no chances of resonance phenomenon.
• Using this device the reactive power supported to the system or bus i.e. enhances voltage profile of the system.

The power circuit topology includes a three-phase VSC, a dc-side capacitor Cdc, and an LCL output filter. In transmission and distribution power systems, the STATCOM is normally connected to the point of common coupling (PCC) through a step-up transformer. Inductor Lo represents the leakage inductance of the STATCOM transformer (the magnetizing inductance is not considered here).

The electrical network is represented by grid impedance (Rg and Lg) in series with an ac voltage source. The grid impedance physically models other power system transformers as well as the line impedance. Note that the values of Rg, Lg, and vg are the reflected quantities to the primary side of the STATCOM transformer.
The voltage at the PCC and the current at the converter side i are sensed and supplied to the control system. This current is preferred for control purposes instead of the current at the ac network side (flowing through Lo) due to the improvement achieved in the system robustness.

Focus on the STATCOM operation and performance under abnormal network conditions.

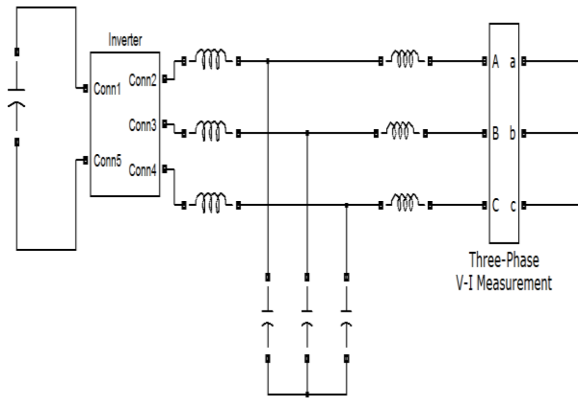

Fig 2: simulation design of STATCOM

As probably the most severe cause of malfunctioning of grid-connected equipment is unbalanced voltage sags, this is the usual source of abnormal situations considered in these studies. Voltage sags typically tend to deteriorate the performance of the power converters and electrical machines connected to the ac network. In particular, a reduction of the power quality is noticed in this equipment, which is caused by a ripple in the output power and an increase in the current harmonic distortion.

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Several control schemes have been recently introduced to cope with these problems. Voltage deviations were reduced in the ac network by injecting negative-sequence reactive power. A coordinated control that supplies both positive-sequence and negative sequence reactive power was introduced. This study reveals that it is possible to simultaneously correct the deviation in the positive-sequence voltage and attenuate the negative sequence voltage to a preset value.

The theoretical limits of the reactive power delivered to the ac network were established in order to ensure that the maximum output current is not exceeded during the voltage sag, thus guaranteeing a safe STATCOM operation. The interesting results presented in this paper were extended to other reactive power control strategies.

CONTROL STRATEGIES

The control system for the STATCOM should provide control input u in accordance to the following objectives.

1) The capacitor voltage Vdc should be regulated to the dc voltage set point V ∗ dc. This ensures the absorption of a small active power from the ac network necessary to compensate for power losses.

2) The maximum current should not be exceeded. A current set point I∗ is employed in the control system to perform this task.

3) The PCC voltage should be regulated between set points V*max and V*min, which are the maximum and minimum voltages at the PCC, respectively. Three control strategies to set the values for these set points during unbalanced voltage sags are presented and discussed.

The control consists of an external voltage loop, an internal current loop, and a space vector modulator. The internal loop is a tracking regulator designed to provide fast and accurate current control. Proportional and resonant regulators are employed for this task.

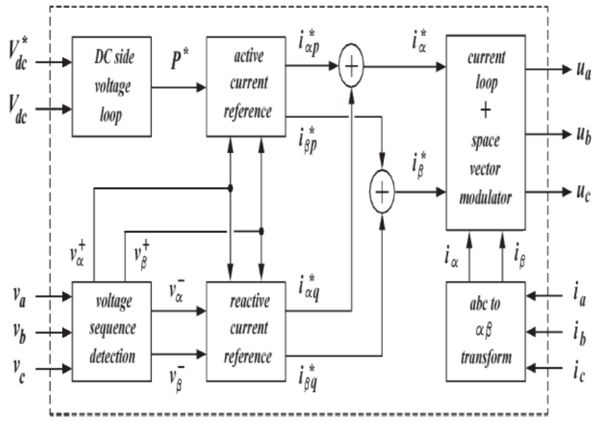

Fig 3: The STATCOM control system.

The expressions of the reference signals that fix the maximum amplitude of the phase currents to a predefined value (i.e., the set point I*) are deduced. This objective should also be reached when the phase currents are unbalanced. In addition, at the end of this section, the mechanism of reactive power injection of the proposed current reference generator is revealed through the analysis of the positive- and negative-sequence reactive power. Note that the injected current could be easily limited to fixed maximum amplitude by using a standard reactive power control in cascade with a current limiting block. However, in this case, the injected current will be clipped during an over current condition, resulting in an unacceptable total harmonic distortion. As shown in the following, the proposed current generator limits the maximum amplitude to a predefined value without distorting the current waveforms. As the active power is only employed to compensate for power losses, the active current is negligible in relation to the reactive current.

The aim of this section is to devise a voltage control loop that provides the values of the set point I* and the control gain kq according to the PCC voltage set points V* max and V*min. Then, by setting different values for these voltage set points, several voltage support control strategies can be defined. It is easy to observe that the current set point I* controls the reactive power delivered to the ac network.

In fact, by increasing the current set point, a higher injection of reactive power is achieved, which also

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increases the positive sequence voltage at the PCC. Therefore, this set point is employed here to regulate the positive-sequence voltage V^+ to the reference $(V^+)^*$. Moreover, the control gain kq allowsa balanced injection of reactive current through positive andnegative sequences. In particular, the negative-sequence voltageat the PCC decreases, by decreasing the value of the gain kq. As a result, this control gain is used to regulate thenegative-sequence voltage $V^-$to the reference $(V^-)^*$.

According to the given discussion, the diagram of the proposedvoltage support control scheme is shown in Fig. 3. Itincludes the reactive current reference generator derived inSection III and the voltage set-point generator presented in thissection. The value of the current set point I* is generated bya PI regulator, fed by the error between the positive-sequencevoltage and its voltage set point. In addition, a PI regulator,fed by the error between the negative-sequence voltage andits voltage set point, produces the value of the control gainkq. The outputs of these two regulators are limited by themaximum values allowed for these two variables, as shown in Fig. 3. Note that the voltage set points V*max and V*min areinputs to this control scheme. To complete the implementationof the proposed generator, however, it is necessary to derivethe expressions that relate the voltage set points V*max and V*minwith the voltage symmetrical component set points $(V^+)^*$ and (V−)*. This derivation is carried out in the following.

The first control strategy, known from now on as control strategy 1 (CS1), is devised for nominal ac voltage operation range. In this case, the voltage regulation is ideally achieved by setting the following voltage set points:

V*max = 1.01Vnom, V*min = 0.99Vnom

A simple way to reduce the reactive current injection is to set the voltage set points to the limits specified in grid codes for normal operation. This setting defines the second control strategy, known as control strategy 2 (CS2), which can be formulated as

V*max =1.10Vnom, V*min =0.88Vnom

The dynamic set points for CS3 can be written as

V*max = [1.10 − kp, I (Imax – I*)] Vnom,

V*min = [0.88 + kp, I (Imax – I*)] Vnom

Where kp, I is a proportional term gain. Therefore, CS3 can be viewed as an intermediate solution between CS1 and CS2. Note that, when the current set point I∗ is coming near to the maximum current Imax, then CS3 voltage set points approach to CS2 set points. On the contrary, when the current set point comes close to 0 A, the maximum deviation of CS3 set points is obtained. Obviously, this deviation must be saturated by the limits defined. Thus, in this situation, the CS3 strategy is approaching to the CS1 strategy. To sum up, an adaptive voltage positioning is proposed, which reduces the negative-sequence voltage at the PCC by setting intermediate voltage set points.

SIMULATION RESULTS

The proposed STATCOM was tested with voltage sag presented. This eventhas a largesteady-state imbalance (see the time interval from 0 to 0.1 sor from 0.35 to 0.5 s) and a variable voltage profile during thetransient state (see the time interval from 0.1 to 0.35 s). For thisreason, the chosen voltage sag is a good candidate to evaluatethe performance of the proposed control solution in adversestringent network conditions.

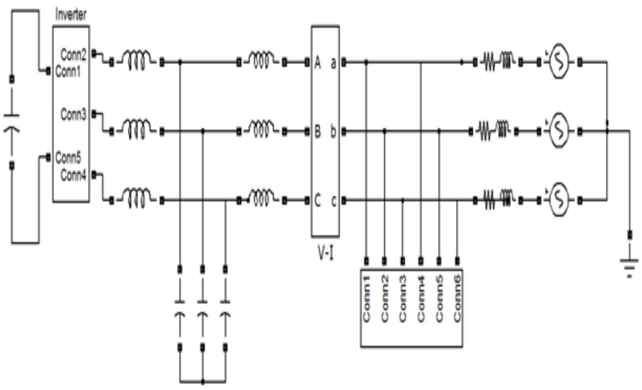

Fig 4: simulation design of the power system, including the STATCOM

Note that the amplitude of the other phases is changing over time (always with a value lower than the specified rated current) as a result of the variable voltage sag profile. The next set of experiments was conducted to evaluate the voltage support control strategies presented. In this case, the voltage control loops were activated, providing variable values for the current set

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point I*and the control gain kq in accordance with the considered control strategies.

The STATCOM operation in steady state and under the voltage sag is illustrated. Three experiments were carried out by using CS1, CS2, and CS3 during the voltage sag. Note that, in steady state, the CS1 was employed in the three experiments. Excellent results were achieved in steady state, in comparison with the waveforms depicted, when the STATCOM was activated, the voltage at the PCC was inside the range defined by the CS1 voltage set points.

This fact can be clearly observed. (See, in particular, the time interval from 0 to 0.1 s.) As a consequence, the negative-sequence voltage at the PCC was nearly eliminated during steady state with a reactive current of 0.5 p.u. and a control gain kq = 0.02. This corresponds to a positive-sequence reactive power of 0.27p.u. And a negative sequence reactive power of 0.02 p.u. The performance of the proposed control strategies during the voltage sag can be clearly. Poor results were obtained with CS1; Note that the voltage at the PCC does not track the voltage set points expressed from 0.1 to 0.35 s. In fact, this voltage is even lower than the 0.88-p.u. limit during a certain time interval. This is due to the saturation of the voltage support control loops, as can be observed.

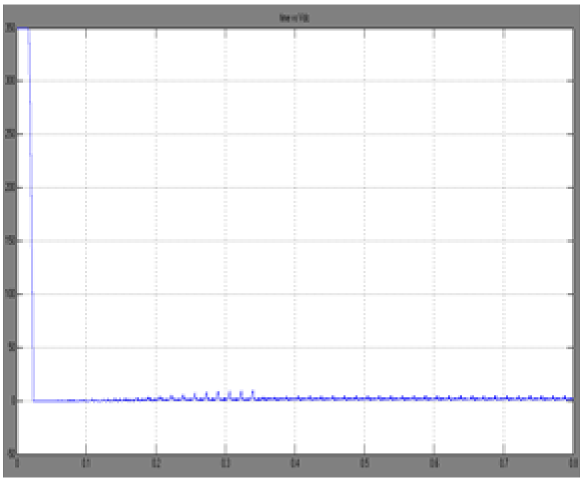

Fig 5: Simulation wave form of DC input voltage for STATCOM

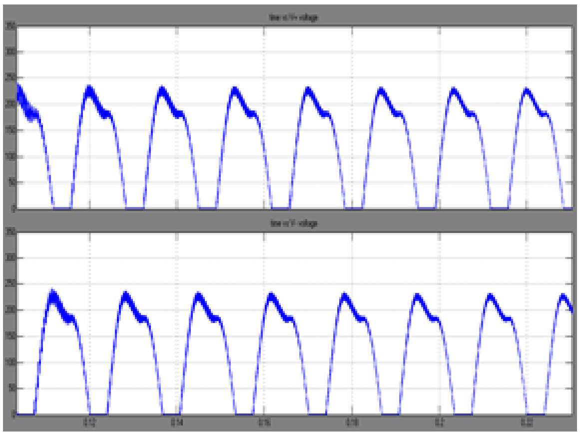

Fig 6: Simulation wave forms of V+ voltage loop and V- voltage loop

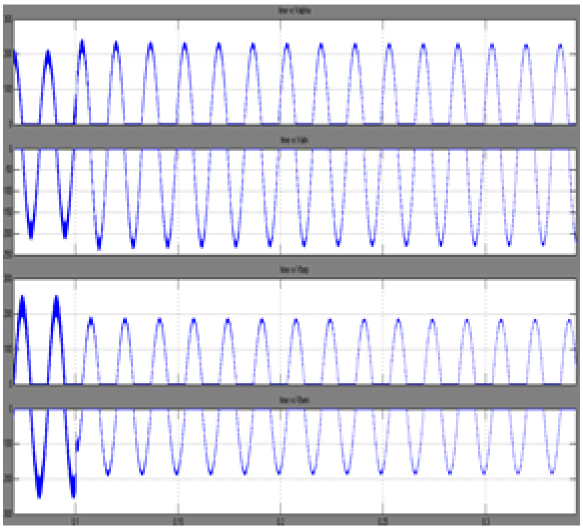

Fig 6: Simulation wave form of Valpha+, Valpha-, Vbeeta+, and Vbeeta-

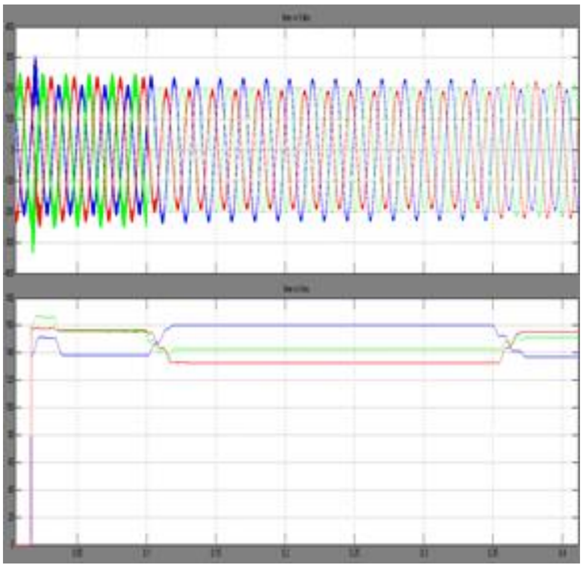

Fig 7: AC network voltage and rms current for CS1

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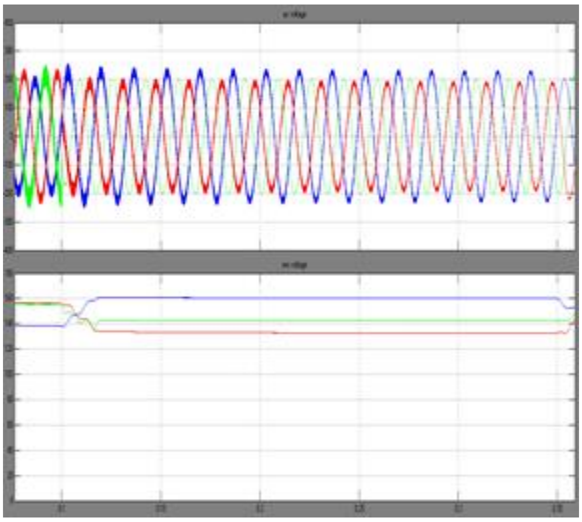

Fig 8: AC network voltage and corresponding RMS voltage for CS2.

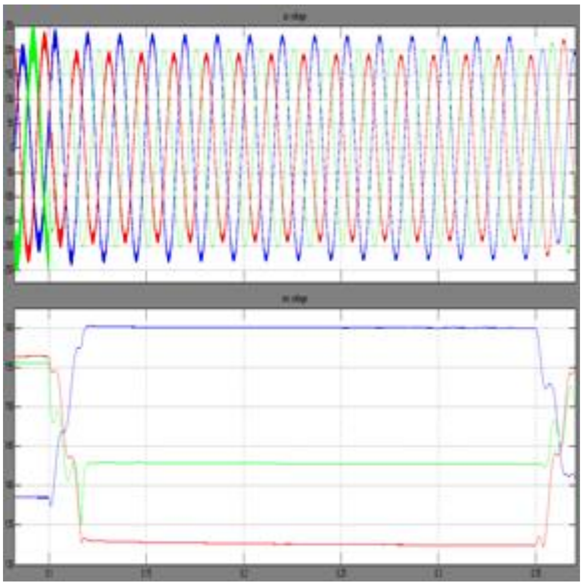

Fig 9: AC network voltage and corresponding RMS valueCS3.

CONCLUSION

This paper presents a novel STATCOM-based controlscheme of FACTS device for power quality improvement. Three control strategies are proposedto verify the effectiveness of the control scheme under severeunbalanced voltage sags.In comparison with existingvoltage control loops based on a voltage-reactive power droopcharacteristic, the proposed control ensures an accurate voltageregulation to a predefined voltage set point provided that theSTATCOM rated power and the impedance of the ac networkare large enough.

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