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Voltage Control Strategies for Static Synchronous Compensators under Unbalanced Line Voltage Sags

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ABSTRACT: Static synchronous compensators have been broadly employed for the provision of electrical ac network services, which include voltage regulation, network balance, and stability improvement. Several studies of such compensators have also been conducted to improve the ac network operation during unbalanced voltage sags. This 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 current reference generator has as a main feature the capacity to supply the required reactive current even when the voltage drops in amplitude during the voltage sag.

Thus, a safe system operation is easily guaranteed by fixing the limit required current to the maximum rated current. The voltage control loop is able to implement several control strategies by setting two voltage set points. In this paper, three voltage support control strategies are proposed, and their advantages and limitations are discussed in detail. The two theoretical contributions of this paper have been validated by experimental results. Certainly, the topic of voltage support is open for further research, and the control scheme proposed in this paper can be viewed as an interesting configuration to devise other control strategies in future works.

I. INTRODUCTION

The traditional configuration of the electrical ac network is nowadays changing. High penetration of renewable energy sources, located close to the point of power consumption, is noticed in recent years . With small transmission and distribution distances, power losses are clearly reduced. In addition, the reduction of the network congestion,the improvement of local power quality, and the provision of ancillary services are notable advantages of the present distributed power generation scenario [2]. Reactive power exchange with the ac network is one of the ancillary services provided by the distributed renewable energy sources. This service can be used to greatly increase the margin to voltage collapse and, thus, to improve the stability of the electrical network. Reactive power is also employed for voltage regulation, network balance, and voltage support during transient abnormal conditions .Distributed renewable energy sources with low rated power traditionally use reactive power control to govern directly the power factor of the installation. As the generation capacity rises, voltage control is the preferred choice since the ability of these high power sources to influence the terminal voltage increases in this case. The evolution of grid codes for wind power plants clearly illustrates this idea. Most of the previous and current grid codes consider wind power plants as marginal energy sources and specify reactive power (current) injection requirements Some grid codes that require voltage control have recently emerged as the penetration of wind power is growing significantly. In these codes, the voltage regulation is linked with the reactive power injection normally by means of $V-Q$ curves. In a future scenario, where the penetration of the distributed power plants will be high enough to replace some conventional power generators, the voltage regulation should be carried out by positioning the terminal voltage at a predefined level. This operation will overcome the traditional steady-state error observed in the droop $V-Q$ voltage control.

The capacity of reactive power compensation by renewable energy sources is limited. These sources, interfaced by power inverters, are mainly conceived to export all available active power; thus, the power rating of the inverters is easily achieved. In addition to energy sources, constant power loads can also supply reactive power to the electrical

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network . Interfaced by active rectifiers, these widely used loads absorb constant active power from the ac network. However, they can exchange only a small amount of reactive power according to the power rating of the active rectifier. As an interesting alternative to renewable energy sources and constant power loads, static synchronous compensators. can also be regarded as fast voltage–ampere (VA) sources. In fact, STATCOMs are grid-connected voltage source converters (VSCs) normally dedicated to reactive power injection. Active power is consumed in the STATCOM during the system startup (to charge an internal dc-side capacitor). In the steady state, the active power absorption is very small, and it is only used to compensate for power losses. Consequently, the VA rating of the STATCOM is generally dedicated to reactive power exchange.

II. LITERATURE SURVEY

Power Generation and Transmission is a complex process, requiring the working of many components of the power system in tandem to maximize the output. One of the main components to form a major part is the reactive power in the system. It is required to maintain the voltage to deliver the active power through the lines. Loads like motor loads and other loads require reactive power for their operation. To improve the performance of ac power systems, we need to Manage this reactive power in an efficient way and this is known as reactive power Compensation. There are two aspects to the problem of reactive power compensation: load compensation and voltage support. Load compensation consists of improvement in power factor, balancing of real power drawn from the supply, better voltage regulation, etc. of large fluctuating loads. Voltage support consists of reduction of voltage fluctuation at a given terminal of the transmission line. Two types of compensation can be used: series and shunt compensation. These Modify the parameters of the system to give enhanced VAR compensation. In recent years, static VAR compensators like the STATCOM have been developed. These quite satisfactorily do the job of absorbing or generating reactive power with a faster time response and come under Flexible AC Transmission Systems (FACTS). This allows an increase in transfer of apparent power through a transmission line, and much better stability by the adjustment of parameters that govern the power system i.e. current, voltage, phase angle, frequency and impedance.

III. STATCOM

STATCOM technology has been extensively studied and developed in literature. Investigation of new power circuit topologies that improve the performance of existing Configurations was reported in . Control design issues and performance optimization can be found in . The operation and integration of the STATCOM in a weak ac network was analyzed in [23]. Most studies, however, focus on the STATCOM operation and performance under abnormal network conditions [24]–[30]. 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.

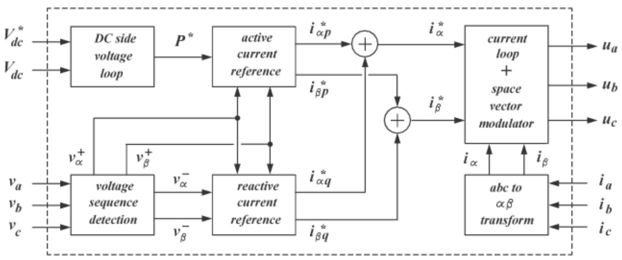

Diagram of the power system, including the STATCOM and the model of the electrical ac network

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. 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 in. A coordinated control that supplies both positive-sequence and negative sequence reactive power was introduced in. This study reveals that it is possible to simultaneously correct the deviation in the positive-

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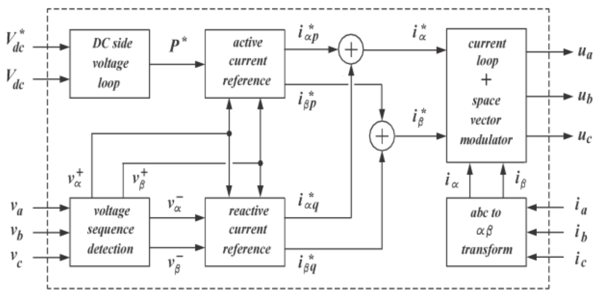
sequence voltage and attenuate the negative sequence voltage to a preset value. In, the theoretical limits of the reactive power delivered to the ac network were established in order to ensure that the maximum output current is not exceeded during the voltage sag, thus guaranteeing a safe STATCOM operation. The interesting results presented in this paper were extended in to other reactive power control strategies. This paper presents a flexible voltage support control loop with two voltage set points. By setting the values of these set points, different control strategies for voltage support can be devised. In this paper, three strategies are proposed, and their advantages and limitations are discussed in detail. The first strategy sets the set points as in normal network operation. The performance of This strategy during the voltage sag is good enough if the current limit is not reached. Otherwise, the control saturates, and the System operation is clearly deteriorated. As an alternative, two control strategies are thus introduced to cope with this saturation problem. Section II presents the STATCOM considered in this paper.

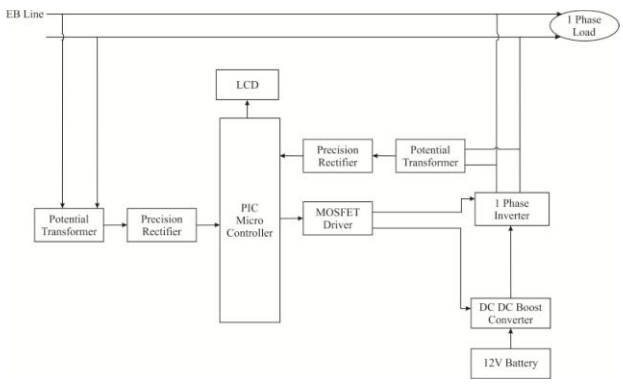
Section III introduces the new reactive current reference generator. Section IV derives the voltage control scheme and proposes several voltage support control strategies. The advantages and limitations of the proposed strategies are discussed. Section V validates the theoretical contributions by experimental
results. Section VI is the conclusion.

3.1 SYSTEM DESCRIPTION

This section describes the STATCOM, including the power circuit topology and the control system. In addition, it introduces the basic concepts necessary to study the system.



Block Diagram



3.2 Control System

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 (see Section III).

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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 in Section IV. The previous objectives are accomplished with the control system shown in Fig. 2. 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. In the Laplace domain, these compensators are implemented by the following transfer function (both in α and β current channels.

IV. REACTIVE CURRENT REFERENCE GENERATOR

The first contribution of this paper is a reactive current reference generator. This section is devoted to the derivation of this generator. In particular, in this section, 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. Therefore, only reactive current reference is considered in this section.

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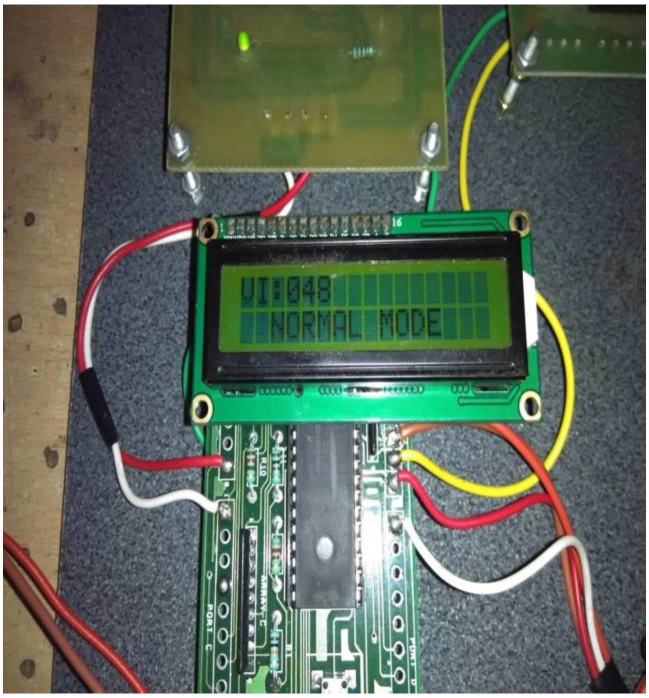
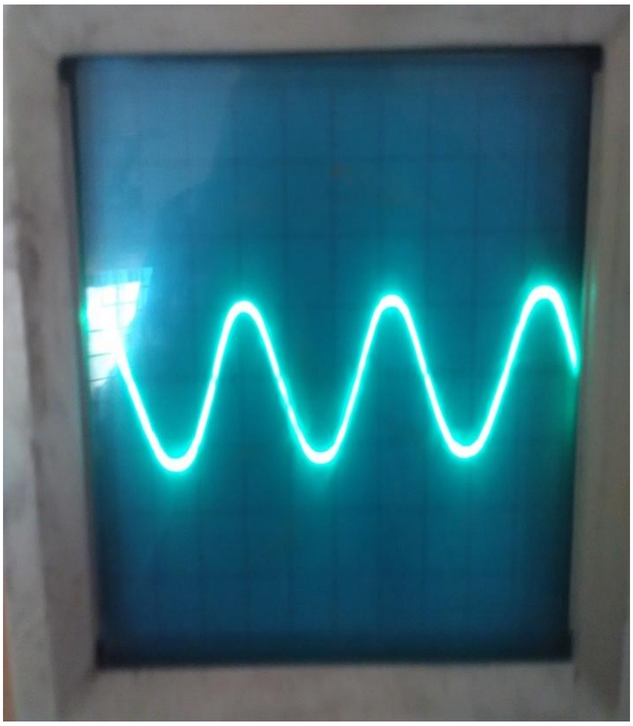
NORMAL MODE OPERATION

Normal mode



Line Voltage Waveform (reference Voltage = 48V Ac)



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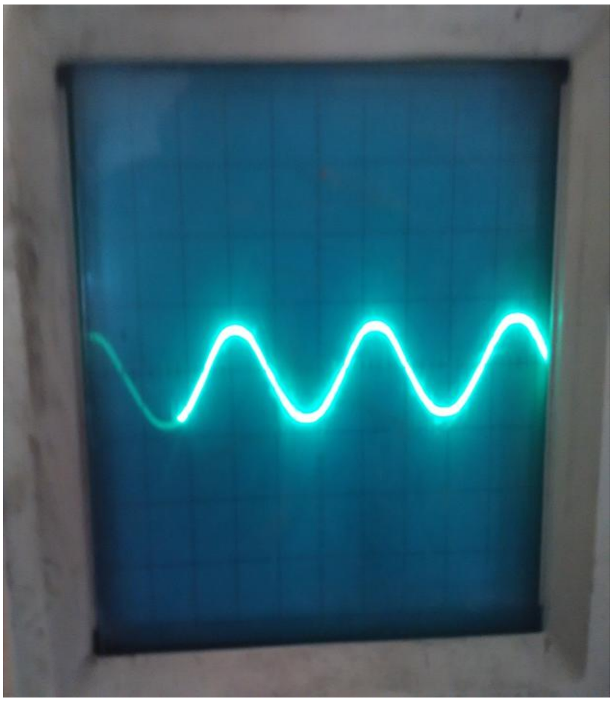
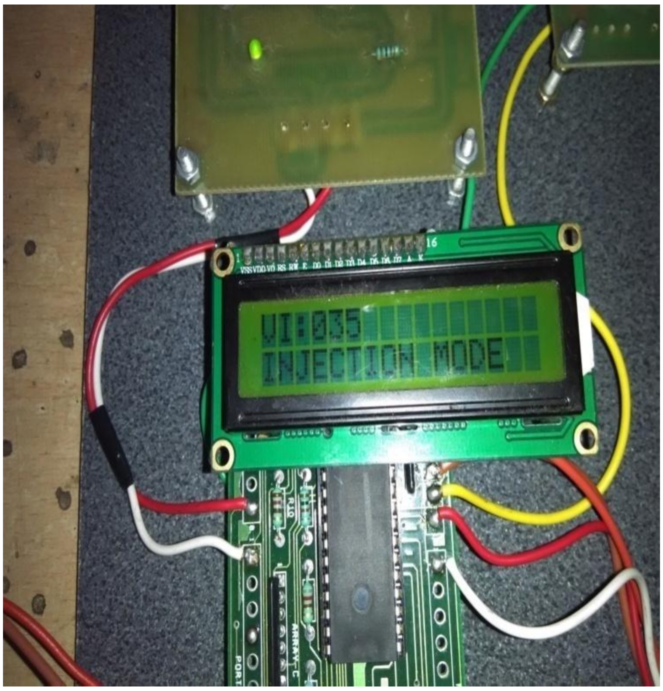
INJECTION MODE OPERATION

Line Voltage Low Waveform (35v Ac)



Injection Mode



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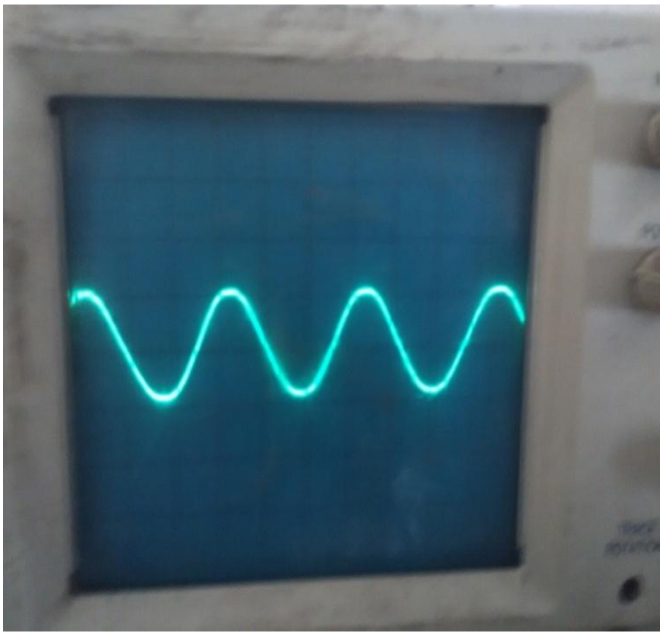
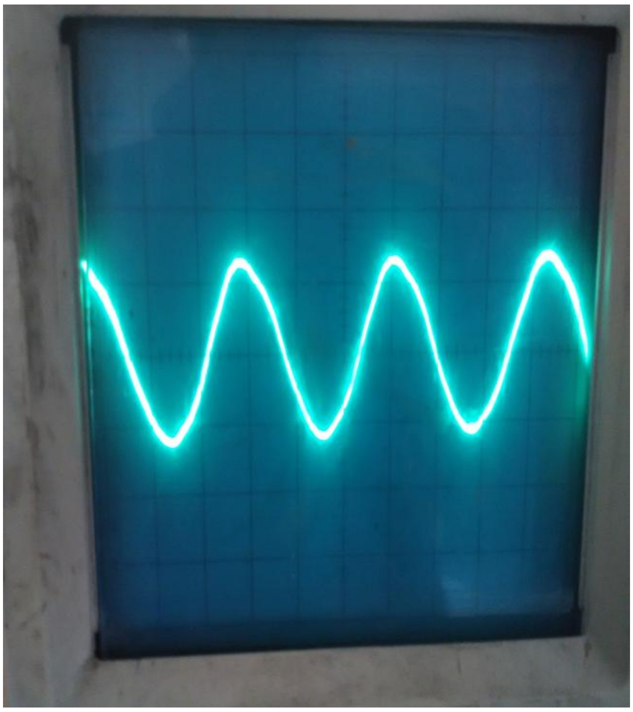
Injection mode Line voltage Improvement waveform (48v Ac)



BUCK MODE OPERATION
Line Voltage High Waveform (56v Ac)



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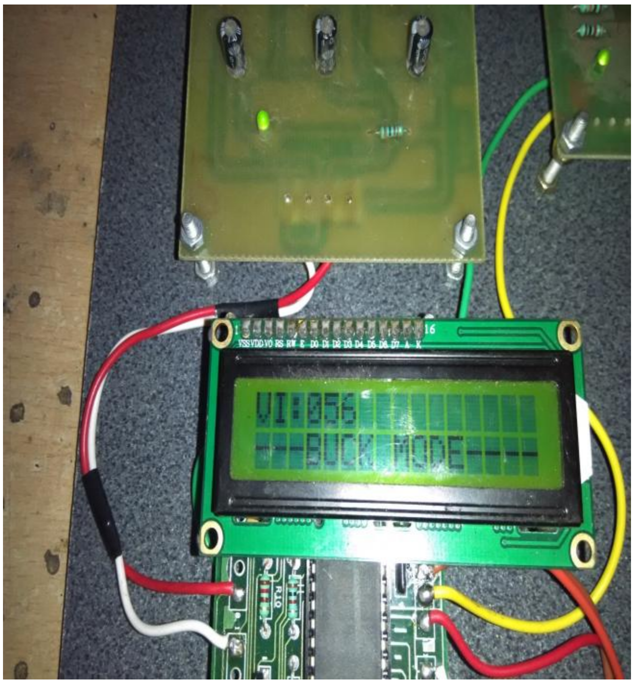
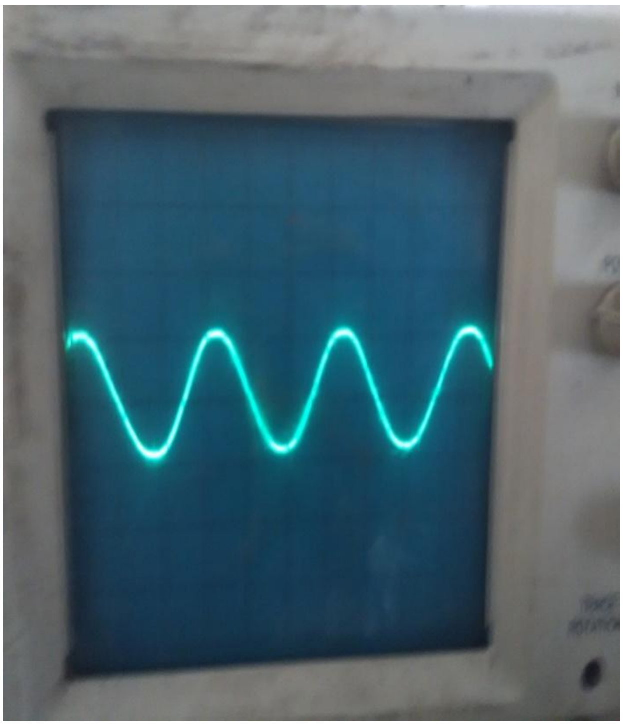
BUCK MODE



Buck mode Line voltage Control waveform (48v Ac)



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V. CONCLUSION

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 study, the injected current will be clipped during an over current condition, resulting in an unacceptable total harmonic distortion. 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. This experiment output is given below,

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