



## Voltage Support Control Strategies under Unbalanced Voltage Sags for Static Synchronous Compensators.

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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.*

**Index Terms**—Power quality, reactive power control, static synchronous compensator (STATCOM), voltage sag.

### 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 . 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.

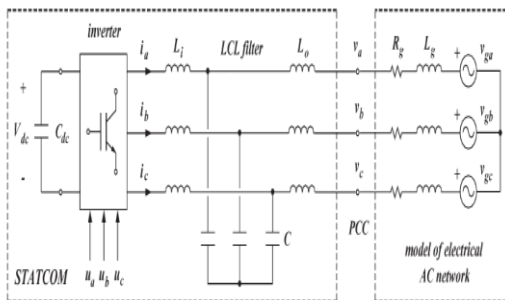


Diagram of the power system, including the STATCOM and the model of the electrical ac network.

### Existing System:

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 Fig. 1 shows the diagram of the STATCOM considered in this paper. The power circuit topology includes a three-phase VSC, a dc-side capacitor  $C_{dc}$ , 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. In Fig. 1, inductor  $L_o$  represents the leakage inductance of the STATCOM transformer (the magnetizing inductance is not considered here). The electrical network is represented by a grid impedance ( $R_g$  and  $L_g$ ) 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  $R_g$ ,  $L_g$ , and  $v_g$  are the reflected quantities to the primary side of the STATCOM transformer.

### Proposed System:

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 a 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.

### VOLTAGE SUPPORT CONTROL STRATEGIES

The second contribution of this paper is a voltage support control scheme intended for STATCOMs under unbalanced voltage sags. This section is devoted to the derivation of this voltage control. In addition, three voltage support control strategies are introduced and discussed in detail.

#### Control Objectives

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. From (33) and (34), 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 increases the positive sequence voltage at the PCC [29]. Therefore, this set point is employed here to regulate the positive-sequence voltage  $V^+$  to the reference  $(V^+)^*$ . Moreover, the control gain  $kq$  allows a balanced injection of reactive current through positive and negative sequences. In particular, the negative-sequence voltage at the PCC decreases, by decreasing the value of the gain  $kq$ . As a result, this control gain is used to regulate the negative-sequence voltage  $V^-$  to the reference  $(V^-)^*$ .

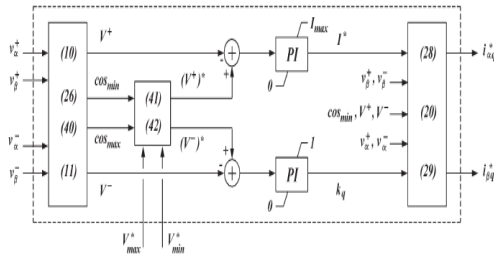
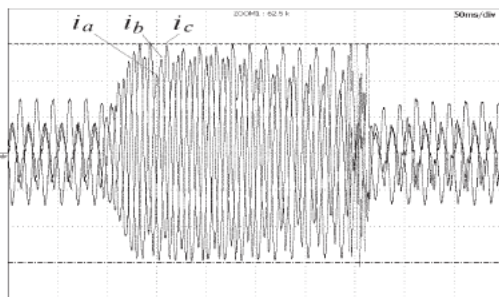


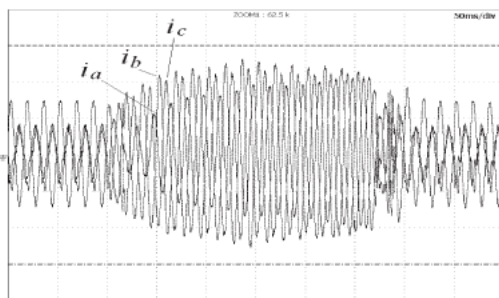
Diagram of the proposed reactive current reference generator with voltage support auxiliary service.

**EXPERIMENTAL VALIDATION**

This section validates the theoretical contributions of this paper by experimental results. Two sets of experiments are reported to confirm the features of the reactive current reference generator and the voltage support control scheme.



EXPERIMENT 1: steady state: CS1, voltage sag: CS1 (a)

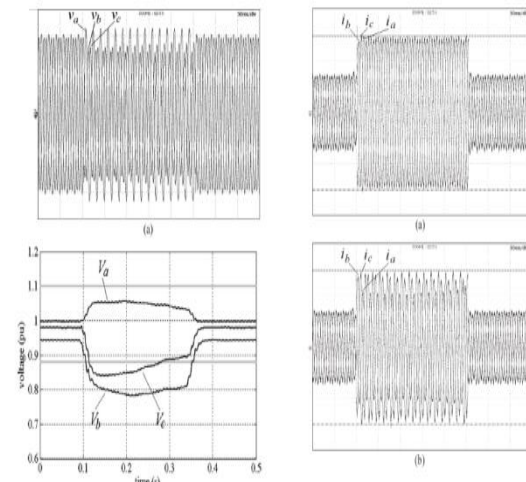


EXPERIMENT 2: steady state: CS1, voltage sag: CS2 (b)

**Experimental Setup**

A laboratory prototype of the power system shown in Fig. 1 was build using a Semikron three-phase insulated-gate bipolar transistor inverter and a programmable Pacific Power ac power supply. The nominal values for the power system parameters are listed in Table I. The control system shown in Figs. 2 and 4 was implemented in a TMS320F28335 floating

point digital signal processor from Texas Instruments. The bandwidths of the internal and external control loops were conveniently separated, i.e., 1.2 kHz and 60 Hz, respectively, to avoid undesired interactions. Table II lists the control parameters that fulfill this requirement.



**CONCLUSION**

A complete control scheme intended for STATCOMs operating under unbalanced voltage sags has been presented in this paper. The first contribution is a reactive current reference generator programmed with a current set point instead of the conventional reactive power set point. As an interesting feature, this generator guarantees a safe operation of the STATCOM by naturally limiting the amplitude of the current delivered to the ac network. The main advantage in comparison with previous reference generators is that the online calculation of the maximum reactive power is not required since the output limits in the proposed algorithm are constant values even in the presence of grid voltages with imbalances. The second contribution is a voltage control loop that makes possible the introduction of several voltage support control strategies by simply modifying two voltage set points. Three control strategies are proposed to verify the effectiveness of the control scheme under severe unbalanced voltage sags. The CS1 has good results in normal network conditions but has poor results during abnormal conditions with significant voltage imbalance. In fact,



a STATCOM with higher power rating is required to supply the necessary reactive current to fulfill the requirements specified by the CS1. The CS3 and CS3 relax the stringent specifications of CS1 and provide good results during the unbalanced voltage sag by changing the position of the voltage set points.

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