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# Digital implementation of an advanced static compensator for voltage profile improvement, power-factor correction and balancing of unbalanced reactive loads

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**Abstract**

In this paper, a three-phase advanced static compensator (STATCOM) is proposed to compensate reactive power either for regulating ac supply voltage at a constant value or for unity power-factor and balancing of unbalanced reactive loads. An insulated gate bipolar transistor (IGBT) based current controlled pulse width modulated (CC-PWM) and voltage source inverter (VSI) is employed as the STATCOM. A TMS320C31 DSP is used to implement the control algorithm of the STATCOM. To regulate the instantaneous ac supply voltage across the load through shunt reactive power compensation, a sliding mode controller (SMC) over the amplitude of supply voltage is used to obtain a reactive component of the reference supply current in quadrature with the supply voltage. Another SMC over the voltage of a self-supporting dc bus of the STATCOM is used to compute an active component of reference supply current in-phase with the supply voltage. An indirect PWM current control over the reference (computed) and sensed supply current is employed to generate the gating pulses of the IGBTs of the STATCOM. Test results are presented and discussed in detail to demonstrate the reactive power compensation for terminal voltage regulation and power-factor correction along with load balancing capabilities of the proposed advanced STATCOM. 

*Keywords:* Advanced static compensator; Voltage source inverter; Voltage regulation; Power-factor correction; Load balancing

## 1. Introduction

In three-phase ac systems, most of the loads are lagging power-factor in nature, which need reactive power resulting in reduction in ac terminal voltage, low efficiency and poor utilization of the ac network. In addition, there is also some load unbalancing because of unequal loading of three-phases of ac supply, resulting in voltage unbalance, fluctuations and disturbance to other consumers. The problems of reactive power deficits at different points in the ac network and load unbalancing have been recognized long ago. Many attempts [1–14] have been made to study, analyze and to compensate reactive power at different levels of the ac system, and balancing the unbalanced loads using passive (L-C) and active (solid state) elements. Gyugyi [1], Miller [2], Tremayne [4], Mathur [5], El-Sadak [8], Byerly et al. [3], Kneschke [7], Kearly et al. [10], Czarnecki [11], and Kern et al. [13] have reported the load balancing and reactive power compensation for power-factor improvement and voltage regulation using less-loss reactive elements. Some of them have used thyristor controlled reactors along with capacitors to achieve a smooth and stepless compensation, which introduces harmonics and switching surges in the system. Akagi et al. [6] and Furuhashi et al. [9] have developed the concept of instantaneous reactive power compensation, but these are confined only to balanced systems. Dixon et al. [14] have reported a control system for active power-filter for load balancing, which has neither a self-supporting dc bus nor an ac voltage regulation. Bhavaraju and Enjeti [12] have reported an active power-filter for load balancing only, and have

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used CSI configuration which requires a heavy dc inductor and large ac capacitors.

This paper aims to develop an advanced static compensator (STATCOM) for reactive power compensation and balancing the unbalanced reactive loads in a three-phase ac system. The STATCOM uses a voltage source inverter (VSI) with the structure as reported in literature [6,14]. A generalized control algorithm of the advanced STATCOM is implemented on a TMS320C31 DSP [15], which either can regulate ac load terminal voltage or can improve power-factor to unity along with load balancing, while maintaining a self-supporting dc bus of the STATCOM. Reference supply currents are computed using ac load terminal voltage and dc bus voltage of the STATCOM. Carrier wave based pulse width modulated (PWM) current control over reference and sensed supply currents are employed to generate the gating pulses of the insulated gate bipolar transistors (IGBT) of the STATCOM. Test results are presented and discussed in detail to demonstrate the reactive power compensation for load terminal voltage regulation and power-factor correction along with load balancing features of the advanced STATCOM.

## 2. System configuration and control scheme

Fig. 1 shows the basic building block of the developed advanced STATCOM system. The STATCOM consists of a three-phase ac mains (supply), having source impedance and three-phase unbalanced lagging power-factor loads. A three-phase IGBT based VSI bridge with input ac inductors and dc bus capacitor is used as the STATCOM. The control algorithm of the STATCOM is made generalized and flexible either to regulate ac load terminal voltage or to improve the power-factor of load to unity along with load balancing. Since these two features of voltage regulation and power-factor improvement are different [2], and cannot be achieved simultaneously with a pure reactive compensator, the control algorithm is made flexible to be set to either one of these two conditions. It also caters a self-supporting dc bus of the STATCOM along with the main objective of reactive power compensation and load balancing.

Fig. 2 shows the proposed control scheme of the STATCOM. The symbol '*' is used to denote reference values of voltage and current signals. In double subscripts, the first represents supply (s), load (l) and compensator (c) and the second subscript represents the phases a, b and c. The subscript dc represents dc bus quantities. The supply currents must feed only active power to load on the system for the unity power-factor and balanced condition, while they must also feed reactive power (leading/lagging) for lagging/leading power-factor loading, to regulate the ac load terminal voltage [2]. Therefore, for ac load voltage regulation and load balancing, the reference supply currents consist of two components; one in-phase with the supply voltages to feed active power of the load and the second one in quadrature with the supply voltage to supply reactive power. The amplitude ($I^*_{spd}$) of the in-phase component of reference supply currents is computed using the sliding made controller (SMC) over the dc bus voltage of the STATCOM. The amplitude ($I^*_{spq}$) of the quadrature component of reference supply currents is computed using another closed loop SMC over the amplitude of supply voltage. The three-phase sinusoidal variations of these two components of reference supply currents are obtained by multiplying their amplitudes by their respective unit current vectors and then adding them together, to derive the total three-phase reference supply currents. The three-phase reference supply currents are fed to the PWM current controller along with sensed supply currents. For the case of the unity power-factor operation, the amplitude ($I^*_{spq}$) of the quadrature component of the reference supply current is set to

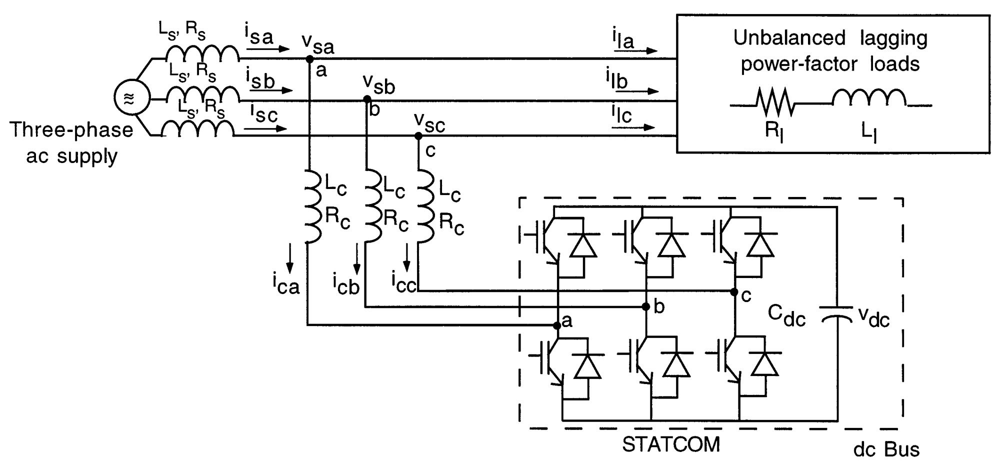


Fig. 1. Basic building block of the advanced STATCOM.