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She–PWM Cascaded Seven level Inverter With Adjustable DC Voltage Levels Control For D-Statcom Applications

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***Abstract*—In this paper presents a new multilevel selective harmonic elimination pulse-width modulation (MSHE–PWM) technique for transformer less static synchronous compensator (STATCOM) system employing cascaded H-bridge inverter (CHI) configuration. The proposed MSHE–PWM method optimizes both the dc-voltage levels and the switching angles, enabling more harmonics to be eliminated without affecting the structure of the inverter circuit. The method provides constant switching angles and linear pattern of dc-voltage levels over the modulation index range. This in turns eliminates the tedious steps required for manipulating the offline calculated switching angles and therefore, easing the implementation of the MSHE–PWM for dynamic systems. Although the method relies on the availability of the variable dc-voltage levels which can be obtained by various topologies, however, the rapid growth and development in the field of power semiconductor devices led to produce high-efficiency dc–dc converters with a relatively high-voltage capacity and for simplicity, a buck dc–dc converter is considered in this paper. Current and voltage closed loop controllers are implemented for both the STATCOM and the buck converter to meet the reactive power demand at different loading conditions. The technique is further compared with an equivalent conventional carrier-based pulse-width modulation to illustrate its enhanced characteristics. The effectiveness and the theoretical analysis of the proposed approach are verified through both simulation and experimental studies.**

I. INTRODUCTION and LITERATURE SURVEY

It is well known that the behaviour and operation of electric machines and drives are often difficult topics for students to comprehend and instructors to teach. Classical methods of teaching machines often focus on steady-state machine performance or reduced-order models, such as the classical voltage-behind-reactance models of synchronous machines, for describing dynamic performance. Power electronic circuits, such as rectifiers/inverters are usually taught from a textbook based approach, where concepts such as commutation are described in terms of closed form functions of the phase angle delay, output current, and commutating inductance. Although these methods are effective, several educators have noted the utility of using computer simulation and object-oriented graphical tools to illustrate machine and drive system performance [1-6]. Using these tools, concepts can be made more visual to students. For example, the commutating inductance or phase-angle delay of a rectifier can be adjusted by the student and repeated simulations performed to determine the effects. The simulated results can then be used to support corresponding theories. Simulation of machines can be used to observe steady-state and transient performance, as well as observe the errors of the various approximations used to obtain closed form solutions of the transient behaviour.

Recently, the authors have begun to develop a library of machine and drive models for power engineering education using the Advanced Continuous Simulation Language-Graphic Modeller (ACSL-GM). ACSL-GM is a commercial, general-purpose, differential-equation-based, simulation language that provides a graphical front-end for building models in block-diagram format. ACSL-GM was chosen as a basis for the library for several reasons. First, models developed within ACSL-GM can be used on either Unix-based or Windows (3.1, 95, NT)-based operating systems, and are cross-platform compatible. Second, anyone can obtain a free ACSL-Viewer that allows the use of models developed and compiled in the full version of ACSL-GM (navigate, change model parameters, run simulations, print and plot results), without having to purchase software. This means the models can be incorporated into homework's, prelabs, and lectures, without any compatibility issues or financial burden on the students. Third, the graphical interface provides a means to imbed model complexities within several block layers. For example, the block-diagram implementation of a machine model may be placed under a bitmap image of the cross-sectional view of the machine. The user initially sees the cross-sectional view of the machine and can click-down through the block layers to obtain more model information. This provides a means to create models that can be used by a wide-range of students (undergraduates and graduates). Fourth, ACSL-GM is a compiled language, therefore simulations are very time-efficient. Because of the efficiency, simulations of very large-scale systems, including power electronic-based shipboard and aircraft generation systems have been developed as part of the authors' research [7-9]. Thus models developed as part of research are easily transferrable to the classroom with little effort, providing an excellent means of integrating research into the curriculum.

Several control strategies of multilevel CHI-based STATCOM systems have been implemented for VAR and/or harmonic compensations and voltage regulation by using either frequency- or time-domain approaches to meet the predefined performance requirements. Most recent algorithm development adopts time-domain approach due to its ability to compute the reference currents and precisely traces the load changes almost instantaneously. The well-known *abc*-to-*dq* transformation or else known as synchronous rotating reference frame which incorporates decoupling feed-forward/feedback systems with appropriate control algorithms is commonly used to achieve lower steady-state errors and acceptable transient characteristics in response to a step change of the loading conditions [2]. A multifunction STATCOM system that employs more than one control strategies in the time-domain to tackle various power disturbance problems has been reported in [10]. In [11-15], an experimental work based on a scaled down prototype was developed to present a time-domain control scheme with its proposed modulation strategy to prevent the inverter's transformer from dc magnetization problem. An integrated control which incorporates both the voltage and current controls to compensate the unbalance problem caused by the load and the voltage source was proposed in [52].An interesting comparison between three types of balance control strategy, namely, the active voltage vector superposition, modulation index regulation, and phase shift angle regulation has been reported in [16-20] for delta-connected twelve level CHI topology controlled by CB-PWM. It was concluded that the former offers good control performance with strong regulation capability followed by the phase shift angle regulation method and modulation index regulation method. New modified selective swapping (MSS) algorithm was presented along with the design and implementation of twenty one-level CHI-based STATCOM in [16] and [17] to provide VAR compensation. The method is compared with the conventional swapping scheme to balance the dc-link capacitor voltages and it was concluded that the MSS outperforms the latter in terms of dc-link voltage ripple but at the expenses of higher switching frequency and hence, switching losses. A model predictive control (MPC) scheme is reported in [10] for a nineteen-level CHI-based STATCOM to simultaneously balance the dc-link capacitor voltages, minimize the inverter switching losses, and provide good current reference tracking. The MPC scheme is further improved in [14] by incorporating SVM technique to reduce the switching losses and dc capacitor voltage ripple.

II. POWER QUALITY

The contemporary container crane industry, like many other industry segments, is often enamored by the bells and whistles, colorful diagnostic displays, high speed performance, and levels of automation that can be achieved. Although these features and their indirectly related computer based enhancements are key issues to an efficient terminal operation, we must not forget the foundation upon which we are building. Power quality is the mortar which bonds the foundation blocks. Power quality also affects terminal operating economics, crane reliability, our environment, and initial investment in power distribution systems to support new crane installations. To quote the utility company newsletter which accompanied the last monthly issue of my home utility billing: 'Using electricity wisely is a good environmental and business practice which saves you money, reduces emissions from generating plants, and conserves our natural resources.' As we are all aware, container crane performance requirements continue to increase at an astounding rate. Next generation container cranes, already in the bidding process, will require average power demands of 1500 to 2000 kW – almost double the total average demand three years ago. The rapid increase in power demand levels, an increase in container crane population, SCR converter crane drive retrofits and the large AC and DC drives needed to power and control these cranes will increase awareness of the power quality issue in the very ne Power quality problems are defined as:

'Any power problem that results in failure or misoperation of customer equipment, manifests itself as an economic burden to the user, or produces negative impacts on the environment.'

When applied to the container crane industry, the power issues which degrade power quality include:

• Power Factor
• Harmonic Distortion
• Voltage Transients
• Voltage Sags or Dips
• Voltage Swells

III. DESCRIPTION OF D-STATCOM OPERATION

A D-STATCOM is a shunt device that regulates the system Voltage by absorbing or generating reactive power at a point of Coupling connection. The schematic diagram of a DSTATCOM. Is shown in Fig 1. The D-STATCOM is a solid State DC/AC power switching converter that consists mainly Of a three-phase PWM voltage source converter (VSC) bridge Having six igbts with associated anti-parallel diodes. It is Connected to the distribution network via the impedance of the Coupling transformer. A DC-link capacitor provides constant DC link voltage.

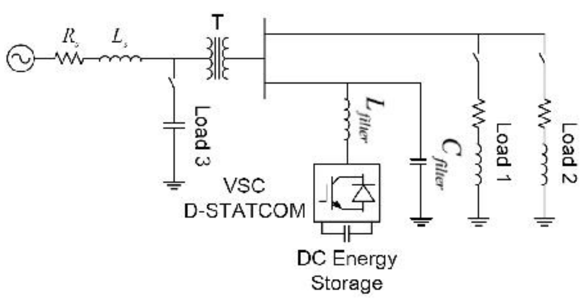


Fig. 1. Simplified power system equipped with a D-STATCOM

The output voltage of the D-STATCOM is generated by a DC/AC voltage source converter operated from an energy storage capacitor. From the DC input voltage, provided by a three-phase output voltages at the frequency of the AC power system. Each output voltage is in phase with and coupled to the corresponding AC voltage via coupling reactance

. By varying the magnitude of output voltage produced, the reactive power exchange between D-STATCOM and AC system is controlled. If the amplitude of output voltage is increased (or decreased) above the AC system voltage, the converter generates (or absorbs) reactive power for the AC system. DSTATCOM acts as a shunt compensator connected in parallel to the system so that it can inject appropriate compensation currents. The D- STATCOM has several advantages, compared to a conventional static var compensator (SVC). It gives faster responses and can produce reactive power at low voltage. Also, it does not require thyristor-controlled reactors (TCR) or thyristor-switched capacitors (TSC) that normally produce low order harmonics.

PROPOSED CONTROL STRATEGY FOR D-STACOM

In general, power compensation by D-STACOM can have various functions such as elimination of power oscillation, improvement of power factor, elimination of harmonic current, etc. Under a balanced three-phase supply condition, some criteria must be met to optimize the overall system compensation. The research conducted by aimed to compensate the source current become purely sinusoidal and deliver the minimum average real power to the load. Although under non-linear loading it can guarantee only one optimal criterion.

In this paper multiple objectives for shunt power compensation are proposed. In addition, power factor correction of a protected load can be included in the control scheme by zeroing reactive power supplied by the source. As mentioned previously, the compensator must supply the oscillating power components to the load. In order to compensate the oscillating power flow by means of PWM converters, the DC voltage across the DC link capacitor must be large enough and kept constant at that value to stabilize the compensation. Therefore, DC link voltage regulator must be added to the control loop.

To separate the oscillating real power components a low-pass filter is used. Together with the switching and ohmic losses of the PWM converter, the instantaneous real power reference is formed. Similarly, the instantaneous reactive power reference can be set as zero to achieve unity power factor. In practice, the reference signals for generating the switching pattern to drive IGBT gates are current waveforms, modified to equate the compensating current in αβ coordinates as expressed. Therefore, the αβ current is transformed back to the *abc* coordinate for switching pattern generation as described. With this power factor correction, the reactive power regulator is also added to the loop as shown in Fig. 4. The overview of the proposed control scheme can be depicted as shown in Fig. 5.

$$\begin{bmatrix} i_{C\alpha}^{*} \\ i_{C\beta}^{*} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} -\tilde{p} + \bar{p}_{loss} \\ -q \end{bmatrix} \tag{10}$$

$$\begin{bmatrix} i_{Ca}^{*} \\ i_{Cb}^{*} \\ i_{Cc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{C\alpha}^{*} \\ i_{C\beta}^{*} \end{bmatrix} \tag{11}$$

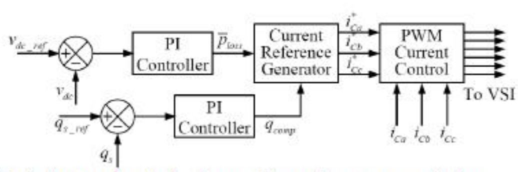


Fig. 4. Proposed control scheme with reactive power regulation

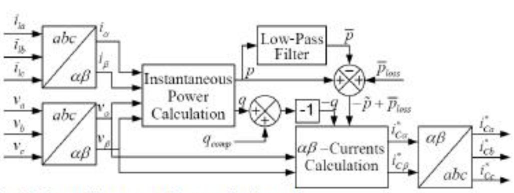
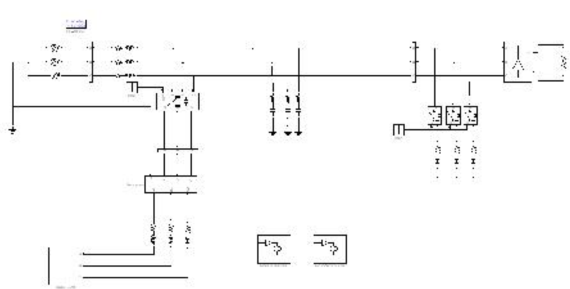
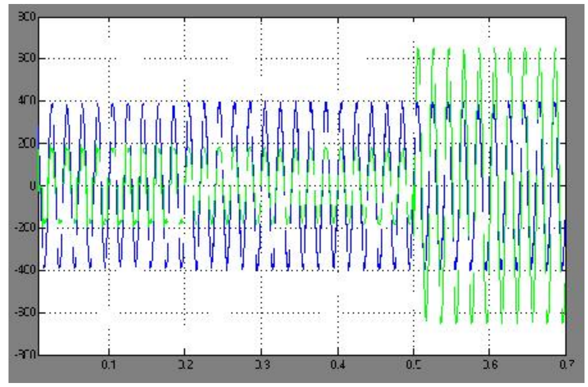


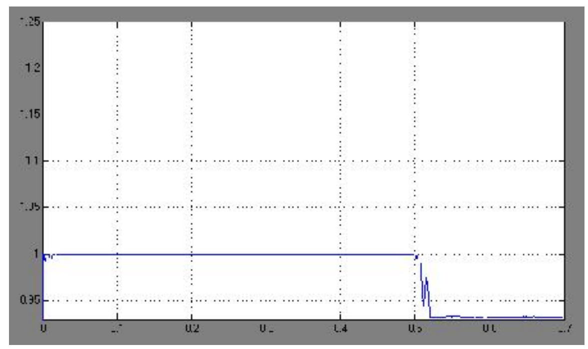
Fig. 5. Overall proposed control scheme

CASE STUDY SIMULATION AND RESULTS
D-STATCOM CASE I:

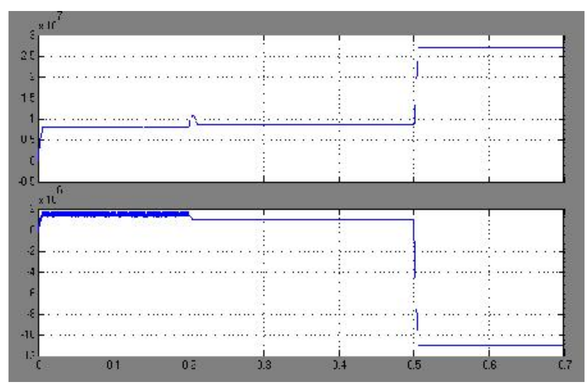




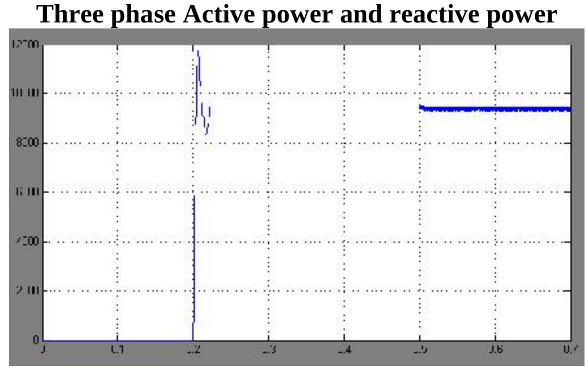
Source voltage (Vsabc) and current (Isabc)



Power factor

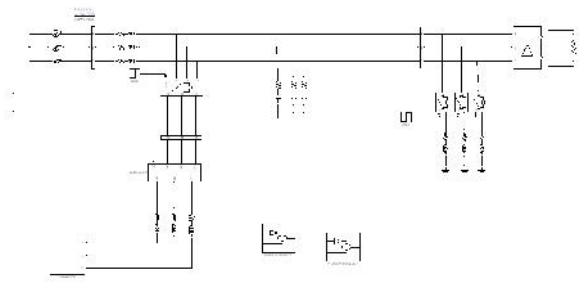


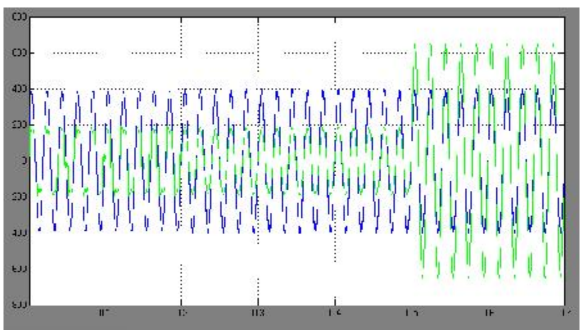
Three phase Active power and reactive power



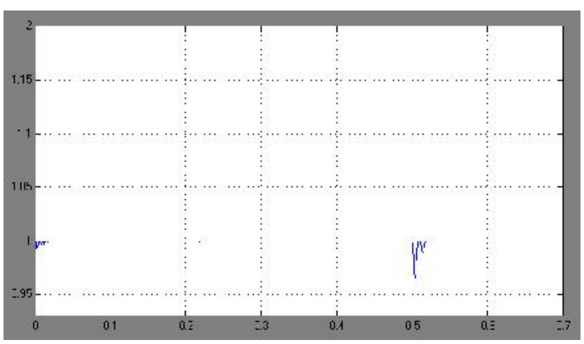
DC voltage

D-STATCOM CASE II:

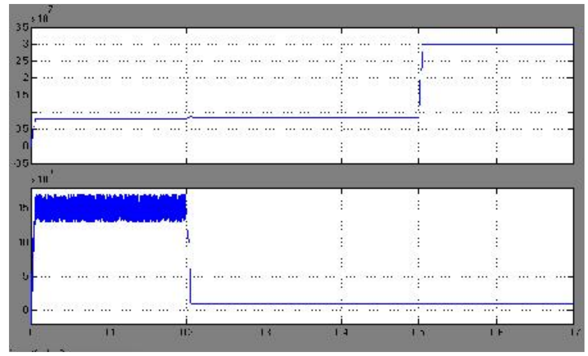




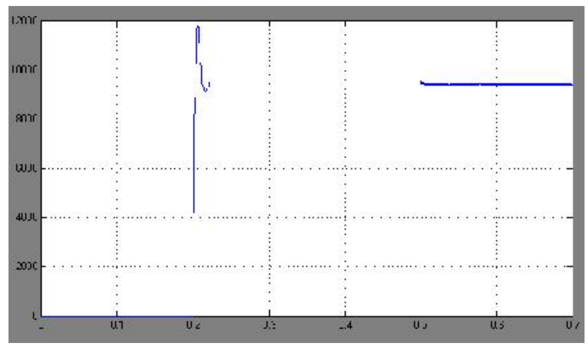
Source voltage (Vsabc) and current (Isabc)



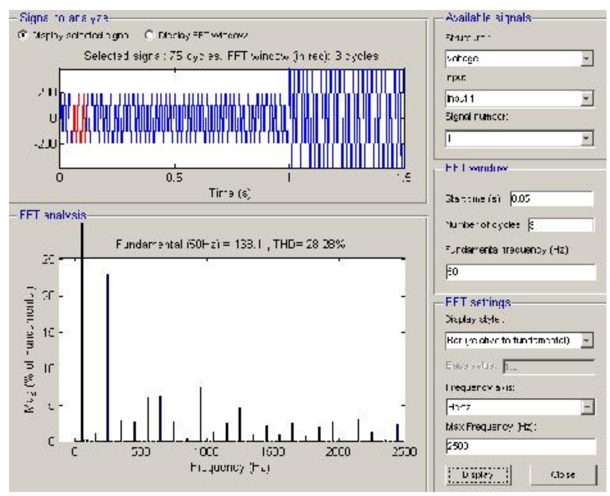
Power factor



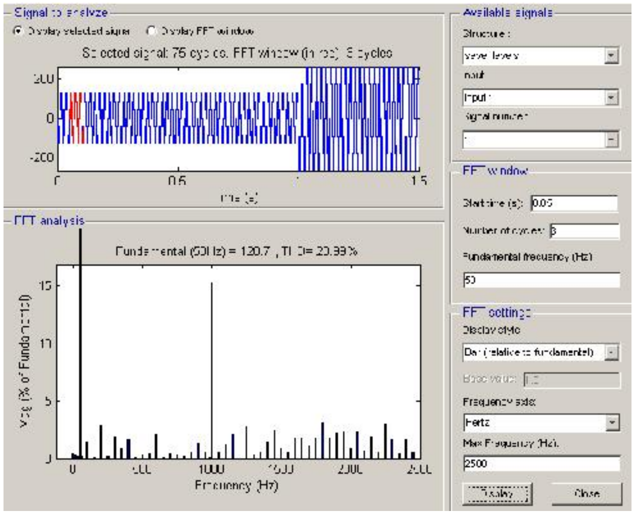
Three phase Active power and reactive power



DC voltage



THD of Fivelevel Inverter with SHE Controller



THD of Sevenlevel Inverter with SHE Controller

CONCLUSION

This paper presents a modified control scheme to compensate a distribution feeder loading with non-linear loads. The compensation consists of four main objectives that are i) regulation of real powers delivering to loads, ii) regulation of DC link voltage to ensure PWM converter operation, iii) correction of power factor, and iv) Improvement in THD. Modification of the control scheme made in this paper is to add the reactive power regulation into the control loop. With zero reactive power reference, unity power factor can be achieved. As a result, the modified control scheme can regulate DC link voltage and real power delivery at specified level while reactive power drawn from the load was cancelled by that injected from D-STATCOM.

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