

SHE–PWM Cascaded Five level Inverter with Adjustable DC Voltage Levels Control for D-STATCOM Applications

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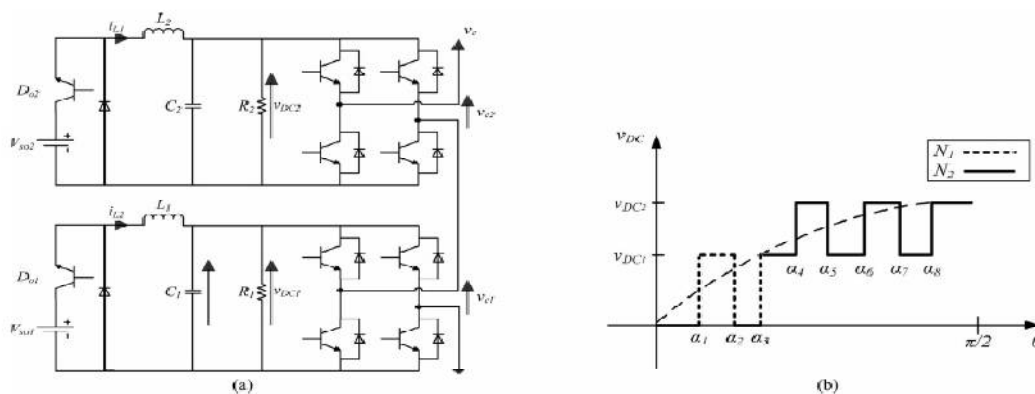
ABSTRACT: This paper presents the enhancement of voltage sags, Harmonic distortion and low power factor using Distribution Static Compensator (D-STATCOM) with fuzzy pulse-width modulation (MSHE–PWM) technique for transformer less static synchronous compensator (STATCOM) system employing hybrid multilevel 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.

KEYWORDS: Cascaded H-bridge inverter (CHI), MSHE-PWM, STATCOM, reactive power (VAR) compensation

I. INTRODUCTION

The large penetration of renewable sources, which are intrinsically uncertain and highly variable by nature as an Effective means of power generation has arisen new challenges to existing power networks. Nonlinear loads such as single phase ac tractions systems make the network to operate under undesired conditions, restricting the maximum active power transfer and significant unbalance enforcement. The rapid development of the power electronics industry on the other hand has opened up opportunities for improving the operation and management Of power system networks via flexible ac transmission system facts controllers such as static synchronous compensator STATCOM to enhance neighbouring utilities and regions for more economical and reliable exchange of power. Initially, the conventional voltage-source-inverters based STATCOM system have proven their practicality and superiority as the most effective solution for compensation over the traditional thyristor-based compensators due to their ability to compensate for a wider range of VAR in fraction of cycles. Furthermore, multilevel inverters have recently proven their ability to overcome problems associated with the conventional two-level inverters and therefore have received an extensive research in the last few decays. There are various topologies of multilevel inverters that have been proposed and reported in the open literature. Among all these, the multilevel cascaded H-bridge inverter chi has been an attractive topology for STATCOM system due to its modularity, extensibility, and control simplicity. The motivation behind

replacing the conventional VSI with multilevel inverters is to get rid of the bulky, heavy, and costly line-frequency transformer. On the other hand, the choice of the modulation technique plays an important role in a STATCOM control system as it has a high impact on its compensation objectives, transient as well as steady-state performances. Therefore, several pulse-width modulation (PWM) techniques have been investigated, proposed, and documented in the literature; including carrier-based PWM (CB-PWM), multilevel space vector modulation (SVM), stair case modulation, and selective harmonic elimination pwm (SHE-PWM). CBPWM is by far the simplest technique to generate the required multilevel pulses through the intersection of a fundamental reference waveform with the dedicated disposition carrier. There are three well-known disposition methods, namely alternative phase disposition, in phase disposition IPD, and phase opposite disposition POD. A comparative evaluations of these methods based on total harmonic distortion (THD) performance for multilevel inverter topologies with respect to the number of levels, switching frequencies, and modulation indices have been reported in several articles. Zero sequence injected IPD CB-PWM, or else known as the switch frequency optimal PWM technique, with marginal THD improvement is presented in and later in and to further enhances the THD performance in lower modulation indices with additional switching instants. Despite its simplicity, the CB-PWM technique does not offer any direct manipulation over the harmonic contents and, furthermore, exhibits high-switching losses due to high switching frequencies; making its employment into high-power applications is a big concern where high-losses are intolerable. SVM, on the other hand, can be used to manipulate harmonics at low-modulation indices and maintain desired performance characteristics of multilevel inverter in low-switching frequencies. Although efforts have been made to extend the operation of multilevel inverters under SVM into the over modulation region, however, as the number of levels increases, the number of inverter's states also drastically increases resulting in difficulty to compute the duty cycles, selecting the proper switching states



(a) Single-phase five-level inverter (b) SHE-PWM waveform

- 1) Presents a transformer less STATCOM system based on cascaded multilevel inverters (i.e., five-level in this paper, however, the technique is applicable irrespective of the number of level)s enabling the elimination of bulky ,heavy, and costly line-frequency transformer that contributes to almost 70% of the total power losses per a MVA rating .
- 2) The proposed MSHE-PWM method increases the number of freedoms and hence the harmonics that can be eliminated, leading to better harmonic profile and wider converter's bandwidth. It was also able to find the solution of the switching angles for a much wider range of the modulation index when compared with the fixed voltage dc levels case. Furthermore, the method provides constant switching angles and linear pattern of dc-voltage levels over the full range of the modulation index, which in turn eases the implementation of the MSHE-PWM for dynamic systems such as STATCOM.
- 3) The operation with low-switching frequency (i.e., the effective switching frequency is only 1.6 kHz) as compared to SPWM based STATCOM, where the switching frequency ranges between 5 kHz and 10 kHz. Therefore, less losses and less cooling and power dissipation requirement is required, which will considerably reduce the volume and weight of the overall system and hence increase its reliability and performance.

4) The proposed system requires variable dc-voltage and for Simplicity dc-dc buck converter which operated at relatively low-switching frequency of 2 kHz (as opposed to 5 kHz and 50 kHz) is considered in this paper. Furthermore, the rapid growth in the power semiconductor devices and the advanced materials with an expected efficiency of 97% and even as high as 99% with the emergence of silicon carbide (Sic) switching devices and a new magnetic core material, justify the addition of another power switch.

The rest of this paper is organized presents the analysis and the formulation of the proposed method applied to five-level MSHE-PWM inverter. Addresses the STATCOM system configuration and the dc-dc converter controls. Selected simulation and experimentally validated results are reported in the objective of this paper is to exploit the features of the newly developed MSHE-PWM control technique which proposed by the authors into the STATCOM system.

II. RELATED WORK

The proposed single-phase one-leg five-level voltage source chi and its associated MSHE-PWM Output voltage waveform. In this project, eight switching angles within a quarter-cycle with a distribution ratio of $N1/N2 = 3/5$ are assumed as an example to construct the five-level she-pwm waveform as shown in Figure.1. The target in this case is to obtain the optimal switching angles and the optimized levels of the dc-voltage sources that eliminate nine non triplet low order harmonics (i.e., fifth, seventh, eleventh, thirteenth, seventeenth, nineteenth, twenty-third, twenty-fifth, and twenty ninth) while controlling the fundamental component at a predefined value. The STATCOM output voltage waveform is described by Fourier series and the optimal switching angles and the dc voltage levels Where from equation 1 $N1 = 3$ is the number of switching transitions between zero and the first-level, $N2 = 5$ is the number of switching transitions between the first-level and the second-level, and m_{iis} the modulation index. Main Three Phase Simulation Circuit 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 hybrid circuits that are combinations of two of the basic multilevel topologies or slight variations to them. Additionally, the combination of multilevel power converters can be designed to match.

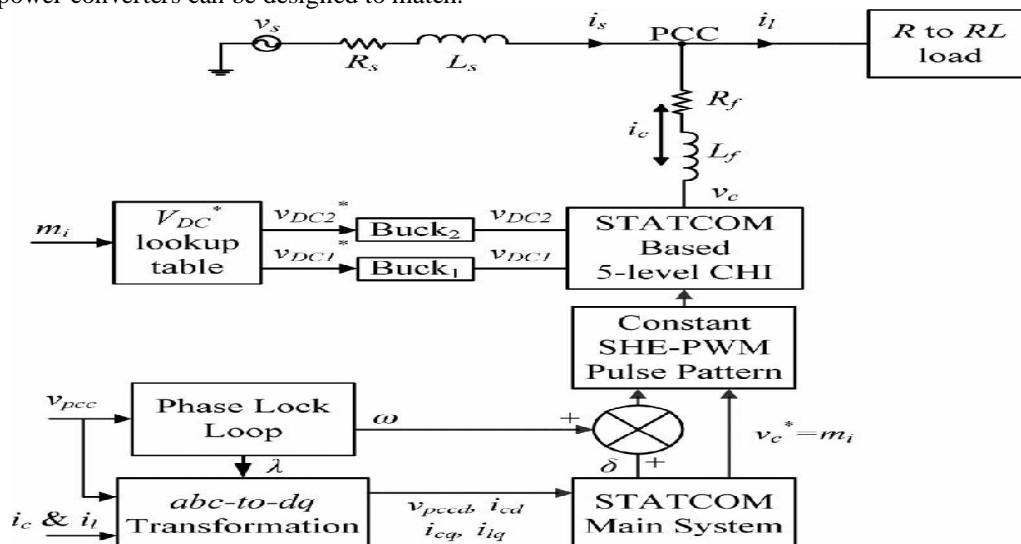


Fig.1 Block diagram of the STATCOM system with the associated proposed control scheme

Voltage levels:

$$\left(v_{DC1} \sum_{l=1}^{N_1} (-1)^{l+1} \cos(\alpha_l) + v_{DC2} \sum_{l=N_1+1}^{N_1+N_2} (-1)^l \cos(\alpha_l) \right) = \frac{m_l \times \pi}{4}$$

$$\left(v_{DC1} \sum_{l=1}^{N_1} (-1)^{l+1} \cos(5\alpha_l) + v_{DC2} \sum_{l=N_1+1}^{N_1+N_2} (-1)^l \cos(5\alpha_l) \right) = 0$$

$$\left(v_{DC1} \sum_{l=1}^{N_1} (-1)^{l+1} \cos(n\alpha_l) + v_{DC2} \sum_{l=N_1+1}^{N_1+N_2} (-1)^l \cos(n\alpha_l) \right) = 0$$

Where v_{min} and v_{max} are the minimum and maximum values of the dc-voltage source, respectively, and v_{DCM} is the Mthdc-voltage level $M= 1, 2$. The constraints are imposed in the formulation to ensure that the resultant waveform is realizable and physically correct. Specifically, assures that the optimal dc-level is within a certain range. An optimization technique based on the approach proposed in is employed to find the solution of and multiple sets of solutions for various multilevel waveforms with different distribution ratios and different ranges of modulation index were obtained. However, only two sets of solutions for the 3/5 waveform It is worth nothing that the eight switching angles within quarter-cycle with a distribution ratio of form equation 2 $N_1/N_2 = 3/5$ make the effective switching frequency of the inverter equals to 1.6 kHz. Therefore, when compared to the CB-PWM based STATCOM with a typical switching frequency ranges between 5 kHz and 10 kHz , the proposed method offers less losses and less cooling and power dissipation requirement, which could considerably reduce the volume and weight of the overall system and hence increase its reliability and performance

III. POWER QUALITY

The contemporary container crane industry, like many other industry segments, is often enamoured by the bells and whistles, colourful 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 disoperation 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

IV. 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 2. 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 igtbs 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

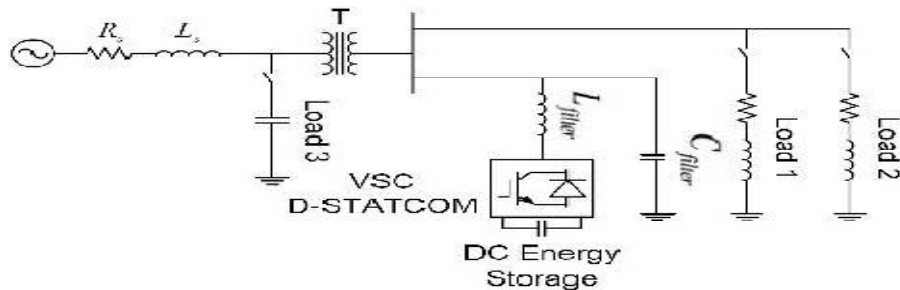


Fig.2. Simplified power system equipped with a DSTATCOM

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 DSTATCOM 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 DSTACOM

In general, power compensation by DSTACOM 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 $\alpha\beta$ coordinates as expressed. Therefore, the $\alpha\beta$ 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. 3. The overview of the proposed control scheme can be depicted as shown in Fig.4.

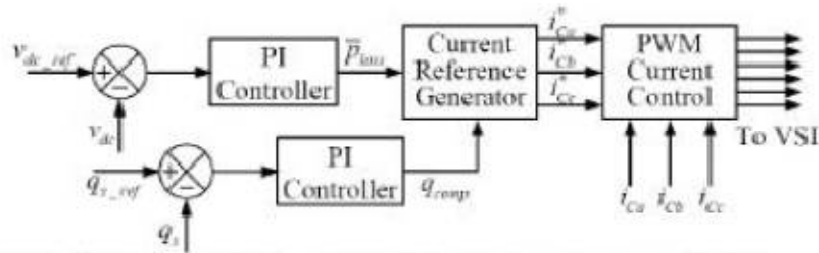


Fig.3. proposed control scheme with reactive power regulation

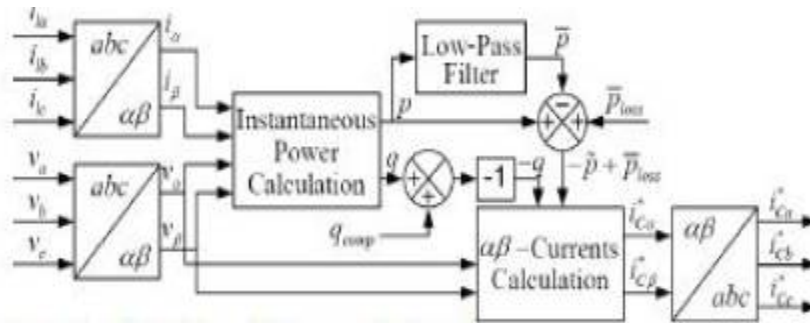


Fig.4. Overall proposed control scheme

V. STATCOM KEY OPERATION

The STATCOM system based on the proposed five-level she-pwm inverter along with the associated control schemes. The STATCOM is shunted to the power system via coupling inductor Z_f at the PCC. The dq current vector controller of the STATCOM system

$$v_{cd}^*(k) = v_{pccd}(k) - R_f i_{cd}(k) + \omega L_f \left[\frac{1}{2} i_{cq}(k) + \frac{1}{2} i_{lq}(k) \right] - K_{p_id} [-i_{cd}(k)] \quad (4)$$

$$v_{cq}^*(k) = -R_f i_{cq}(k) - \omega L_f \left[\frac{1}{2} i_{cd}(k) \right] - K_{p_iq} [i_{lq}(k) - i_{cq}(k)] \quad (5)$$

where v_{pccd} defines the d-axis grid voltage, R_f and L_f , are the coupling resistance and inductance, respectively, ω defines the fundamental grid voltage frequency, i_{cd} and i_{cq} , are the STATCOM active and reactive current, respectively, i_{cd} is the STATCOM current, and i_{lq} is the reference reactive current extracted from the load side. The respective proportional gain equation 6 used K_p $i(d,q)$ of the Controller is given by where T_i defines the selected controller operating rate. The desired STATCOM output voltage magnitude v^*c and its phase angle δ with respect to v_{pcc} is given as The availability of the variable dc-voltage levels which can be easily obtained by advanced dc-dc converters. With the rapid growth in semiconductor devices industry and advanced materials such as nano crystalline soft magnetic core that offers high saturation flux density and high relative permeability leading to an extremely low core loss. The feasibility of the proposed method and for simplicity, dc-dc buck converter operating at only 2 kHz and with a small size of output LC filter and simple control design is considered in provide the variable dc-voltage levels for each cell of the CHI according to the operating point. With the assumption of ideal components, switches, capacitor

C, and inductor L, the voltage closed loop controller for the dc-dc buck converter is designed in continuous conduction mode by using the state space averaging modelling technique. The combination of the magnetic core with the latest trench-gate IGBTs and super-junction MOSFETs has made it possible to improve the system efficiency of the dc-dc converters up to 97% or higher the near future, the emergence of SiC switching devices and a new magnetic core material will allow the system efficiency to reach higher than 99% . This revolution leads to produce relatively medium- to high voltage dc- dc converters with high-switching frequencies ranges from 5 kHz and as high as 50 kHz.

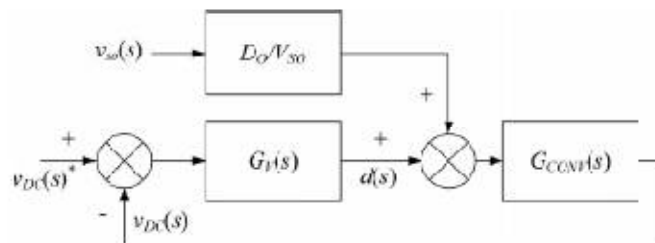


Fig.5. Block diagram of the buck converter with voltage loop feedback control

where the first bracket defines the buck converter’s input voltage deviation at the operating point and the second defines the buck converter’s transfer function $G_{conv}(s)$ for designing the voltage closed loop controller $G_v(s)$. Hence, the control system of the dc-dc buck converter can be simply illustrated by the single line block diagram of figure above. For P, PI, and PID controllers, the $G_v(s)$ shown in is basically an error amplifier for the voltage mode closed-loop controller to generate the duty cycles demand d for the switching device of the buck converter. The transfer function of $G_v(s)$ is defined as

$$G_v(s) = \frac{A}{s} \left[\frac{1 + \frac{s}{\omega_z}}{1 + \frac{s}{\omega_p}} \right]$$

Where A is the gain of the error amplifier, ω_z (i.e., ω_{cross}/K) and ω_p (i.e., $\omega_{cross} * K$), respectively, are the zero frequency and pole frequency based on the selected crossover frequency and K factor value

VI. FUZZY LOGIC CONTROLLER

Most of the real-world processes that require automatic control are non-linear in nature. That is, their parameter values alter as the operating point changes over time or both. In case of conventional control schemes, as they are linear, a controller can only be tuned to give good performance at a particular operating point or for a limited period of time. The controller needs to be retuned if the operating point changes with time. This necessity to retune has driven the need for adaptive controllers that can automatically retune themselves to match the current process characteristics.

Analytical techniques may fail to give a precise solution in a controlling process. Where as an expert or a skilled human operator, without the knowledge of their underlying dynamics of a system can control a system more successfully. So it is worth simulating the controlling strategy based upon intuition and experience can be considered a heuristic decision or rule of thumb decision. This can be possible through the Fuzzy controller.

Fuzzy logic is an innovative technology that enhances conventional system design with engineering expertise. Using fuzzy logic, we can circumvent the need for rigorous mathematical modelling

A human operator is far more successful in controlling a process than a controller designed by modern analytical technique. So it is worth simulating the control strategy based upon intuition and experience and can be considered as heuristic decision or rule of thumb decision.

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In academic and technological arena, Fuzzy is a technical term that deals with ambiguity or vagueness based on human intuitions.

Professor Lotfi A Zadeh introduced the concept of fuzzy sets, according to him. Fuzzy logic is a mathematical imprecise description. During the past several years, FLC has emerged as one of the most active area of research for the application of fuzzy set theory. A fuzzy set is a generalization of the concept of an ordinary set in which the membership function (MF) values can be only one of the two values, 0 and 1. A fuzzy set can be defined as below.

VII.SIMULATION CIRCUITS AND RESULTS

The proposed STATCOM system is first studied through various simulation examples using MATLAB/Simulink software package to investigate the dynamic, transient, and harmonics performances of the proposed MSHE–PWM method. A small scale low-voltage laboratory prototype based on five level CHI is also developed and experiments are conducted to validate the simulation and theoretical findings. The proposed method is further compared with the conventional CB-PWM operated with an equivalent frequency (i.e., 1.6 kHz) to show the superiority and effectiveness of the former.

A. SIMULATION CIRCUIT

The MATLAB diagram of the proposed system is shown in Figure. Several control strategies of multilevel CHI based STATCOM systems have been implemented for VAR and harmonic shown Figure3 compensations and voltage regulation by using either frequency- or time domain approaches to meet the pre defined performance requirements

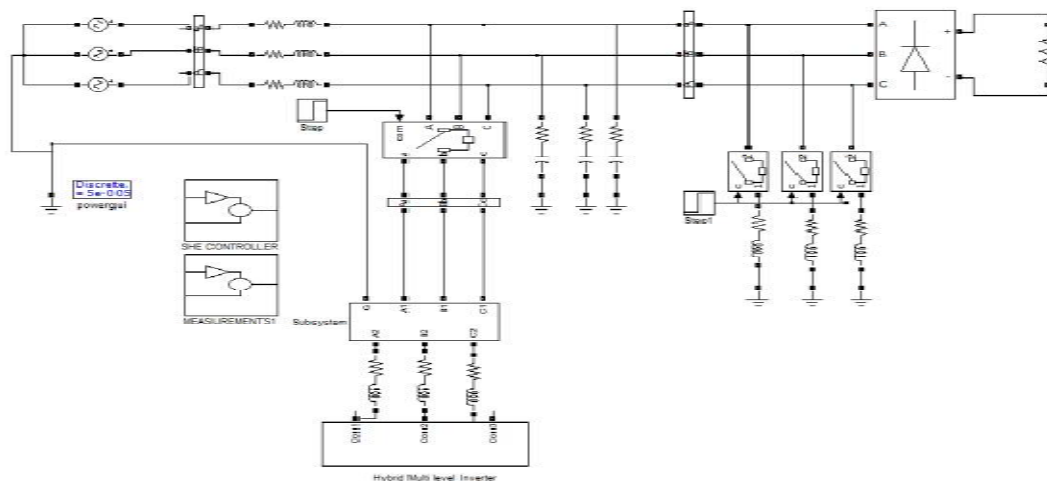


Fig6. Main Three Phase Hybrid Simulation Circuit

B. STATCOM TRANSFORMER

STATCOM Transformer controller based on a new version of SHE–PWM control technique implementable with the cascaded H-bridge topology was proposed and investigated. The p she provides an output with a wider range of modulation index shown in figure.8 by making the dc-voltage levels variant without affecting the number of harmonics being eliminated

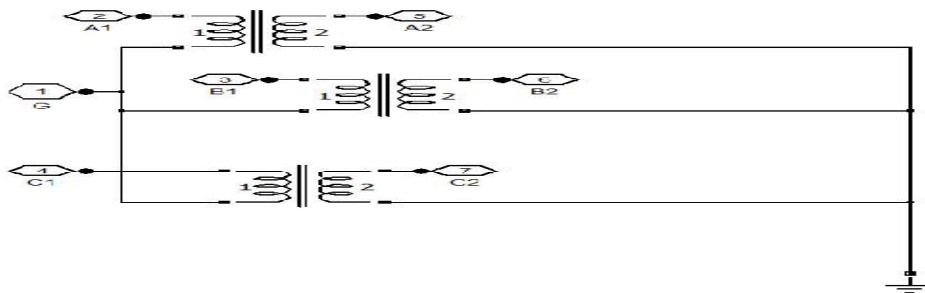


Fig8.STATCOM Transformer

C. SIMULATION RESULTS

The STATCOM system's performances in dynamics, steady-state shown figure9, and transient Operations are investigated at different loading conditions using a linear single-phase reactive load that change from resistive load.

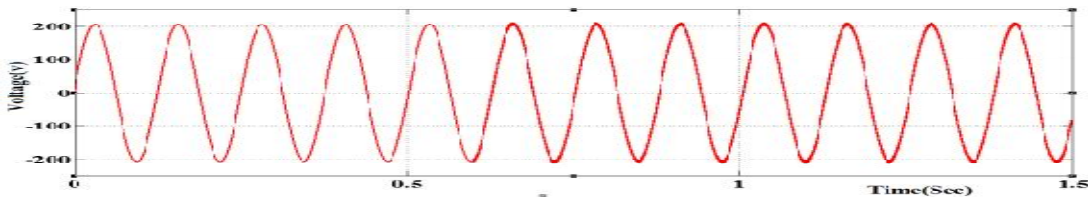


Fig9.Grid Voltage

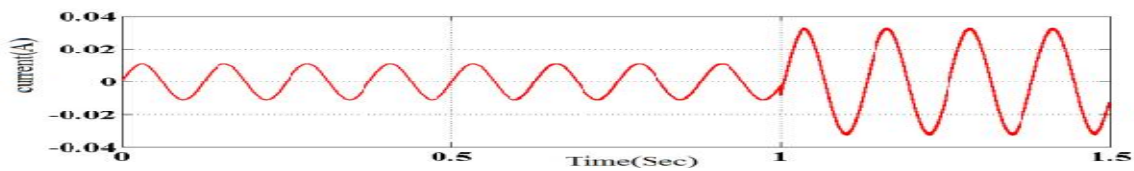


Figure 10. Grid Current

The controllability is used to avoid current intensive or landscape requiring extensions of power, for instance like upgrades or additions of substations and power lines. a better adaptation to varying current conditions

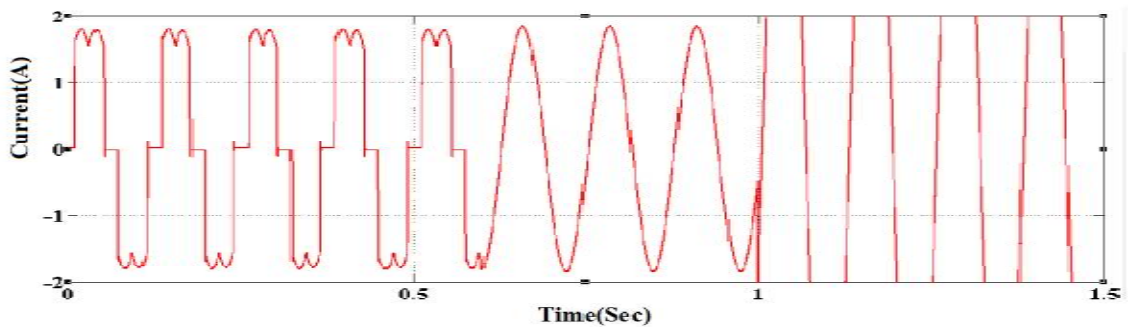


Fig11.STATCOM Current

The STATCOM under loading conditions illustrates reactive current compensation the dynamic and transient responses of the STATCOM reactive current i_{cq} which is consistently tracking the ramp change of the load reactive current i_{lq} .

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Vol. 5, Issue 10, October 2016

The terminal voltage, as well as modification of systems for terminal magnitude upgrade medium voltages level occurring time in varying shown in figure

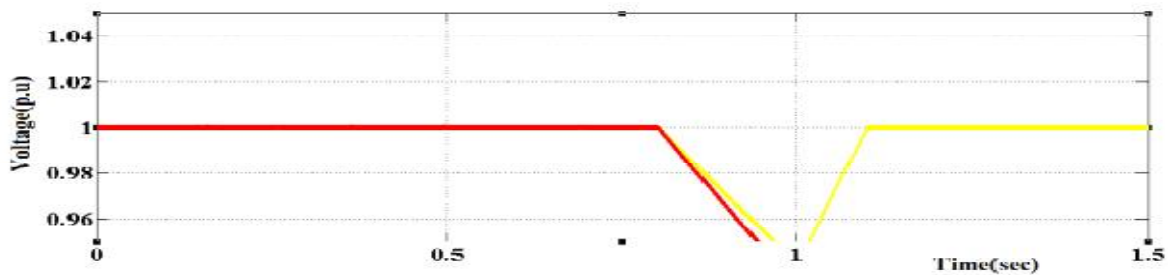


Fig12. Grid voltage magnitude

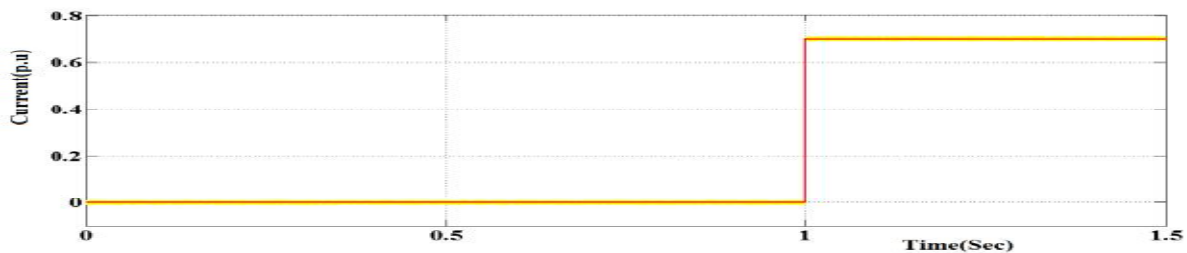


Fig13. Rampchange of measured of measured icq reactive current

Rapidly operating buck conventions can continuously provide the reactive power required to control dynamic voltage oscillations under various system conditions and thereby improve the power system transmission and distribution stability of load voltage.

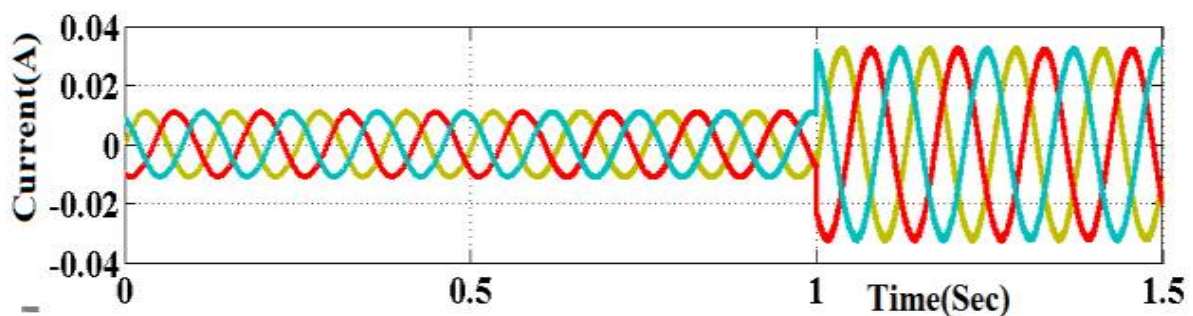


Fig14. Three Phase STATCOM

STATCOM can have various functions such as elimination of power oscillation, improvement of power factor; elimination of harmonic currents 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 figure. Although under non-linear loading it can guarantee only one optimal criterion.

VIII. CONCLUSION

This paper presents a modified control scheme to compensate a distribution feeder loading with non-linear loads. The compensation consists of three main objectives that are i) regulation of real powers delivering to loads, ii) regulation of

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 10, October 2016

DC link voltage to ensure PWM converter operation, and iii) correction of power factor. 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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BIOGRAPHY



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