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# IMPROVED CONTROL STRATEGY FOR TRANSFORMERLESS H-BRIDGE CASCADED STATCOM

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## ABSTRACT

Major power quality issues created in power systems are due to the non-linear load characteristics and fast switching of power electronic equipment. Static Synchronous Compensator (STATCOM) have been developed over the years to solve those problems that exist in power system. This paper presents a transformer less static synchronous compensator (STATCOM) system based on multilevel H-bridge converter with star configuration. The main objective is to improve the real and reactive power flows in the transmission line as well as to eliminate the harmonic content injected into the power system because of usage of non-linear loads. The above problem is solved by employing transformer less STATCOM based on multilevel H-bridge cascaded converter. The STATCOM device inject the reactive power at the Point of Common Coupling (PCC) as a result dynamic compensation is achieved by adopting two control strategies i.e. current control loop and dc capacitor voltage control method.

## 1. Introduction

Early equipment was designed to withstand disturbances such as lightning, short circuits, and sudden overloads without extra expenditure. Current power electronics (PE) prices would be much higher if the equipment was designed with the same robustness. Harmonics has been introduced into power systems by non-linear loads such as arcing devices and saturated coils; however, perturbation rate has never reached the present levels. Due to its non-linear characteristics and fast switching, PE creates most of the Power Quality (PQ) issues. Most of the PQ issues are created due to the non-linear characteristics and fast switching of PE. Approximately 10% to 20% of today's energy is processed by PE and the percentage is estimated to reach 50% to 60% by the year 2010, due to the fast growth of PE capability. A race is currently taking place between increasing PQ issues and sensitivity, on the one hand, and the new PE-based corrective devices, which have the ability to attenuate the issues created by PE, on the other hand increase in such non-linearity causes different undesirable features like low system efficiency and poor power factor. It also causes disturbance to other consumers and interference with the nearby communication networks [2]. The effect of such non-linearity may become sizeable the next few years. Hence it is very important to overcome these undesirable features.

Flexible AC Transmission Systems (FACTS) are being increasingly used in power system to enhance the system utilization, power transfer capacity as well as the power quality of AC system interconnection. As a typical shunt FACTS device, STATCOM is utilized at the PCC to absorb or inject the required reactive power, through which the voltage quality of PCC is improved [4]. In recent years, many topologies have been applied

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to the STATCOM. Among these different types of topology, H-bridge cascaded STATCOM has been widely accepted in high power applications for the following advantages quick response speed, small volume, high efficiency, minimal interaction with the supply grid and its individual phase controllability.

## 2. Literature Survey

Flexible ac transmission systems (FACTS) are being increasingly used in power system to enhance the system utilization, power transfer capacity as well as the power quality of ac system inter connections. As a typical shunt FACTS device, STATCOM is utilized at the PCC to absorb or inject the required reactive power, through which the voltage quality of PCC is improved. Among these different types of topology [5], H-bridge cascaded STATCOM has been widely accepted in high power applications for the following advantages are quick response speed, small volume, high efficiency, minimal interaction with the supply grid and its individual phase control ability [1]. Compared with diode-clamped converter or flying capacitor converter, H-bridge cascaded STATCOM can obtain a high number of levels more easily and can be connected to the grid directly without the bulky transformer. This enables us to reduce cost and improve performance of H-bridge cascaded STATCOM. The main drawbacks on using the diode clamped and flying capacitor converter are

- Pre charging of capacitors is necessary and difficult.
- Low response speed
- Large volume

In recent years, many topologies have been applied to the STATCOM. Among these different types of topology, H-bridge cascaded STATCOM has been widely accepted in high power applications for the following advantages quick response speed, small volume, high efficiency, minimal interaction with the supply grid and its individual phase controllability [6]. Compared with diode-clamped converter or flying capacitor converter, H-bridge cascaded STATCOM can obtain a high number of levels more easily and can be connected to the grid directly without the bulky transformer [3]. This enables us to reduce cost and improve performance of H-bridge cascaded STATCOM. There are two technical challenges exist in H-bridge cascaded STATCOM to date. Firstly, the control method for the current loop is an important factor influencing the compensation performance [11]. Secondly, H-bridge cascaded STATCOM is a complicated system with many H-bridge cells in each phase, so the DC capacitor voltage imbalance issue which caused by different active power losses among the cells, different switching patterns for different cells .In terms of current loop control, the majority of approaches involve traditional linear control method, in which the nonlinear equations of the STATCOM model are linearized with a specific equilibrium [9]. The most widely used linear control schemes are Proportional Integral (PI) controllers which is to regulate reactive power through decoupled control strategy, the PI controller is employed in synchronous *d-q* frame. However, it is hard to find the suitable parameters for designing PI controller and the performance of PI controller might degrade with the external disturbance. In this paper, a new nonlinear control method based on Passivity Based Control (PBC) theory which can guarantee Lyapunov function dynamic stability is proposed to control the current loop. It performs satisfactorily to improve the steady and dynamic response [7]. For DC capacitor voltage balancing control, by designing a PR controller for overall voltage control, the control effect is improved, compared with the traditional PI controller [8].

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## 3. FACTS Based Solutions

A static synchronous compensator (STATCOM), also known as a "static synchronous condenser" ("STATCON"), is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. Installing a STATCOM at one or more suitable points in a grid will increase power transfer capability by enhancing voltage stability and maintaining a smooth voltage profile under different network conditions. The STATCOM also enables improvements in power quality. This proposed work is simple and can be easily implemented by digitally. It has superior performance over conventional methods in terms of harmonic reduction in STATCOM output current.

## 4. Control Strategies

The whole control algorithm mainly consists of four parts, namely, passivity-based control, overall voltage control, clustered balancing control and individual balancing control [6]. The first three parts are achieved in DSP, while the last part is achieved in FPGA [11]. As the first level control of the dc capacitor voltage balancing, the aim of the overall voltage control is to keep the dc mean voltage of all converter cells equals to the dc capacitor reference voltage. The common approach is to adopt the conventional PI controller which is simple to implement. However, the output voltage and current of H-bridge cascaded STATCOM are the power frequency sinusoidal variables and the output power is the double power frequency sinusoidal variable, it will make the dc capacitor also has the double power frequency ripple voltage. The aim of the individual balancing control as the third level control is to keep each of 12 dc voltages in the same cluster equals to the dc mean voltage of the corresponding cluster. It plays an important role in balancing 12 dc mean capacitor voltages in each cluster. Due to the symmetry of structure and parameters among the three phases, a-phase cluster is taken as an example for the individual balancing control analysis. By setting the cutoff frequency and the resonant frequency of PR controller, it can reduce ripple voltage in total error.

## 5. Proposed System

As a typical shunt FACTS device, STATCOM is utilized at the PCC to absorb or inject the required reactive power, through which the voltage quality of PCC is improved. The power switching devices working in ideal condition is assumed. *Vsa* , V*sb* and *Vsc* are the three phase voltage of grid. *Va* , *Vb* and *Vc* are the three-phase voltage of STATCOM. *isa* ,*isb* and *isc* are the three-phase current of grid. *ia* , *ib* and *ic* are the three-phase current of STATCOM. *ila*, *ilb* and *ilc* are the three-phase current of load. Udc is the reference voltage of DC capacitor. *C* is the dc capacitor. *L* is the inductor and *Rs* is the starting resistor.

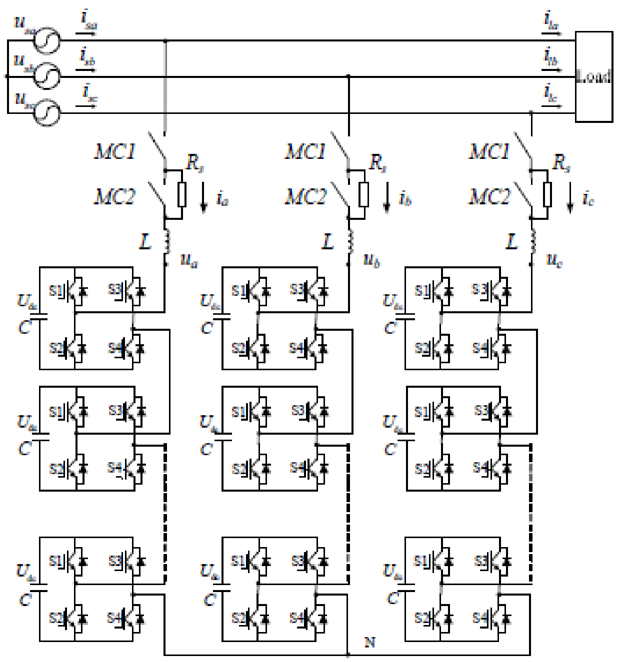


**Figure 1 Diagram of the proposed system**

In this scheme in order to make power compensation, an H-bridge STATCOM is developed. Each H-bridge cluster consists of four MOSFETS switches. L is the inductor. Rs is the starting resistor. As FACTS core equipment, STATCOM based on H-bridge cascade, which takes the full-controlled power electronic devices constitute a voltage source inverter (MOSFETS) as the core, and uses the cascade multi-level and PWM technology, has many advantages, such as: small output harmonic currents, less area, short response time, a wide range of reactive power compensation, easy to maintain, easy to expand, and low cost etc. So it has become the focus of research of domestic and foreign experts, and gradually applied to the high-voltage transmission grid. DC capacitor of each module of STATCOM based on H-bridge cascade is independent of each other, and switching losses, circuit losses, the switch allocation status and pulse delay differences, which led to the DC bus voltage imbalance exists. The DC side control strategy of the hierarchical distributed which is divided into the upper control and lower control is adopted. The upper control stabilizes overall DC bus voltage, that is the average of the entire device module DC bus voltage; lower control stabilizes each module DC bus voltage. STATCOM based on the H-bridge cascade and carrier phase shift PWM(CPS-SPWM) technology; Secondly, On the basis of the STATCOM direct power control algorithm based on virtual flux, the distributed voltage is introduced.

## 6. Proposed Control Strategy

There are two technical challenges exist in H-bridge cascaded STATCOM to date. Firstly, the control method for the current loop is an important factor influencing the compensation performance. Secondly, H-bridge cascaded STATCOM is a complicated system with many H-bridge cells in each phase, so the dc capacitor voltage imbalance issue which caused by different active power losses among the cells, different switching

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patterns for different cells, parameter variations of active and passive components inside cells will influence the reliability of the system and even lead to the collapse of the system. In terms of current loop control, the majority of approaches involve traditional linear control method, in which the nonlinear equations of the STATCOM model are linearized with a specific equilibrium. The most widely used linear control schemes are PI controllers to regulate reactive power. The common approach is to adopt the conventional PI controller which is simple to implement. However, the output voltage and current of H-bridge cascaded STATCOM are the power frequency sinusoidal variables and the output power is the double power frequency sinusoidal variable, it will make the dc capacitor also has the double power frequency ripple voltage.

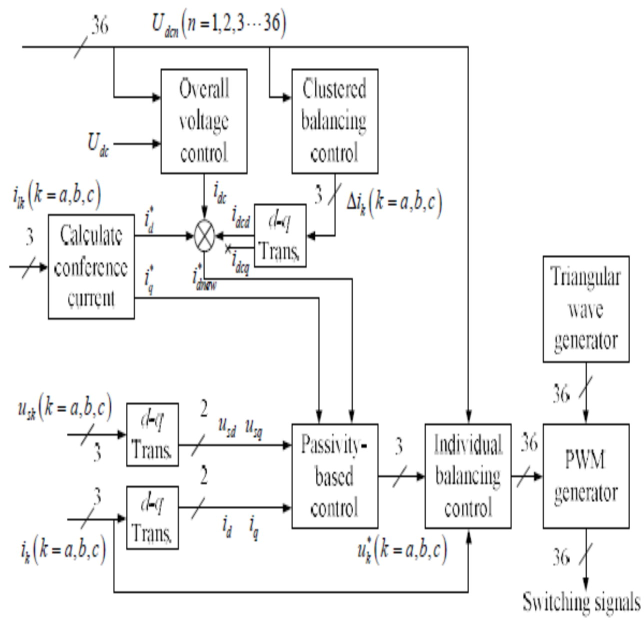


**Figure 2 Control design of H-bridge Cascaded STATCOM**

The whole control algorithm mainly consists of four parts, namely, passivity-based control, overall voltage control, clustered balancing control and individual balancing control. The first three parts are achieved in DSP, while the last part is achieved in FPGA.As the first level control of the dc capacitor voltage balancing, the aim of the overall voltage control is to keep the dc mean voltage of all converter cells equals to the dc capacitor reference voltage. In general, when using PI controller, in order to ensure the stability and the dynamic performance of system, the bandwidth of the voltage loop control is set to be 200Hz to 500Hz and it is difficult to restrain the negative effect on the quality of STATCOM output current which is caused by the 100Hz ripple voltage. Moreover, because of static error of PI controller, it will affect not only the first level control but also the second and third one. Especially during the startup process of STATCOM, it will make the voltage reach the target value with a much larger overshoot. To resolve the problem, it adopts PR controller for the overall voltage control. The gain of PR controller is infinite at the fundamental frequency and very small at the other frequency. Consequently, the system can achieve the zero steady state error at fundamental frequency. By setting the cutoff frequency and the resonant frequency of PR controller appropriately, it can reduce a part of ripple voltage in total error, decrease the reference current distortion which is caused by improve the quality of STATCOM output current.

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## 7. Simulation Model of the Proposed System

The simulation model of the system was designed which is composed mainly of three-phase source, a non-linear load, STATCOM, coupling transformer, three phase voltage measurement. All the subsystems are modelled separately, integrated and then recombined to simulate the system.

### i. Test System without Compensation

The Figure shows the test system without compensation. Three phase source having phase to phase rms voltage of 11KV is being connected to coupling transformer through a three phase transformer.

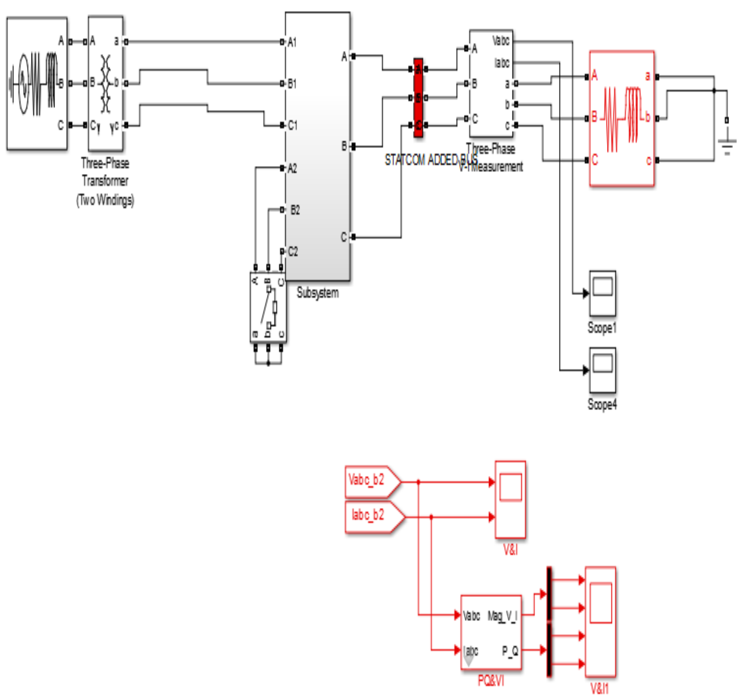


**Figure 3 Test System without Compensation**

### ii. Test System with Compensation

The Fig 6.2 shows the test system with compensation. Three phase source having phase to phase voltage of 11KV is being connected to PCC through a step up transformer. The output voltage of three phase transformer is 220KV. Apart from three phase source, a non-linear load and STATCOM is connected to PCC. Consider a non-linear load having R=1000 ohm and L= 800 H.

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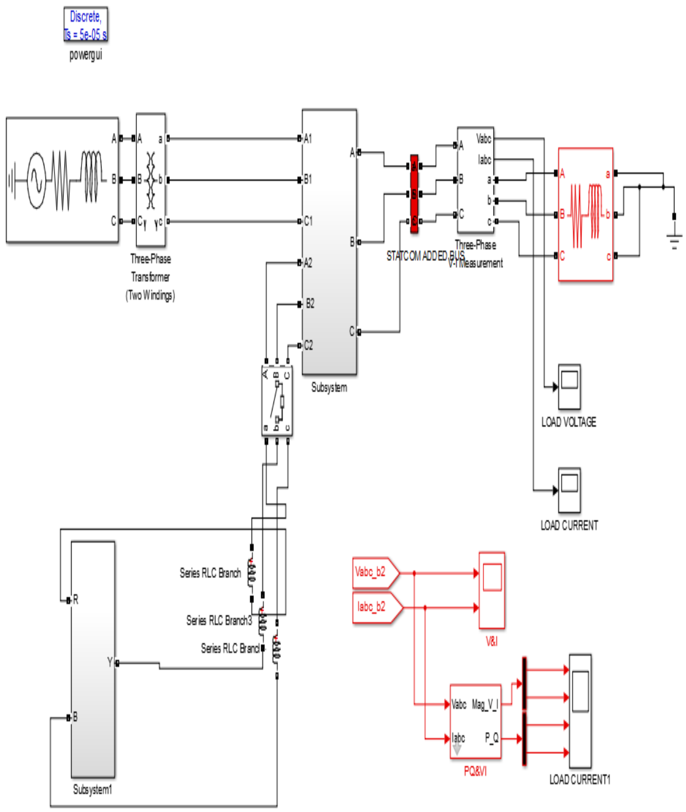


**Figure 4 Test System with Compensation**

## iii. Output Waveforms of the Proposed System

### Load voltage

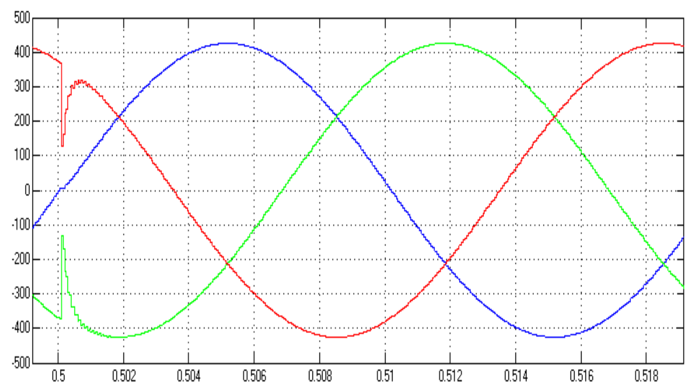


**Figure 5 Load Voltage without Compensation**

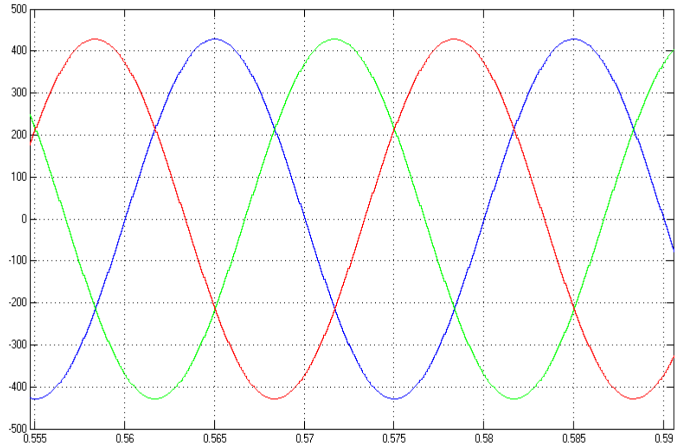


**Figure 6 Load Voltage with Compensation**

**Load current**

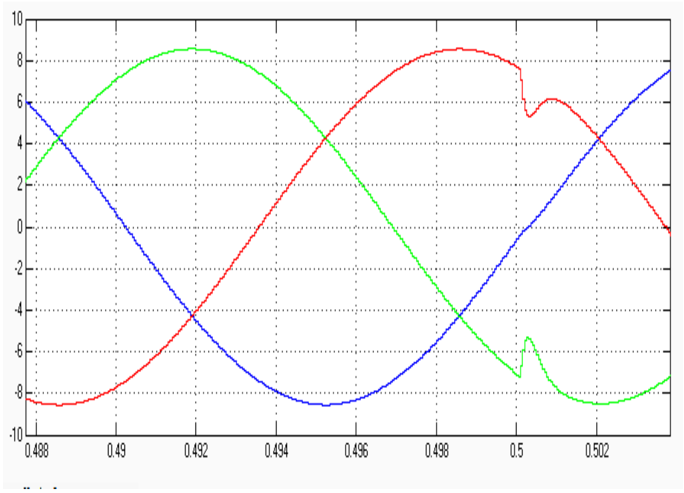


**Figure 7 Load Current without Compensation**

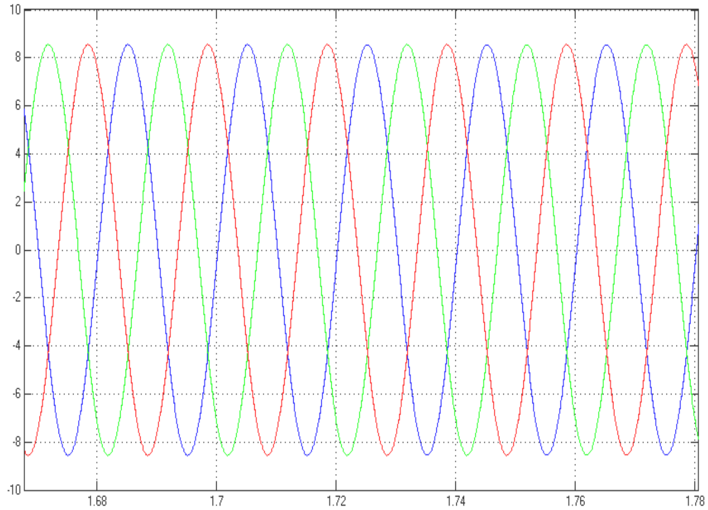


**Figure 8 Load Current with Compensation**

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**Multilevel Inverter Output**

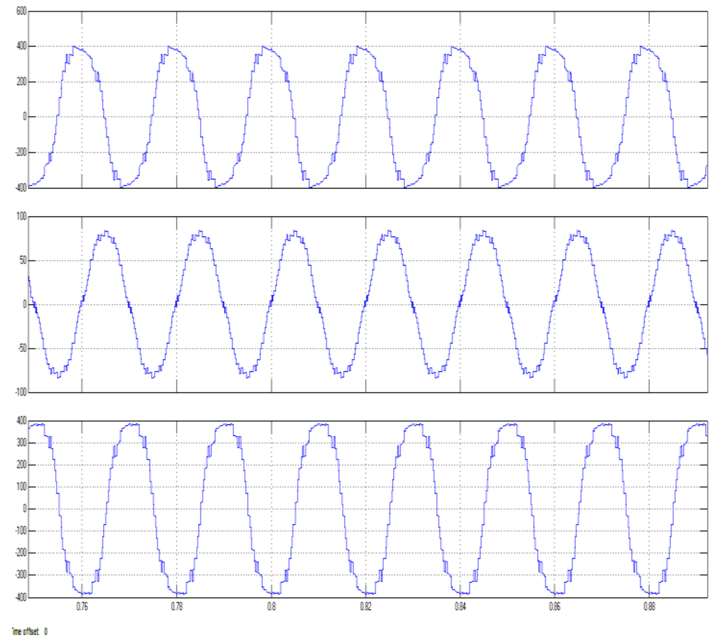

**Figure 9 Multilevel Inverter Output**

**Real and Reactive Power at PC**

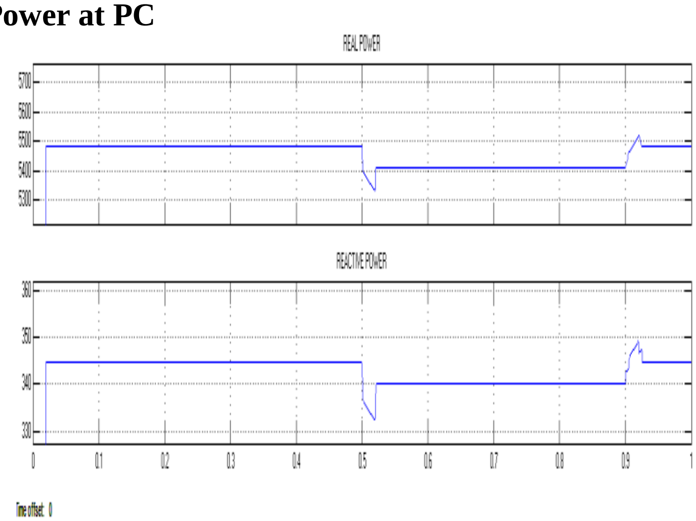


**Figure 10 Real and Reactive power without Compensation**

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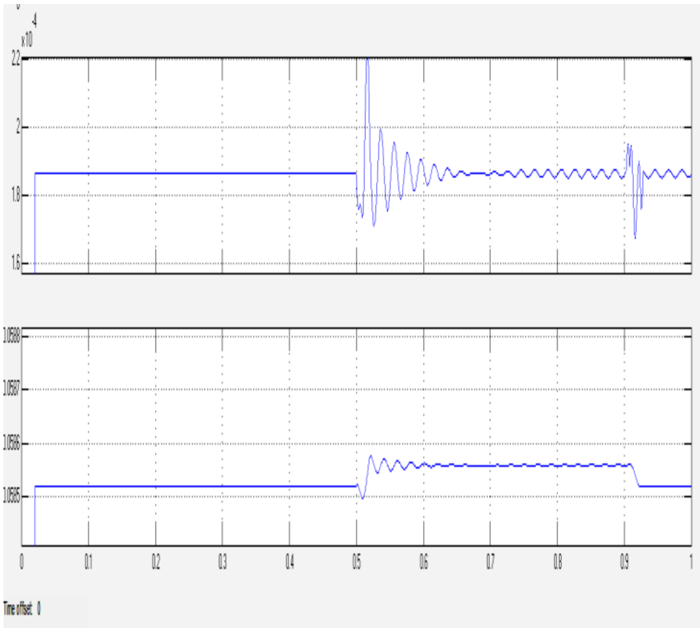


**Figure 11 Real and Reactive power with Compensation**

## Total Harmonic Distortion

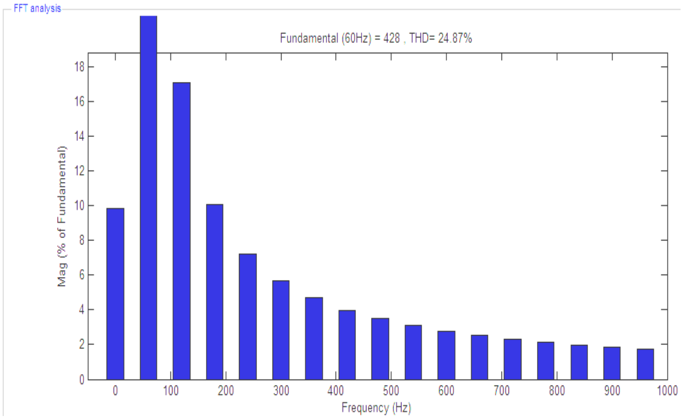


**Figure 12 Total Harmonic Distortion without Compensation**

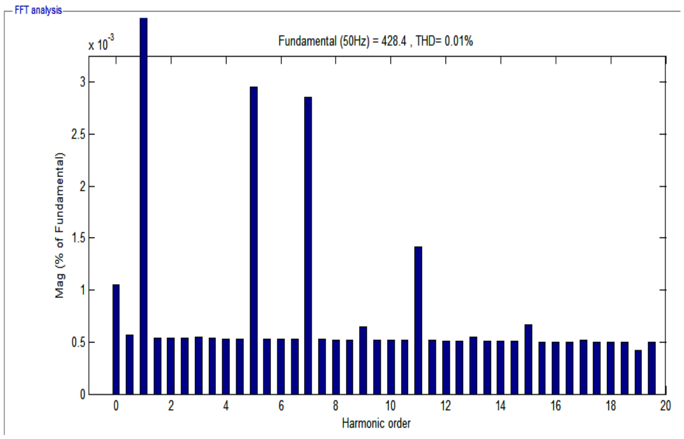


**Figure 13 Total Harmonic Distortion with Compensation**

It is observed that for the test system without compensation, it is observed from the output waveforms that the load voltage is around 300V and load current is distorted and it is found to be 6A. Similarly the real and reactive power at PCC is 5.4KW and 340VAR respectively. For the same strategy, the percentage of THD obtained is 24.87%. For the test system with compensation, it is observed from the output waveforms that load voltage is 440V and load current is 8A. Similarly the real and reactive power at PCC is 5.485KW and 344.6VAR respectively. For the same strategy, the percentage of THD obtained is 0.01%.

## 8. Experimental Setup

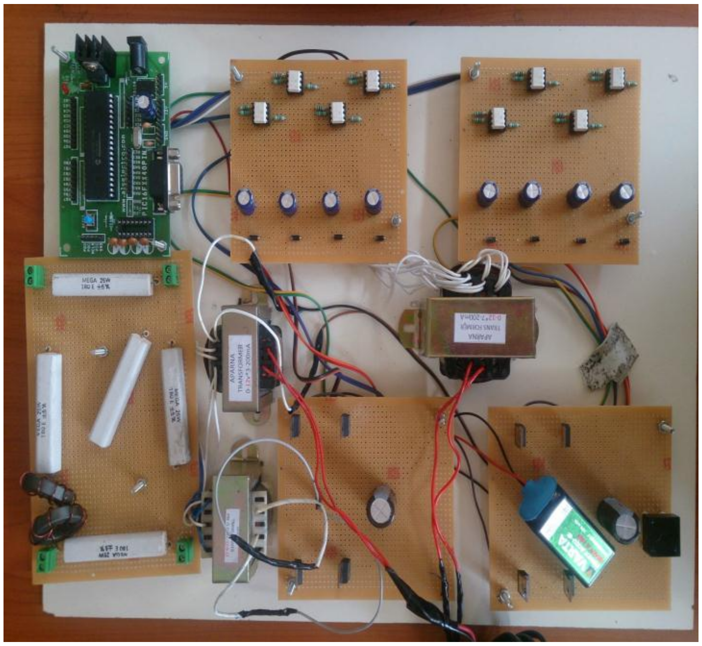

**Figure 14 Experimental Setup**

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## 9. Conclusion

This proposed paper has analysed the fundamentals of STATCOM based on multilevel H-bridge converter with star configuration. And then, the actual H-bridge cascaded STATCOM rated at 10 kV 2 MVA is constructed and the novel control methods are also proposed in detail. The proposed methods has the following characteristics.

A PBC theory based nonlinear controller is first used in STATCOM with this cascaded structure for the current loop control, and the viability is verified by the experimental results. The PR controller is designed for overall voltage control and the experimental result proves that it has better performance in terms of response time and damping profile compared with the PI controller. The ADRC is first used in H-bridge cascaded STATCOM for clustered balancing control and the experimental results verify that it can realize excellent dynamic compensation for the outside disturbance. The individual balancing control method which is realized by shifting the modulation wave vertically can be easily implemented in FPGA. The experimental results have confirmed that the proposed methods are feasible and effective. In addition, the findings of this study can be extended to the control of any multilevel voltage source converter, especially those with H-bridge cascaded structure.

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