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Power Quality Improvement Using Multilevel Inverter Based Statcom

[1*]R. Selvaganapathy, [2]R. Kannan [3]A. Ravi
[1*]Research Scholar, Department of Electrical Engineering, Annamalai University, Annamalainagar, India
[2]Associate Professor, Department of Electrical Engineering, Annamalai University, Annamalainagar, India
[3]Professor and Head, Department of EEE, A.V.C. College of Engineering, Mayiladuthurai India

ABSTRACT

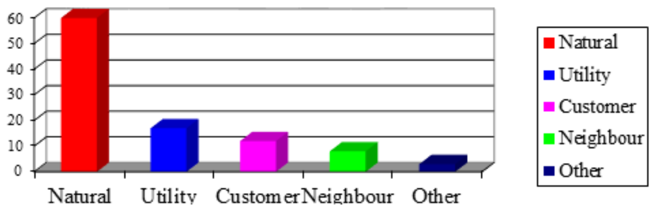
Power Quality is a major concern for power system utilities become of several events of voltage collapses. The term electric power quality broadly refers to maintaining a near sinusoidal power distribution bus voltage at rated magnitude and frequency. Also, the energy supplied to a customer must be uninterrupted from the reliability point of view. It is to be noted that even though power quality (PQ) is mainly a distribution system problem, power transmission systems may also have an impact on the quality of power. In this paper a PI control algorithm with space vector pulse width modulation method (SVPWM) used for the power quality improvement with a multilevel inverter based STATCOM. The induction generation based wind form is practiced in that topology. Real and reactive power analysis and STATCOM compensation have been studied.

Keywords: STATCOM, Power Quality

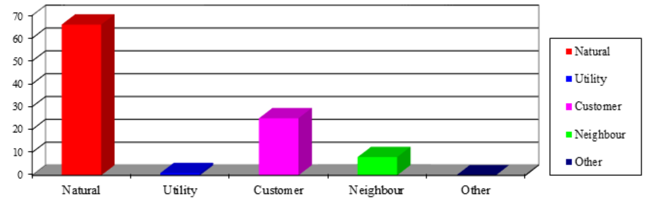
I. INTRODUCTION

Both electrical utilities and end-users are becoming seriously concerned about electrical power quality. It has been one of the most prolific buzzwords in the power industry since the late 1980s. It is an umbrella concept for different forms of power system disturbances. The problems under this umbrella aren't really new.

The causes of power quality issues are many misperceptions. Fig. 1 Represent the results of a survey conducted by Georgia Power Company in which both utility workers and consumers were asked what causes power quality problems. Although surveys of other market sectors which suggest different splits between groups, these charts clearly show one common theme that occurs consistently in such surveys: the perspectives of utility and consumer are often very different. Although both appear to blame natural causes (e.g., lightning) for two-thirds of occurrences, consumers, even more often than maintenance workers, believe the utility is at fault. When a piece of equipment has a power problem, end users can be quick to complain of a "outage" or "glitch" that caused the problem. Utility reports, however do not suggest irregular events on the customer's feed.



Customer Perception



Utility Perception

Fig. 1 Results of a survey on the causes of power quality problems. (*Courtesy of Georgia Power Co.*)

II. CASCADED H-BRIDGE MULTILEVEL INVERTER

Cascade Multilevel inverters are based on a sequence of single-phase inverters. This structure can achieve medium voltage output using only normal low-voltage mature technology components. Usually, to achieve the necessary output voltage, connect three to 'n' inverters in series. These converters are also highly modular since each inverter can be seen as a module with similar circuit topology, control structure and modulation (Parastar et al, 2007). Therefore a malfunction in one of these modules can be replaced quickly and easily. Moreover, with an acceptable control strategy, the defective module can be bypassed without stopping the load, giving almost continuous overall availability (Park et al, 2005). Numerous literature were noticeable especially on this technology. However, cascade multilevel inverter study is a hot topic in multilevel structures. But it's feasible to know the reason behind it.

However, for CMI such balancing – capacitors are completely absent. However, this is summarized in Table 1.

Table 1 Comparison of Traditional Multilevel Topologies

Converter Type	**DCMLI**	**FCMLI**	**CHMLI**
Main Switching	(m-1)*2	(m-1)*2	(m-1)*2
Main Diodes	(m-1)*2	(m-1)*2	(m-1)*2
Clamping Diodes	(m-1)* (m-2)	0	0
Balancing Capacitors	0	(m-1)* (m-2)/2	0
DC Bus Capacitors	(m-1)	(m-1)	(m-1)/2

III. CASCADED MULTILEVEL INVERTER

Cascaded H-bridge converters consist of power conversion cells, each supplied by an independent dc source on the dc side and AC-connected in series. This topology's benefit is that each bridge's modulation, control, and protection specifications are modular. Unlike diode-clamped and flying-capacitor topologies, isolated dc sources are required for each cell in each phase. Fig. 2 displays a single-phase topology of an independent dc voltage converter. An output voltage waveform is obtained by summing bridge output voltages:

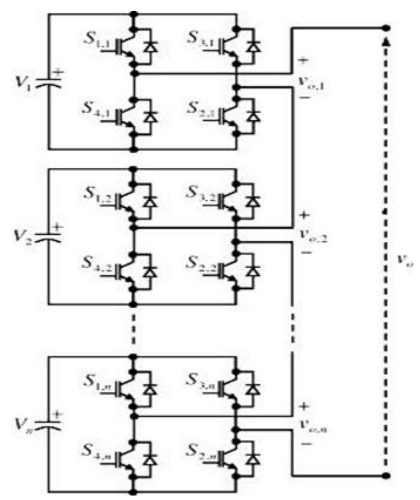


Fig 2. Single phase structure of Cascaded inverter

$$v_o(t) = v_{o,1}(t) + v_{o,2}(t) + ... + v_{o,N}(t) \quad (1)$$

Where *N* is the number of cascaded bridges. The output voltage of the inverter, *v*o(*t*), may be determined from the switching states of the individual cells by the following equation:

$$v_o(t) = \sum_{j=1}^{N} (\mu_j \quad 1) V_{dc,j}, \quad \mu_j = 0 \text{ or } 1 \quad 2 \quad (2)$$

If all dc voltage sources in Fig. 6.2 are equal to *V*dc the converter is then known as symmetric multilevel converter. The effective number of output voltage levels (*n*) in symmetric multilevel converter may be related to the number of cells (*N*) by:

$$n = 2N + 1 \quad (3)$$

The maximum output voltage (*V*o, Max) of this *N* cascaded multilevel is:

$$V_{o,Max = NV_{dc}} \quad (4)$$

To have a wide number of output levels without increasing converter levels, asymmetric multilevel converters may be used. In (Nabavi-Niaki Iravani 1996, Padiyar Kulkarni 1998), the sources of dc voltages are suggested to be selected according to a geometric progression of 2 or 3. N of these cascade converters may achieve the following distinct voltage levels:

$$n = n^{N+1} \quad 1 \ \text{if} V_{dc,j} = 2^{j \quad 1} V_{dc,} j = 1,2,........., N \quad (5)$$

$$n = 3^N \ \text{if} V_{dc,j} = 3^{j \quad 1} V_{dc,} j = 1,2,........., N \quad (6)$$

The maximum output voltage of these *N* cascaded multilevel converters is:

$$V_{o,Max} = \sum_{j=1}^{N} V_{dc,j} \quad (7)$$

Eq. (6.7) can be written as follows:

$$V_{o,Max} = (2^N - 1) V_{dc} \quad \text{if} V_{dc,j} = 2^{j-1} V_{dc,} j = 1,2,........., N \quad (8)$$

$$V_{o,Max} = \frac{(3^N \quad 1)}{2} V_{dc} \quad \text{if} V_{dc,j} = 3^{j \quad 1} V_{dc,j} = 1,2,........., N \quad (9)$$

Comparing Equations (3) – (9), asymmetric multilevel converters will produce more voltage levels and higher potential output voltage with the same number of bridges.

IV. STATCOM AS INVERTER

One of the greatest uses for cascade multilevel inverters is power efficiency devices like STATCOMs and universal power conditioners (Saravanan et al, 2007). (Saravanan et al, 2007). (Saravanan et al, 2007). These devices are linked directly to medium-voltage networks as shown in Fig.6.9 and do not need active power injection at nominal operating level. To satisfy the first condition, as many inverters as possible can be attached to the operating voltage without using a transformer.

STATCOM is a converter model FACTS system offering superior performance compared to conventional compensation methods using thyristor switched capacitors and thyristor-controlled reactors. It also provides unique ability to access real power directly with the AC device, offering efficient new flow control options and dynamic disruption counteraction. Fig. 3 displays a STATCOM schematic diagram. The charged capacitor Cd supplies the converter's DC voltage, and generates a range of controllable three-phase output voltages synchronous with the AC power device. The reactive power exchange between converter and AC device can be regulated by varying the amplitude of output voltage E1. Reducing the output voltage amplitude below the AC system, lagging current results, and the STATCOM is used as an inductor. Here, reactive power is absorbed. If the amplitudes are similar, no power exchange happens.

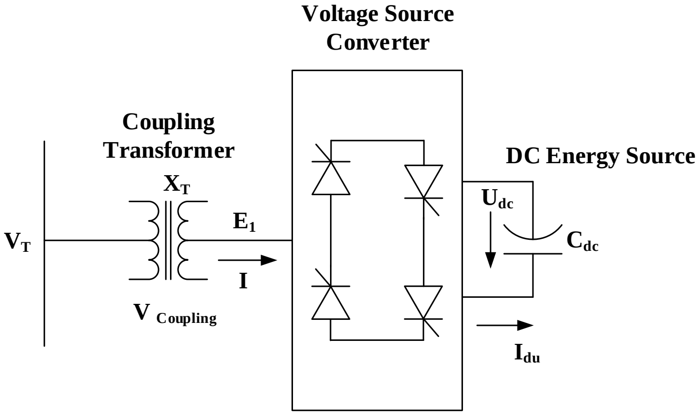


Fig 3 Static Synchronous Compensator

4.1 Modeling of STATCOM

The basic structure of an STATCOM with PWM-based voltage controls is depicted in Fig. 4. Eliminating the dc voltage control loop on this figure would yield the basic block diagram of a controller with a typical phase angle control strategy.

The STATCOM models proposed here is based on the power balance equation,

$$P = Pdc + Ploss$$

PWM controls are becoming a more practical option for transmission system applications of VSC-based controllers, due to some recent developments on power electronic switches that do not present the high switching losses of IGBTs, which have typically restricted the use of this type of control technique to relatively low voltage applications.

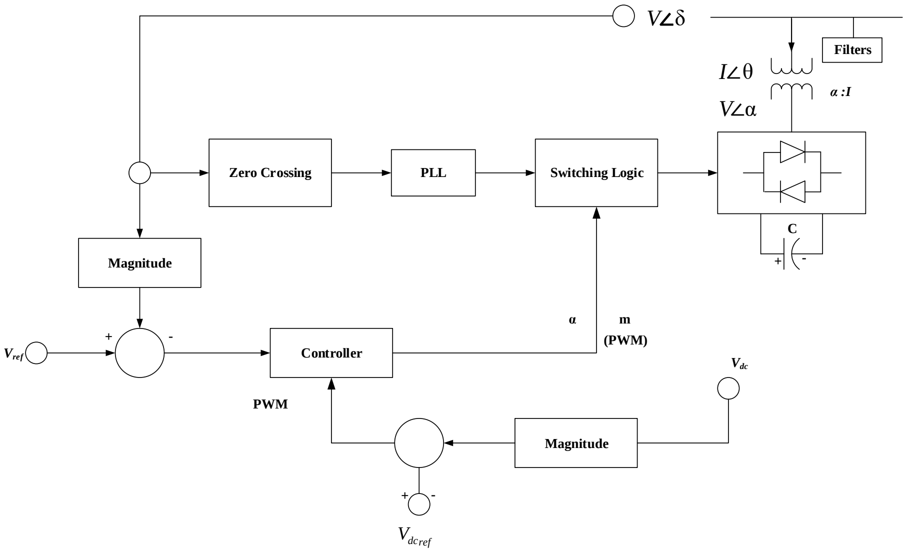


Fig 4 Block diagram of an STATCOM with PWM voltage control.

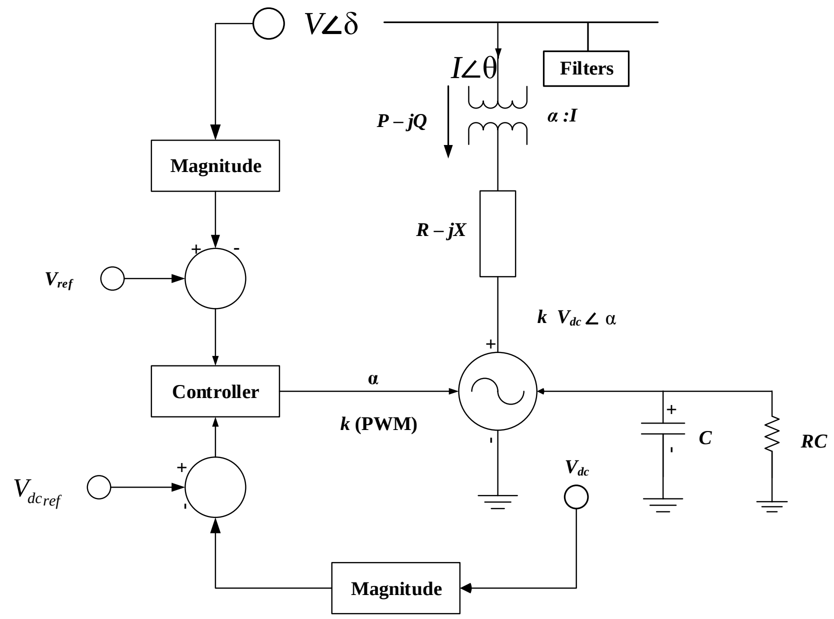
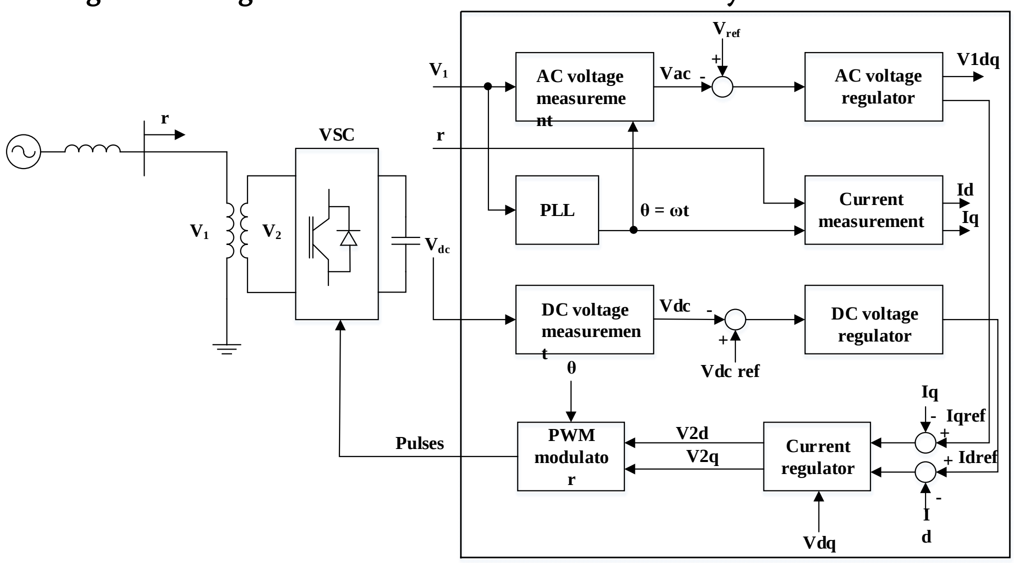


Fig 5 Transient stability model of an STATCOM with PWM voltage control

In PWM controls, switching losses associated with the relatively fast switching of the electronic devices and their snubbers play an important role in the simulation, as these have a direct effect on the charging and discharging of the capacitor, and hence should be considered in the modeling.

4.2 Single-Line Diagram of an STATCOM and its Control System



Control System

Fig 6 STATCOM Control System

The control system consists of:

- A phase-locked loop (PLL) which synchronizes on the positive-sequence component of the three-phase primary voltage V1. The output of the PLL (angle Θ=ωt) is used to compute the direct-axis and quadrature-axis components of the AC three-phase voltage and currents (labeled as Vd, Vq or Id, Iq on the diagram).

- Measurement systems measuring the d and q components of AC positive-sequence voltage and currents to be controlled as well as the DC voltage Vdc.
- An outer regulation loop consisting of an AC voltage regulator and a DC voltage regulator. The output of the AC voltage regulator is the reference current I reef for the current regulator (I q = current in quadrature with a voltage which controls reactive power flow). The output of the DC voltage regulator is the reference current Id ref for the current regulator (Id = current in phase with a voltage which controls active power flow).
- An inner current regulation loop consisting of a current regulator. The current regulatory controls the magnitude and phase of the voltage generated by the PWM converter (V2d V2q) from the Idref and Iqref reference currents produced respectively by the DC voltage regulator and the AC voltage regulator (in voltage control mode). The current regulator is assisted by a feed forward type regulator which predicts the V2 voltage output (V2d V2q) from the V1 measurement (V1d V1q) and the transformer leakage reactance.

The STATCOM block is a Phasor model which does not include detailed representations of the power electronics. You must use it with the Phasor simulation method, activated with the Powerful block. It can be used in three-phase power systems together with synchronous generators, motors, dynamic loads and other FACTS and DR systems to perform transient stability studies and observe the impact of the STATCOM on electromechanical oscillations and transmission capacity at the fundamental frequency.

V. SPACE VECTOR PUSE WIDTH MODULATION

Space Vector Modulation (SVM) is an algorithm for the control of Pulse Width Modulation (PWM). It is used for the creation of Alternating Current (AC) waveforms; most commonly to drive 3 phase, AC powered motors at varying speeds from DC using multiple class-D amplifiers. There are various variations of SVM that result in different quality and computational requirements. One active area of development is in the reduction of Total Harmonic Distortion (THD) created by the rapid switching inherent to these algorithms. The main aim of any modulation technique is to obtain a variable output having a maximum fundamental component with minimum harmonics.

Six active vectors are (V1, V2, V3, V4, V5, V 6). DC link voltage is supplied to the load. Each sector (1 to 6): 60 degrees. Two zero vectors are (V0, V7). They are located at the origin. No voltage is supplied to the load.

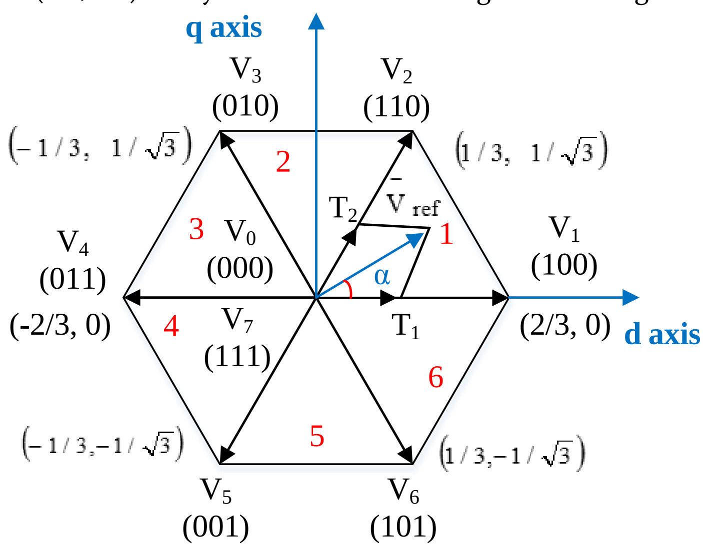


Fig. 7 Basic switching vectors and sectors.

The eight combinations, phase voltages and output line to line voltages are shown below in Table 2.

Table 2 Phase voltages and output line to line voltages in SVPWM

Voltage Vectors	Switching Vectors			Line to neutral voltage			Line to line voltage		
	a	B	c	Van	Vbn	Vcn	Vab	Vbc	Vca
Vo	0	0	0	0	0	0	0	0	0
V1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V2	1	1	0	1/3	1/3	-2/3	0	1	-1
V3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V4	0	1	1	-2/3	1/3	1/3	-1	0	1
V5	0	0	1	-1/3	-1/3	2/3	0	-1	1
V6	1	0	1	1/3	-2/3	1/3	1	-1	0
V7	1	1	1	0	0	0	0	0	0

VI. VOLTAGE STABILITY ANALYSIS

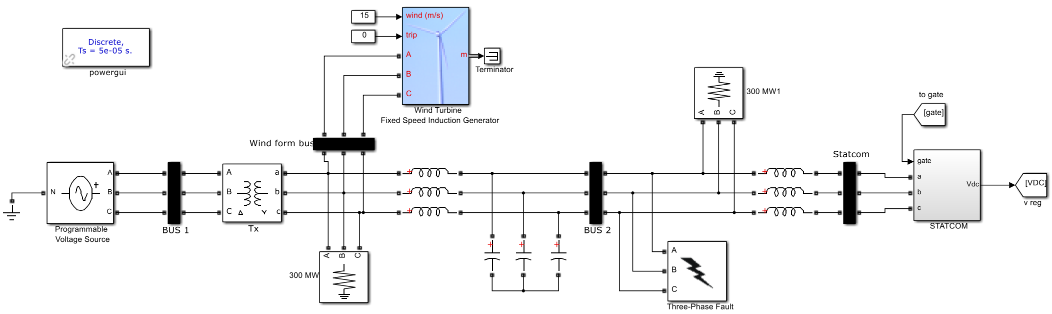


Fig. 8 Matlab/Simulink model of proposed system

A 500 kV, 60Hz source is connected to a grid having two 300MW connected to bus 1 and bus 2. 1.5MVA, 25kV, 60Hz Wind Farm is connected to the grid as shown in Fig. 8. STATCOM is connected to bus 2. An asynchronous fault is (LLG) is introduced between bus 1 and 2 at the time period of 0.8 to 1 sec.

In fixed speed machines, the generator is directly connected to the main supply grid. The frequency of the grid determines the rotational speed of the turbine rotor, which in turn is translated into the generator rotational speed (through the gearbox). The generator speed depends on the number of pole pairs and the frequency of the grid. This feature in the controller requires additional design effort and manual of control in the region may lead to an optimization that considers the life of the gearbox and other wind turbine elements. The greatest advantage of WT's with asynchronous generators is their simple and robust construction. Also, there is no need for synchronization device. Except bearings, no parts are subjected to wear and tear. The wind turbine with two generator performs better mainly because the small generator has more poles than the large generators, that is the rotor speed of smaller generator becomes closer to the rotor speed that would capture more energy and also the price tends to be slightly lower.

Voltage and Current responses are analyzed to evaluate the dynamic performance of the system. A three phase five level cascaded H-Bridge Multilevel inverter used as an STATCOM in this work to compensate the voltage disturbances occurred in the transmission line. Fig. 9 shows the structure of proposed five-level H-bridge inverter.

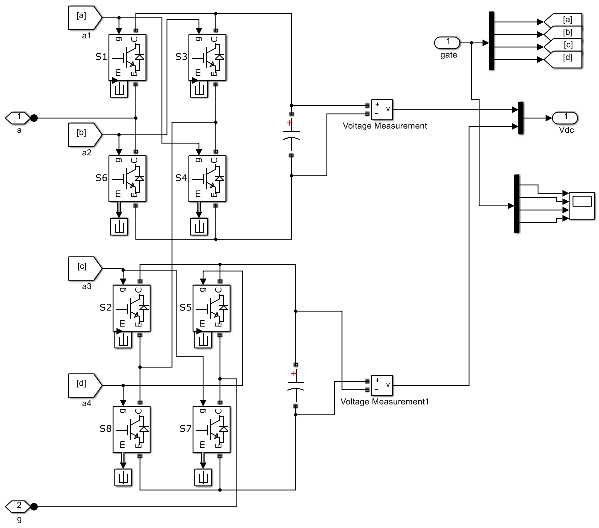


Fig. 9 Simulink model of five level cascaded H-bridge inverter

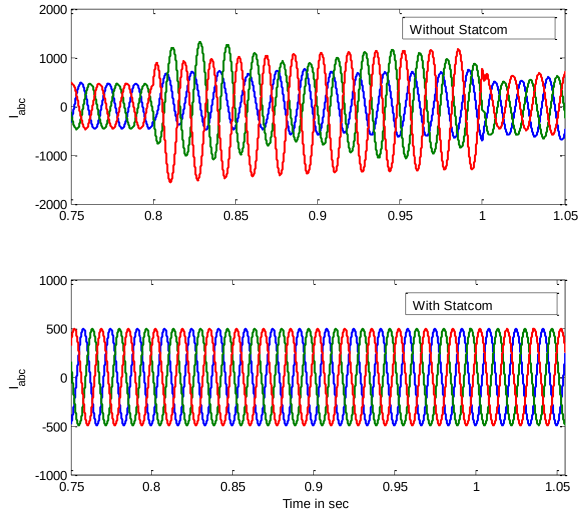


Fig. 10 Current response at bus1 with and without STATCOM

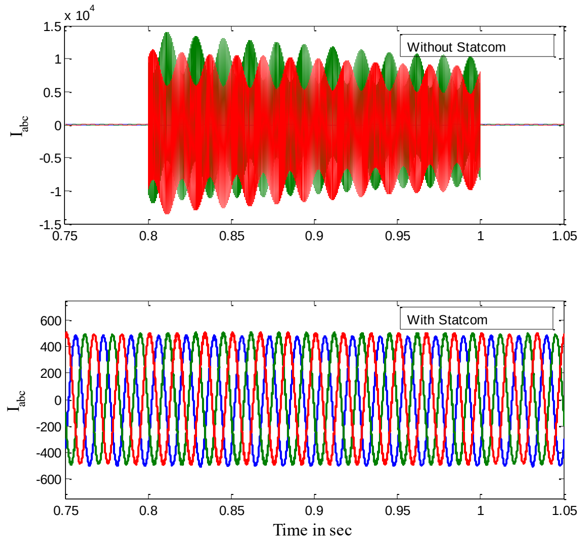


Fig. 11 Current response at bus2 with and without STATCOM

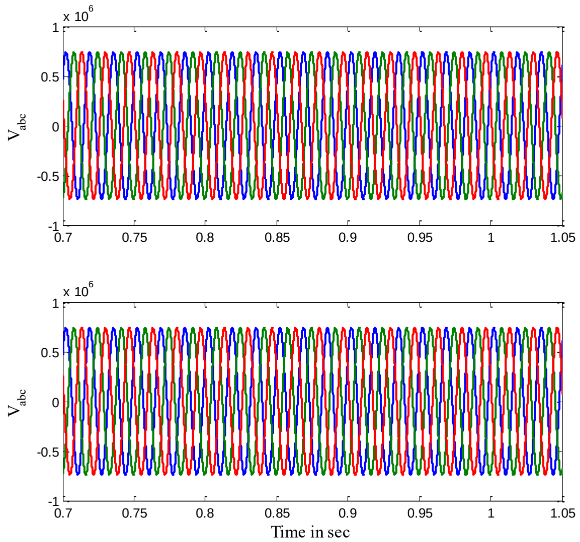


Fig. 12 Voltage response at bus1 with and without STATCOM

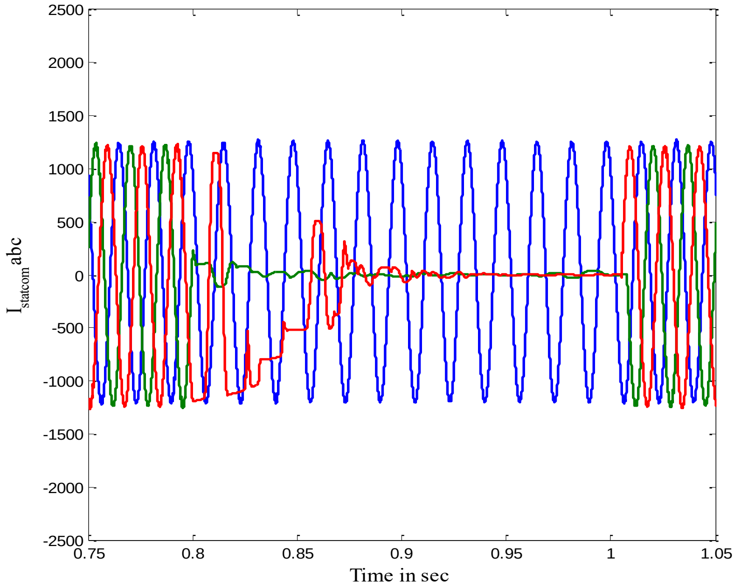


Fig. 13 Current response at STATCOM

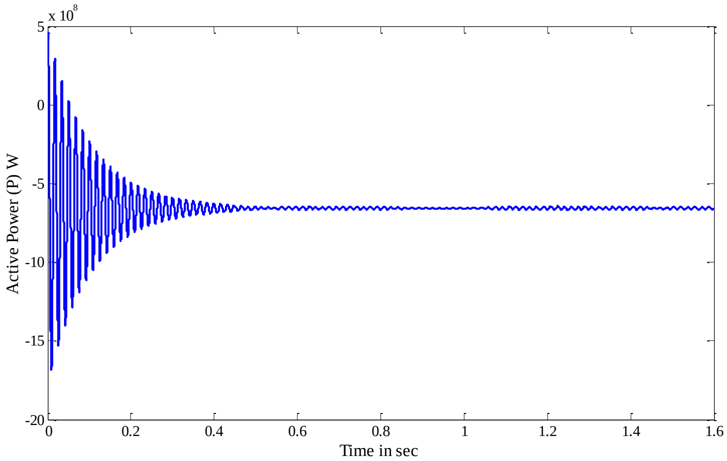


Fig. 14 Active power of the system with STATCOM

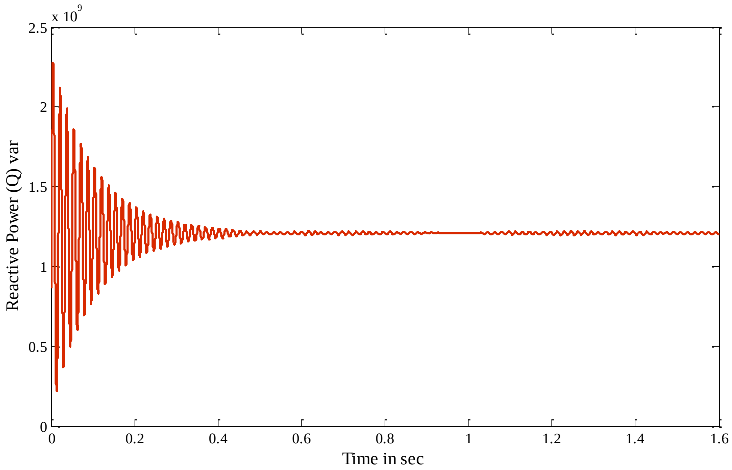


Fig. 15 Reactive power of the system with STATCOM

Fig. 10 shows a current response at the base without and with STATCOM implementation. From the figure 6.18, it is observed that the response without STATCOM is fully distorted, but with response STATCOM the distortion is fully compensated during the fault condition.

Similarly, the implementation of STATCOM again proves its effect to compensate the load current and bring to steady state at bus2, during a fault condition. The response is shown in Fig. 11.

Fig. 12 shows the voltage response at bus 1 with and without STATCOM. It is observed that there is no effect on voltage during the fault condition, the only load current is distorted. The compensated load current injection from STATCOM during fault condition period of 0.8 to 1 sec is shown in Fig. 13. Fig. 14 and Fig. 15 show the active and reactive power of the proposed system during STATCOM compensation.

From figure 14, it is observed that the negative real power indicates that power is flowing in the direction opposite from grid to the generator. For a generator, it would mean that power is flowing from the grid/bus into the generator to keep it spinning. This happens when the engine/turbine is not generating enough power to overcome friction/windage losses, and the electrical bus has to supply power to the generator to keep it spinning.

Similarly, from figure 15, negative reactive power means reactive power is flowing in the direction opposite from convention. Normally a generator supplies reactive power to a bus to 'feed' the reactive loads on the bus. The convention is that inductive loads consume 'positive reactive power', and capacitive loads are said to supply 'positive reactive power.' You could also argue that capacitive loads supply 'negative' reactive power which cancels out the 'positive' reactive power of inductive loads.

VII. CONCLUSION

A PI control algorithm with space vector pulse width modulation method (SVPWM) used for the power quality improvement with a multilevel inverter based STATCOM. The induction generation based wind form is practiced in that topology. Real and reactive power analysis and STATCOM compensation have been studied

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