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# REACTIVE POWER COMPENSATION OF SOLAR POWER INTEGRATED CONVENTIONAL GRID SYSTEM USING STATCOM

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**Abstract**
Voltage stability, reactive power adjustment, and breakdown are the most frequent problems power systems encounter today due to the rising demand for electricity. All of these problems have as their main worry the impending collapse of the transmission systems, which has been made even more problematic by the frequent fluctuations in load. As a result, research in this area has continued despite the lack of documented optimal solutions for a very long time. Here in the present work, author has implemented single phase inverter as STATCOM in grid-tied mode for a combined power system consisting of conventional energy sources combined with renewable energy sources such as solar energy. The single phase inverter has been designed with H Bridge and LCL filters. The result findings are depicted that, the proposed design is capable for reactive power compensation and voltage stability hence can be proposed for integrated system of combined power plants. Modeling and analysis software includes simulink and MATLAB.
**Keywords:** STATCOM, Reactive power, Single phase inverter, Grid-tied mode.

## 1. Introduction

The flexible alternating current transmission system (FACTS) is an emerging technology based on new power electronics devices that provides a way to improve ac transmission systems' stability, reliability, and energy transfer capabilities [1].More precisely, introducing a FACT system results in: higher power control so that energy can flow in the described routes of transmission or distribution lines; improved capacity to transmit power across restricted zones, allowing for a reduction in the generating reserve margin; reducing the consequences of malfunctions and equipment failure to prevent cascading outages; and fluctuations in the power system are also dampened [2].
Broadly, power electronics devices can be classified into various groups as per their employment in the system. The first group of power electronics devices includes their application to renewable sources of energy, such as grid-connected photovoltaic (PV) panels via inverters. The second group of power electronics devices includes their use for energy storage systems, such as battery energy storage systems. The third types of power electronics devices are Flexible AC Transmission Systems (FACTS) that improve the grid's dynamic behavior, power quality, and stability [3].The present work is focus on to the third group of power electronics devices such as FACT devices.

The various FACT devices includes thyristor-controlled series capacitor (TCSC), static synchronous series compensator (SSSC), thyristor-controlled phase-shifting transformer (TCPST), the interline power flow controller (IPFC), the dynamic flow controller (DFC), unified power flow controller (UPFC) and static shunt controller devices (STATCOM) etc. Out of these all devices are STATCOM is mostly used for reactive power compensation across the transmission system.

The STATCOM is a shunt-connected element that controls the amplitude and phase angle of the 3- $\phi$ voltage that STATCOM sends to the grid to regulate the grid's reactive power. Through reactive power control, the STATCOM has become capable of managing the voltage level at the coupling point in transmission and distribution networks. Here in the present work, author has propose a revolutionary smart inverter or PV-STATCOM that may be used to regulate a solar inverter as a reactive power compensation in distribution line. Further, a Dq0 control technique that is most common approach in STATCOM has been employed as inverter's controller, with the outer voltage loop forming the desired active and reactive current commands to maintain the voltages at the point of common coupling and compensate for STATCOM losses.

Due to the current trend and rapid expansion of electrical distribution networks that are linked with renewable energy sources, the addition of additional features has become a necessary demand in order to synchronize the power flow between distributed energy sources and the distribution network [4-5]. Such kinds of systems result in safe and diverse energy sources that are found to be effective in improving the transmission and distribution system's efficiency, minimizing carbon emissions, improving power quality and system stability, and lowering energy prices [6-7]. In contrast to such benefits, the system's non-reliability of the energy source and reliance on renewable energy are several disadvantages.

Hence, across such frameworks or power supply systems, power converters or power inverters play crucial role, especially at the time when electricity is produced in a format that is irreconcilable with the distribution network, such as the DC output through batteries, photo - voltaic modules and fuel cells etc. Furthermore, such an interface must be equipped with control techniques that optimize the amount of power taken from the source and sent to the grid while maintaining grid quality standards [8]. The solution for this is power electronic inverters or convertors that used to link DGs or renewable energy sources to the grid [9].

Power inverters or converters, like static devices like STATCOM and the Unified Power Flow Controller or UPFC, can be used for active and reactive power compensation, as well as power factor improvement, in the Flexible AC Transmission System (FACTS) network. DG systems in which power electronics inverters or converters have been used are fulfilling the same function as when it comes to FACTS technologies. They are quite useful.

Numerous distributed generation systems have been implemented in domestic or rural regions in which the power distribution system is generally supported by a single phase. Hence, a single-phase inverter is necessary in such situations. Because the FACTS systems that have been stated previously are usually larger scale three-phase systems. If anyone has been encouraged to incorporate analogous power electronic converter control algorithms into single-phase inverters, they must either modify the system or create new algorithms.

When utility voltages and currents are out of balance, various compensators based on the three-phase framework fail to generate sinusoidal current waveforms on the utility side [10]. Hence, it might be the leading reason for continuing with single-phase compensation strategies further. A single-phase inverters in grid-tied mode has been a proven technique as per [11] to provide an appropriate power quality and minimum current harmonics along two side flow of energy as a result single-phase inverters are usually employed in Distributed Generation (DG) systems. A single phase inverter has the capability to operate in distinct modes: one is islanded mode or stand-alone mode other is grid-tied mode [12]. In case system is in grid tied mode, both true as well reactive power (P and Q) can be delivered to the load, depending on the system design.

Similarly, in case the grid system is operating in stand-alone mode, the current as well power sharing among the grids has been zero as they are functioning independently [13]. Due to controlling mechanisms, the inverter can share power when a grid fault occurs [14].

## 2. Literature review

Previously, researchers have developed a number of approaches for exchanging active and reactive power in single-phase grid-tied systems. In the phase shift technique [15], 2nd order generalized integrators (SOGI) [16], and Transfer function [17], the ortho signal generator (OSG) is employed for rotating inputs. Because of its sophisticated transfer function, the OSG has numerous flaws and that's why it has been refused. Furthermore, the SOGI has a long delay between signals. Due to periodic variations in the grid-tied system, the fictitious axis emulation (FAE) is a potent tool for improving OSG and SOGI. However, it is not ideal for single-phase inverters [18].

Furthermore, in case of the photovoltaic (PV) voltage source inverters, a PI controller has been used in order to feed the controlled electricity into the grid [19]. However, the higher value of THD can lead to uncertainty in the system. For PV VSI, the system dynamics are enriched, and complexity is reduced in [20]. However, the output power raises serious issues about stability. The steady-state error can be terminated using a low-voltage ride-through (LVRT) [21] and a linear quadratic regulator (LQR) [22]. The response time of the engaged controllers, on the other hand, appears to be delayed.

Based on the findings from the literature, this work propose to employee a PID controllers to regulate the real and reactive power of a single-phase grid-tied inverter using DQ current control technique.

It has been noticed that, the rotating reference Frame or RRF has also been employed similarly as the DQ concept that was initially invented for the three-phase inverter, but later on started to be used in single-phase inverter [23]. The greatest strength of this application is that in case the ac variables are RRF converted with fundamental frequency, they are comparable to the dc quantities and can be regulated using the Proportional Integration (PI) control. RRF's PI controllers not only regulate the inverter's electrical output, as well as the output power of traditional current control [24].

In the DQ concept, the PI controllers are identical to those in the framework. Due to DQ transforming features, the DQ concept is also particularly successful in the context of harmonic distortion [25]. The inverter generates an output that is both harmonic and delay-free. To decrease harmonics, an LC filter is constructed and used.

## 3. Proposed design

The present research work is focus on implementation of single-phase inverter that is designed based on IGBT-based H-bridge and a LCL output filter. He circuit for IFBT based H-bridge inverter has been shown in figure 3.1. The output filter of the inverter has been shown in figure 3.2

This model has current as well as voltage measurement at the output. Here in the design of IGBT based H bridge single phase inverter control system with returned signal has been proposed to produces a signal or pulse across the IGBT gate terminal. Furthermore, in order to avoid formation of low impedance across the DC source terminals, the network has been designed in that way the bottom transistor gate control is the inverse of the top in each leg of the bridge.

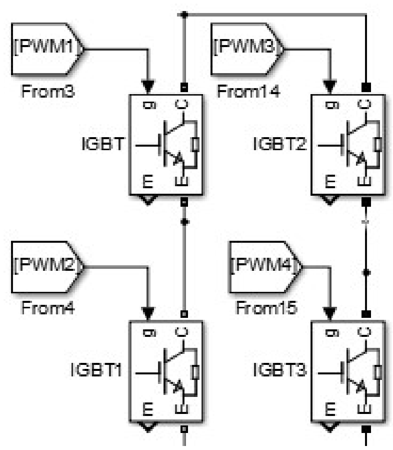


**Figure 3.1:** Single phase inverter

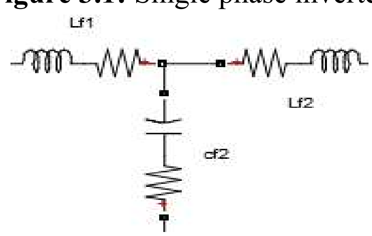


**Figure3.2:** LCL filter

Here the used terminology that is H-bridge is also known as a full bridge somewhere in literature. This technique is quite simple as the requirement of with low component count that must be leads to low cost and high efficiency. That kind of the topology has been chosen over a half bridge that was based on only one pair of switches because a lower DC voltage source is required. In case of half bridge inverters, there is requirement of twice the DC voltage and two capacitors in series in order to provide a neutral output. Here the H-Bridge has been designed based on the Universal Bridge Simulink model block with two legs. This H bridge inverter has been triggered using the Pulse Width Modulation (PWM) generator. Here the mean magnitude of the H-Bridge voltage output over a switching cycle is directly proportionate to the inverter's instructed duty cycle and the magnitude of the DC supply.

In addition to that, for the present design of the inverter, an output filter has been connected with the H bridge design in order to restrict the high frequency current ripple. As such, there is usually a chance of a tradeoff between the size of the filter elements and their weaving speed. The former tends to increase the cost and size of the inverter, while the latter leads to increased switching power loss. The LCL filter was chosen as the modeling output filter. Because of its smaller size, this filter has gained popularity. However, it may cause control stability issues. Finally, the author's proposed H-bridge inverter has been connected to a common and very simple design of a power grid as well as a simple load model in order to represent a load that will be compensated at the DG. The grid side of the bridge has been shown in figure 3.3 given below.

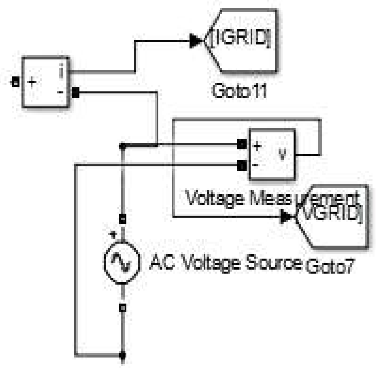


**Figure 3.3:** AC Grid

### 3.1 Parameters Selection of H bridge Single phase Inverter

Here in this section, the parameters selection for the H-bridge inverter has been explained. Table 3.1, given below, demonstrates the value of the chosen parameter for simulating the single phase H bridge inverter.

**Table3.1:** Parameters Values of Single Phase Inverter

| Parameters | Value |
|---|---|
| **Inverter** | Full Bridge or H bridge Inverter (Single Phase) |
| **DC- Voltage (Regulated)** | $400V_{dc}$ |
| **Technology** | Power IGBT |
| **Inverter's Output Voltage Value** | 0-80V |
| **Switching Schemes** | Pulse Width Modulation |
| **Input Capacitance** | 500e-6 micro Farad |
| **Input Resistance** | 1e-3 ohm |
| **Filter** | LCL |
| **Filter resistance** | 0.001 ohm |
| **Filter inductance 1** | 4.06e-3 mH |
| **Filter inductance 2** | 4.35e-3 |
| **Filter Capacitance** | 6.01e-6 micro Farad |
| **Grid voltage** | $325V_{AC}$ |
| **Grid Voltage frequency** | 50Hz |

### 3.2 Control design (ANFIS Network)

ANFIS is the most effective control technique due to the PV system's non-linearity best option. There are five main levels to the architecture. It is the job of the fuzzification layer to calculate the membership functions depending on inputs for temperature and solar irradiation. All input nodes are given a set of seven Gaussian membership functions, the parameters of which may be tweaked to get a desired result.

These tuning knobs encourage the use of an optimization strategy to determine the best setting that results in the smallest possible squared deviation in controller output. Lower and upper Gaussian In this inquiry, interval type-2 It makes use of membership functions.

The value of lower Gaussian membership function is less than, or about the same as, than the higher Gaussian membership function for the same set of input values. The grey area, as explained in, is the region between two known quantities. There are various advantages to membership functions of type 2 are preferred over type 1 ones. some of which are discussed in. The PSO is used to alter each membership function's standard deviation and center, since it has shown to be capable of finding the best possible solution for each variable. This tuning is done for each input throughout the learning process with the goal function of minimising the output of the controller's mean square error.

The ANFIS, the second layer is sometimes is referred to as "rule layer" since it is in charge of coming up with the shooting strengths that are required under the regulations. After the firing strengths have been calculated, the third layer's task is to normalize them by dividing the value of each node by the overall firing strength. The third layer produces a normalized output that is used by an adaptive node in the fourth layer, along with parameters for potential outcomes be adjusted throughout the learning process. This is also why PSO is used when teaching neural fuzzy networks to adapt.

In order to produce the final output, the defuzzed values from the fourth layer are passed on to the fifth layer. In a diagram figure 3.4, the ANFIS network infrastructure might look like this. Figures 3.4 illustrate the membership functions of the inputs to the ANFIS controller. According to the examples given below, the controller employed For each input, there are seven interval type-2 Gaussian membership functions.

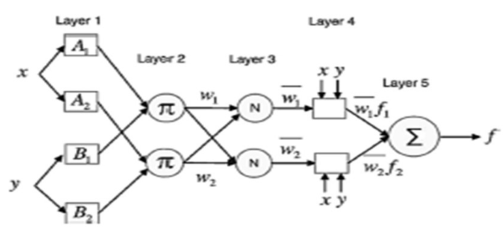


**Figure 3.4:** ANFIS network architecture

## 4. Results and discussion

This section gives the detailed analysis of the results obtained using STATCOM device based on solar input data.

### 4.1 Input results of Solar energy

Table 4.1 displays nameplate information about the simulated PV module. Further figures 4.2 and 11 depict the characteristics of PV voltages and currents at different degrees of solar irradiation. The PV module's output power, which is shown in Fig. 4.3 and is also mentioned in Table 4.1, is identical. Table 4.1 has data to substantiate this.

Table 4.1: Name place reference module

| Module rated power ($P_r$) | 213.15 (W) |
|---|---|
| Voltage at rated power ($V_r$) | 29 (V) |
| Current at rated power ($I_r$) | 7.35 (A) |
| Open circuit voltage ($V_{OC}$) | 36.3 (V) |
| Short circuit current ($I_{SC}$) | 7.84 (A) |
| Number of series cells / Module ($N_s$) | 72 |

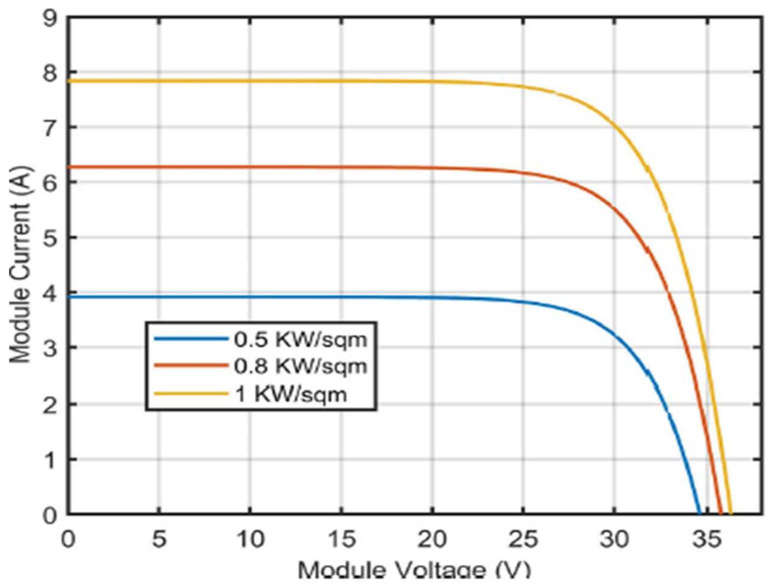


**Figure 4.1:** Varied solar irradiance-generated current-voltage properties.

According to the reference data, the maximum PV output at 29 V is 213.15W. According to this schematic, a voltage supply of 29 V between a PV module's terminals will allow for its maximum allowable output power. Those results were obtained by plugging the previously indicated using a MATLAB application, enter data into the previously given equations.

As per previous responses, a PV grid-connected system may be operated using a power flow control method based on zero-sequence current injection is shown in. Because it handles the problem of imbalanced loads linked when it comes to electricity systems, this technology is regarded as dependable and efficient. According to this analysis, the majority of connected loads employ non-linear power electronic equipment. This concept is regarded to be promising since it provided a zero sequence current injection modified power flow controller solution.

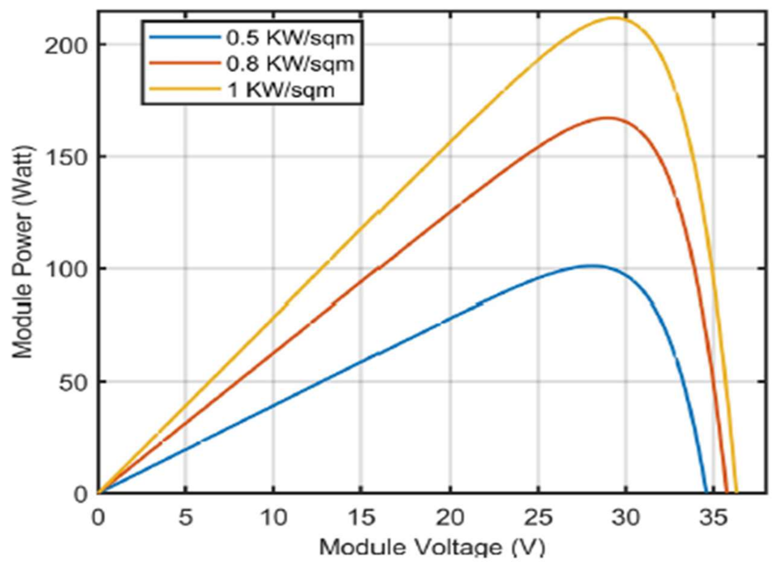


**Figure 4.2:** Power of the output module in relation to solar irradiation

**4.2 STATCOM's results for compensate for reactive power**

The STATCOM is acting as a drain rather than a source if the terminal voltage so at PCC is greater than the operational voltage there at converter's output. This is because the current flows toward the converter, which causes it to absorb inductively power factor from of the point of connection. Additionally, the converter is the recipient of the power. A conversion is said to be in the floating position when there is no interchange of reactive power and the voltage at the output and the voltage at the common coupling point (PCC) are equal.

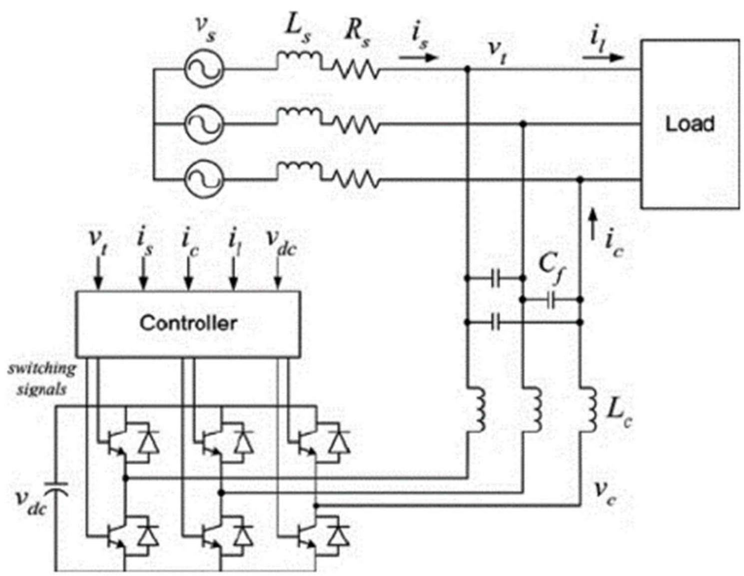


**Figure4.3 :STATCOM connection with the grid**

The STATCOM converter is able to maintain the energy storage capacitor's charge at the amount of voltage that is necessary when employed in reactive power production mode. This is generally achieved by slightly by shifting the output voltage's phase angle relative to the system voltage such that it is later. To reduce internal losses as well as maintain the right voltage across the capacitor, the converter may absorb a little amount of active power at this angle.

To operate as a reactive power compensator for the 100 kW PV system linked to the grid, the STATCOM is used.

The STATCOM output power characteristics after modeling the above load circumstances seen in Figure 4.4.

Figure4.4 illustrates the STATCOM made the necessary adjustments so that the load would get 70 kVAR. Termination value, DC cap voltage, and STATCOM signal waveforms current injection at the PCC.. By adjusting the amount of reactive current drawn from the converter, the STATCOM produces reactive power. Foretelling the need for reactive power, this kind of control tracks load current.

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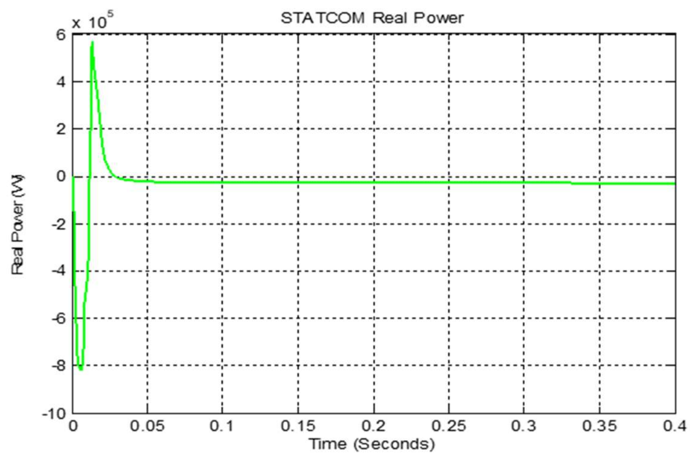
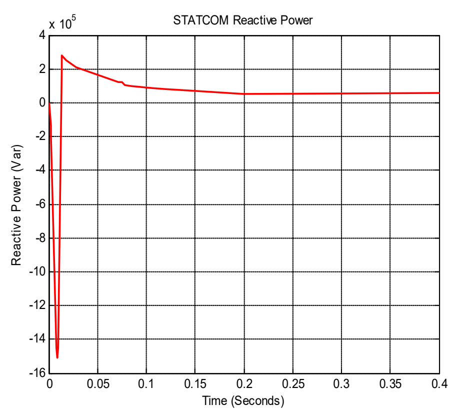
Figure 4.3 elaborates on the power characteristics at the grid's output. Since the reactive current need of the load is met by the STATCOM, the grid does not provide any reactive power to the load




(a) (b)

**Figure 4.3: STATCOM maintains a backup power supply in case (1) Power: a) Active; b) Reactive**

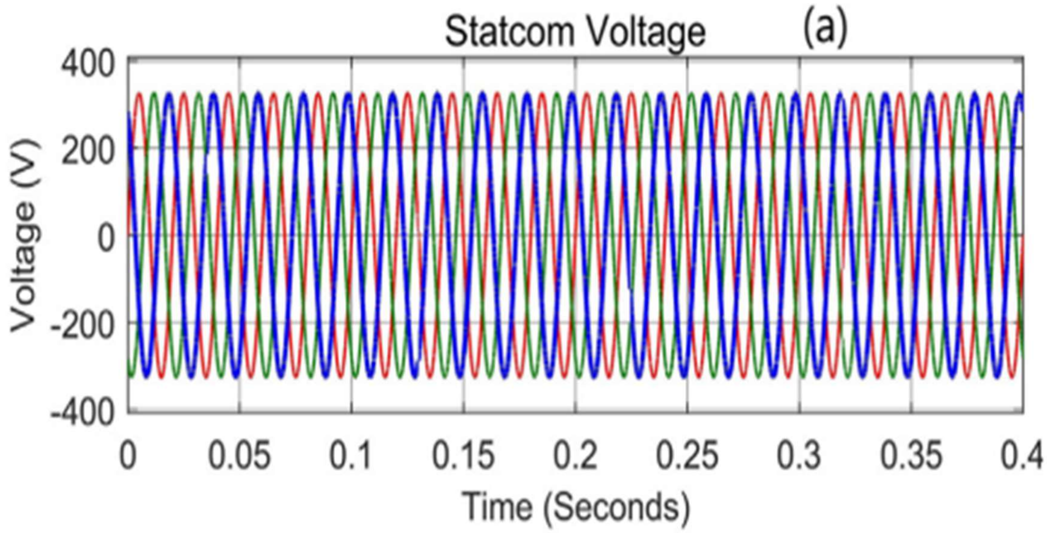
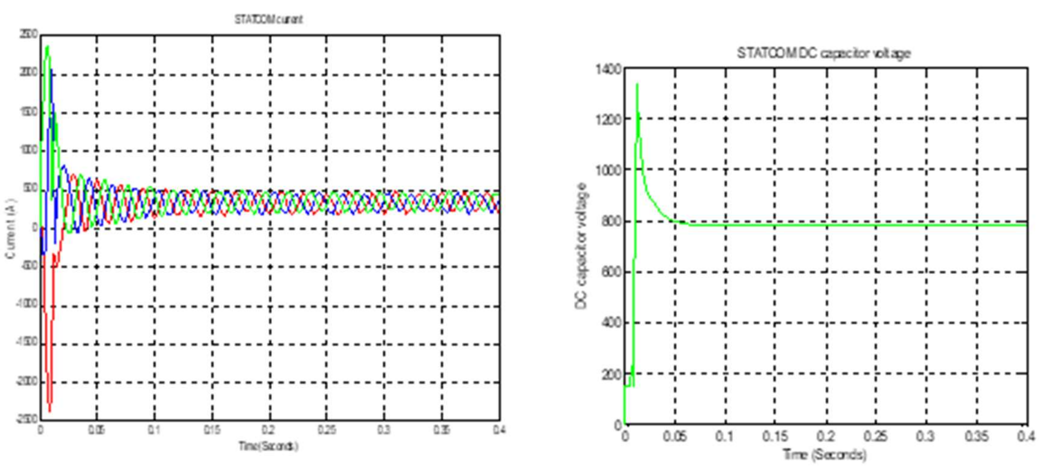



**Figure 4.4: STATCOM voltage**




(a) (b)

**Figure 4.3: Distinctive features of STATCOM transmissions a) terminal voltages STATCOM b) injected currents**

## 5.Conclusion

In the present research work, the author has proposed to implement a single phase inverter as STSTCOM in grid-tied mode for a combined power system consisting of conventional energy sources combined with renewable energy sources. The single phase inverter has been designed with H Bridge and LCL filters. Controlling mechanism that has been implemented for the proposed design of single phase filter is ANFIS Network. The output of signal in ANFIS Network transformation has also been presented in the result section. The result findings are depicted that, the propose design is capable for reactive power compensation  and voltage stability hence can be proposed for integrated system of combined power plants.

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