



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJIRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 12, Issue 10, October 2023

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.423

9940 572 462

6381 907 438

ijirset@gmail.com

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Reactive Power Compensation for Grid Connected Photo Voltaic System

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ABSTRACT: Solar Photo Voltaic system performance depends on environmental conditions. The reactive power of the system can be compensated using facts devices i.e by using TSC-TCR combination. When connecting a PV system to the grid many undesirable impact may occur such as changes in current, harmonics that causes instability in the grid. To solve this problem in facts devises are used. Electronic power devise can improve the performance the power system by controlling active and reactive power flow.The FACTS system can also eliminate current harmonic inject to the system. The reactive power controlled by the SVC in will either capacitive or inductive whether they generate or absorb the reactive power. The use of SVC to control performance of a grid connected PV system is proposed. The system includes PV array, Inverter, Boost Converter, TSC-TCR combination. The boost converter which boost up the output of the PV. The inverter which converts dc to ac. The TSC-TCR combination which is used for reactive power combination.

I. INTRODUCTION

Due to the energy shortage, the integration of renewable energy sources to the electricity grid becomes a interesting research topic nowadays. The number of renewable energy sources and distributed generators is increasing very fast which also brings some threats to the power grid.

In order to maintain or even to improve the power supply reliability and quality of the power system with distributed generation, it is necessary to have some new strategies for the operation and management of the electricity grid. Modern power electronic technology is an important part in distributed generation and the integration of the renewable energy to the power grid.

A photovoltaic system, also photovoltaic power system, solar PV system, PV system or casually solar array, is a power systemdesigned to supply usable solar power by means of photovoltaic. It consists of an arrangement of several components, includingsolar panels to absorb and directly convert sunlight into electricity, a solar inverter to change the electrical current from DC to AC, as well as mounting, cabling and other electrical accessories to set-up a working system. It may also use a solar tracking system to improve the system's overall performance or include an integrated battery solution, as prices for storage devices are expected to decline. Strictly speaking, a solar array only encompasses the ensemble of solar panels, the visible part of the PV system, and does not include all the other hardware, often summarized asbalance of system (BOS). Moreover, PV systems convert light directly into electricity and shouldn't be confused with other solar technologies, such as concentrated solar power (CSP) and solar thermal, used for both, heating andcooling.

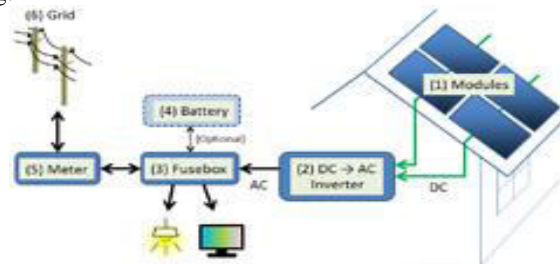


Fig 1: Grid Connection Block diagram

Following problems have been observed in three phase systems:

1. Voltage control at various load conditions
2. Reactive power balance (voltage, transmission losses)
3. Stability problems at energy transfer over long distances
4. Increase of short circuit power in meshed systems
5. Coupling of asynchronous systems
6. Coupling of systems with different system frequencies

The upper ones can be solved by proper use of reactive power compensation based on FACTS devices and the last two problems can be solved using HVDC technology. An electric power system is never in equilibrium for very long time. Frequent occurrences of unwanted situation disturb the equilibrium so that system is almost always in transition between equilibrium or steady state conditions.

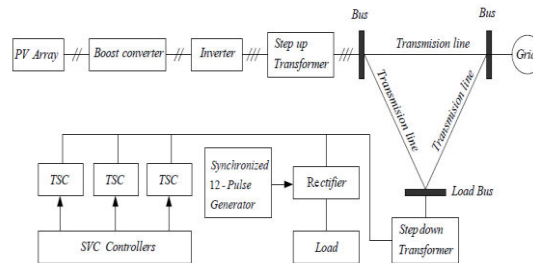


Fig 2: Existing System Block Diagram

A controlled topology for a Grid Connected Photovoltaic System (GCPS) including Static Var Compensators (SVC). The proposed system is consisted of a photovoltaic array, a boost converter, an inverter, a non linear load and a grid. The adaptation of the needed voltage required by the PWM controlled inverter is provided by a boost converter. The used inverter generates a three phase supply that will be used and connected to the grid through a filter grid. Three Thyristor Switched Capacitors (TSC) based SVC are used to perform.

II. PROPOSED SYSTEM

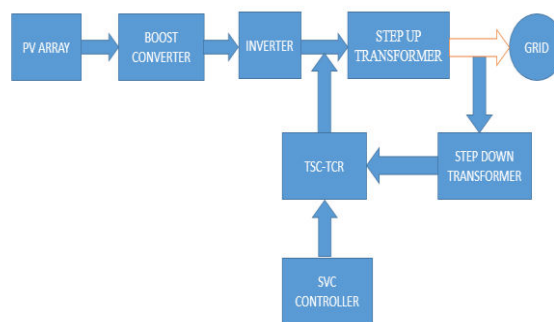


Fig 3.2: Proposed Block Diagram

The use of Static Var Compensators (SVC) to control the performance of a Grid Connected Photovoltaic System (GCPS). The compensator considered in this work contains one Thyristor Controlled Reactor (TCR) and three Thyristors Switched Capacitors (TSC), which are two of the shunt Flexible Altering Current Transmission Systems (FACTS) devices. The proposed configuration incorporates a photovoltaic array, a boost converter, an inverter that generates a three phase supply that will be filtered and connected to the grid through a step up transformer and a non linear load. The positive effect of the TCR and TSC-based SVC on the non linear load current

BASIC PRINCIPLE OF BOOST CONVERTER

The boost is a popular non-isolated power stage topology, sometimes called a step-up power stage. Power supply designers choose the boost power stage because the required output is always higher than the input voltage. The input current for a boost power stage is continuous, or non-pulsating, because the output diode conducts only during a portion of the switching cycle.

The output capacitor supplies the entire load current for the rest of the switching cycle. Figure 1 shows a simplified schematic of the boost power stage. Inductor L and capacitor C make up the effective output filter. The capacitor Equivalent Series Resistance (ESR), R_c , and the inductor dc resistance, R_L , are included in the analysis. Resistor R represents the load seen by the power supply output.

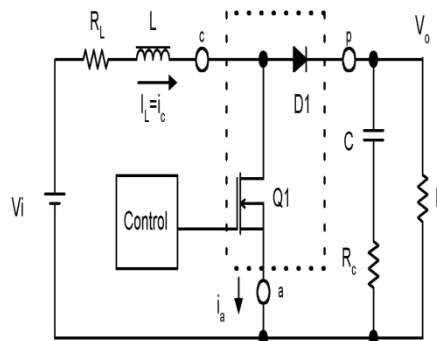


Fig3: Boost Power Stage Schematic Diagram

A power stage can operate in continuous or discontinuous inductor current mode. In continuous inductor current mode, current flows continuously in the inductor during the entire switching cycle in steady-state operation. In discontinuous inductor current mode, inductor current is zero for a portion of the switching cycle. It starts at zero, reaches peak value, and return to zero during each switching cycle. It is desirable for a power stage to stay in only one mode over its expected operating conditions because the power stage frequency response changes significantly between the two modes of operation.

Boost Steady-State Continuous Conduction Mode (CCM)

In continuous conduction mode, the boost power stage assumes two states per switching cycle. In the on state, Q1 is on and D1 is off. In the off state, Q1 is off and D1 is on. A simple linear circuit can represent each of the two states where the switches in the circuit are replaced by their equivalent circuit during each state. Figure 3.4 shows the linear circuit diagram for each of the two states.

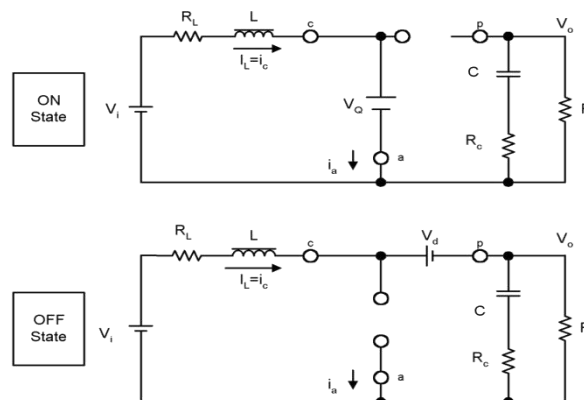


Fig 4: Boost Power Stage States

The duration of the on state is $D \times T_s = T_{ON}$, where D is the duty cycle set by the control circuit, expressed as a ratio of the switch on time to the time of one complete switching cycle, T_s . The duration of the off state is T_{OFF} .

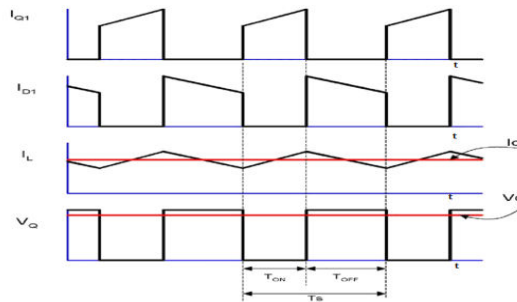


Fig 5: CCM Boost Power Stage Waveforms

Refer to Figures 3.4 and 3.5. The inductor-current increase can be calculated by using a version of the familiar relationship:

$$V_L = L \times \frac{di}{dt} \Rightarrow \Delta I_L = \frac{V_L}{L} \Delta T \quad \text{---(3.1)}$$

The inductor current increase during the on state is given by:

$$\Delta I_L(+) = \frac{V_i - V_Q + I_L \times R_L}{L} \times T_{ON} \quad \text{---(3.2)}$$

The quantity $\Delta I_L(+)$ is the inductor ripple current. During this period, all of the output load current is supplied by output capacitor C.

TYPES OF INVERTERS:

- Voltage source inverter
- Current source inverter
- Impedance source inverter

A dc current source feeds the main inverter circuit, a three phase bridge. The dc current source can be a relatively large dc inductor fed by a voltage source such as a battery or a rectifier. It consists of six switches and with anti-parallel diodes. This diode provides bidirectional current flow and unidirectional voltage blocking capability This inverter has the following conceptual and theoretical barriers and limitations. The ac output voltage has to be greater than the original dc voltage that feeds the dc inductor or the dc voltage produced is always smaller than the ac input voltage. Therefore this inverter is a boost inverter for dc to ac power conversion. For applications where a wide voltage range is desirable, an additional dc to dc buck converter is needed. The additional power conversion stage increases system cost and lowest efficiency. At least one of the upper devices and one of the lower devices have to be gated on and maintained on at any time. Otherwise, an open circuit of the DC inductor would occur and destroy the devices. The open circuit problem by EMI noises misstating-off is a major concern a current source inverter is fed from a constant current source. Therefore load current remains constant irrespective of the load on the inverter. The load voltage changes as per the magnitude of load impedance. When a voltage source has a large inductance in series with it, it behaves as a current source .The large inductance maintains the current constant.

SPACE VECTOR PWM

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.

WORKING PRINCIPLE

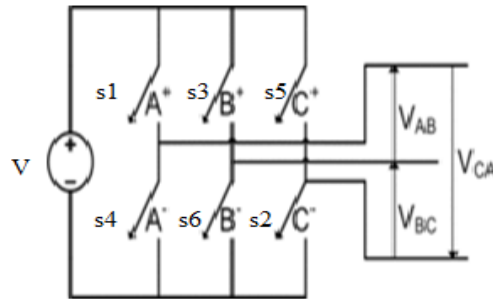


Fig 6 : Topology of basic three phase inverter

A three phase inverter as shown to the right converts a DC supply, via a series of switches, to three output legs which could be connected to a three-phase motor.

The switches must be controlled so that at no time are both switches in the same leg turned on or else the DC supply would be shorted. This requirement may be met by the complementary operation of the switches within a leg. i.e. if A⁺ is on then A⁻ is off and vice versa. This leads to eight possible switching vectors for the inverter, V₀ through V₇ with six active switching vectors and two zero vectors.

To implement space vector modulation, a reference signal V_{ref} is sampled with a frequency f_s (T_s = 1/f_s). The reference signal may be generated from three separate phase references using the *αβγ* transform. The reference vector is then synthesized using a combination of the two adjacent active switching vectors and one or both of the zero vectors. Various strategies of selecting the order of the vectors and which zero vector(s) to use exist. Strategy selection will affect the harmonic content and the switching losses.

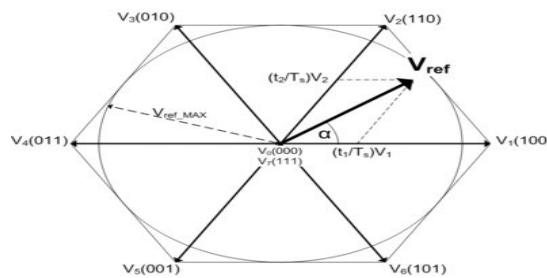


Fig7: SVPWM Structure

Need for Reactive Power Compensation

The main reason for reactive power compensation in a system is;

- 1) The voltage Regulation.
- 2) Increased system stability.
- 3) Better utilization of machines connected to the system.
- 4) Reducing losses associated with the system.

The impedance of transmission lines and the need for lagging VAR by most machines in a generating system results in the consumption of reactive power, thus affecting the stability limits of the system as well as transmission lines. Unnecessary voltage drops lead to increased losses which needs to be supplied by the source and in turn leading

to outages in the line due to increased stress on the system to carry this imaginary power. Thus we can infer that the compensation of reactive power not only mitigates all these effects but also helps in better transient response to faults and disturbances. In recent times there has been an increased focus on the techniques used for the compensation and with better devices included in the technology, the compensation is made more effective.

It is very much required that the lines be relieved of the obligation to carry the reactive power, which is better provided near the generators or the loads. Shunt compensation can be installed near the load, in a distribution substation or transmission substation.

CONCEPT OF FACTS DEVICES

A power electronic-based system and other static equipment that provide control of one or more AC transmission system parameters. As new technology for power transmission system, FACTS and FACTS controllers not only provide the same benefits as conventional compensators with mechanically-controlled switches in steady state but also improve the dynamic and transient performance of the power system. The power electronics-based switches in the functional blocks of FACTS can usually be operated repeatedly and the switching time is a portion of a periodic cycle, which is much shorter than the conventional mechanical switches. The advance of semiconductors increases the switching frequency and voltage-ampere ratings of the solid switches and facilitates the applications.

THYRISTOR SWITCHED CAPACITOR (TSC)

A Thyristor Switched Capacitor (TSC) is a type of equipment used for compensating reactive power in electrical power systems. It consists of a power capacitor connected in series with a bidirectional thyristor valve and, usually, a current limiting reactor (inductor). The thyristor switched capacitor is an important component of a Static VAR Compensator (SVC), where it is often used in conjunction with a Thyristor Controlled Reactor (TCR). Static VAR compensators are a member of the Flexible AC Transmission System (FACTS) family.

Circuit Diagram

A TSC is usually a three-phase assembly, connected either in a delta or a star arrangement. Unlike the TCR, a TSC generates no harmonics and so requires no filtering. For this reason, some SVCs have been built with only TSCs. This can lead to a relatively cost-effective solution where the SVC only requires capacitive reactive power, although a disadvantage is that the reactive power output can only be varied in steps. Continuously variable reactive power output is only possible where the SVC contains a TCR or another variable element such as a STATCOM.

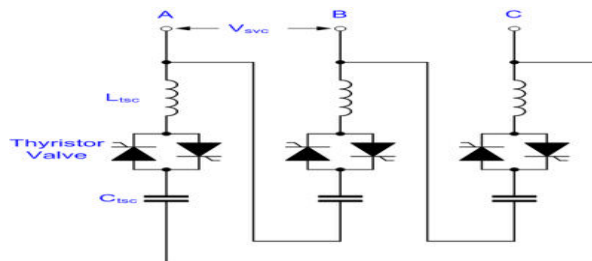


Fig8 : Structure of TSC

Operating Principle

The TCR, the TSC is only ever operated fully on or fully off. An attempt to operate a TSC in ‘‘phase control’’ would result in the generation of very large amplitude resonant currents, leading to overheating of the capacitor bank and thyristor valve, and harmonic distortion in the AC system to which the SVC is connected.

Steady state current

When the TSC is on, or ‘‘deblocked’’, the current leads the voltage by 90° (as with any capacitor). The rms current is given by:

$$I_{tsc} = \frac{V_{svc}}{X_{tsc}} \text{ ----- (3.9)}$$

Where:

$$X_{tsc} = \frac{1}{2\pi f C_{tsc}} - 2\pi f L_{tsc} \text{ .(3.10)}$$

V_{svc} is the rms value of the line-to-line bus bar voltage to which the SVC is connected

C_{tsc} is the total TSC capacitance per phase

L_{tsc} is the total TSC inductance per phase

The TSC forms an inductor-capacitor (LC) resonant circuit with a characteristic frequency of :

$$f_{tsc} = \frac{1}{2\pi f C_{tsc} L_{tsc}} \text{ ---- (3.11)}$$

The tuned frequency is usually chosen to be in the range 150-250Hz. It is an economic choice between the size of the TSC reactor (which increases with decreasing frequency) and the need to protect the thyristor valve from excessive oscillatory currents when the TSC is turned on at an incorrect point of wave (‘misfiring’).

The TSC is usually tuned to a non-integer harmonic of the mains frequency so as to avoid the risk of the TSC being overloaded by harmonic currents flowing into it from the AC system.

TSC Reactor

The function of the TSC reactor is to limit the peak current and rate of rise of current (di/dt) when the TSC turns on at an incorrect time. The reactor is usually an air-cored reactor, similar to that of a TCR, but smaller.

The size and cost of the TSC reactor is heavily influenced by the tuning frequency of the TSC, lower frequencies requiring larger reactors. The TSC reactor is usually located outside, close to the main capacitor bank.

Thyristor Valve

The thyristor valve typically consists of 10-30 inverse-parallel-connected pairs of thyristors connected in series. The inverse-parallel connection is needed because most commercially available thyristors can conduct current in only one direction. The series connection is needed because the maximum voltage rating of commercially available thyristors (up to approximately 8.5kV) is insufficient for the voltage at which the TCR is connected. For some low-voltage applications, it may be possible to avoid the series-connection of thyristors; in such cases the thyristor valve is simply an inverse-parallel connection of two thyristors.

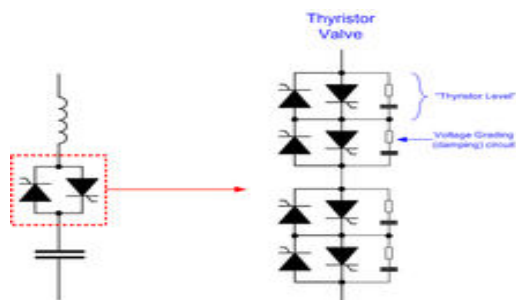


Fig 9: Structure of Thyristor Valve

Typical TSC Valve

In addition to the thyristors themselves, each inverse-parallel pair of thyristors has a resistor–capacitor ‘snubber’ circuit connected across it, to force the voltage across the valve to divide uniformly amongst the thyristors and to damp the "commutation overshoot" which occurs when the valve turns off.

The thyristor valve for a TSC is very similar to that of a TCR, but (for a given AC voltage) generally has between 1.5 and 2 times as many thyristors connected in series because of the need to withstand both the AC voltage and the trapped capacitor voltage after blocking. The thyristor valve is usually installed in a purpose-built, ventilated building, or a modified shipping container. Cooling for the thyristors and snubber resistors is usually provided by deionized water.

Special Types of TSC

Some TSCs have been built with the capacitor and inductor arranged not as a simple tuned LC circuit but rather as a damped filter. This type of arrangement is useful when the power system to which the TSC is connected contains significant levels of background harmonic distortion, or where there is a risk of resonance between the power system and the TSC.

In several “Reloadable SVCs” built for National Grid (Great Britain), three TSCs of unequal size were provided, in each case with the capacitor and inductor arranged as a “C-type” damped filter. In a C-type filter, the capacitor is split into two series-connected sections. A damping resistor is connected across one of the two capacitor sections and the inductor, the tuned frequency of this section being equal to the grid frequency. In this way, damping is provided for harmonic frequencies but the circuit incurs no power loss at grid frequency.

THYRISTOR-CONTROLLED REACTOR (TCR)

In an electric power transmission system, a Thyristor-Controlled Reactor (TCR) is a reactance connected in series with a bidirectional thyristor valve. The thyristor valve is phase-controlled, which allows the value of delivered reactive power to be adjusted to meet varying system conditions. Thyristor-controlled reactors can be used for limiting voltage rises on lightly loaded transmission lines. Another device which used to be used for this purpose is a Magnetically Controlled Reactor (MCR), a type of magnetic amplifier otherwise known as a transductor. In parallel with series connected reactance and thyristor valve, there may also be a capacitor bank, which may be permanently connected or which may use mechanical or thyristor switching. The combination is called a static VAR compensator.

Circuit Diagram

A thyristor controlled reactor is usually a three-phase assembly, normally connected in a delta arrangement to provide partial cancellation of Harmonics. Often the main TCR reactor is split into two halves, with the thyristor valve connected between the two halves. This protects the vulnerable thyristor valve from damage due to flashovers, lightning strikes etc.

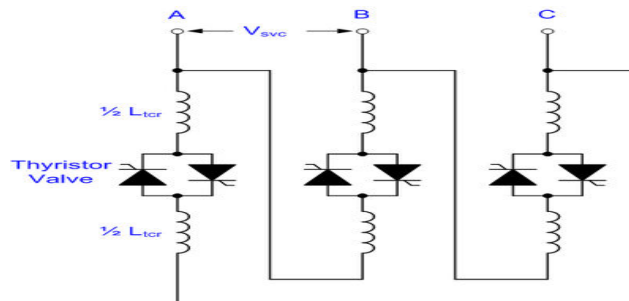


Fig 10: Structure of TCR

Operating Principles

The current in the TCR is varied from maximum (determined by the connection voltage and the inductance of the reactor) to almost zero by varying the "Firing Delay Angle", α . α is defined as the delay angle from the point at which the voltage becomes positive to the point at which the thyristor valve is turned on and current starts to flow.

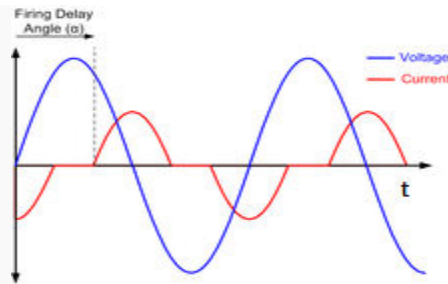


Fig 11: Voltage and current waveforms in a TCR

Maximum current is obtained when α is 90° , at which point the TCR is said to be in "full conduction" and the rms current is given by:

$$I_{tcr-max} = \frac{V_{svc}}{2\pi f L_{tcr}}$$

Where:

V_{svc} is the rms value of the line-to-line busbar voltage to which the SVC is connected

L_{tcr} is the total TCR inductance per phase

The current lags 90° behind the voltage in accordance with classical AC circuit theory. As α increases above 90° , up to a maximum of 180° , the current decreases and becomes discontinuous and non-sinusoidal. The TCR current, as a function of time, is then given by:

$$\omega t < \pi - \alpha: I(\omega t) = I_{tcr-max} \sqrt{[-\cos(\alpha) - \cos(\omega t)]}$$

$$\alpha < \omega t < 2\pi - \alpha: I(\omega t) = I_{tcr-max} \sqrt{[\cos(\alpha) - \cos(\omega t)]}$$

$$\omega t > \pi + \alpha: I(\omega t) = I_{tcr-max} \sqrt{[-\cos(\alpha) - \cos(\omega t)]}$$

Otherwise, zero.

TCR-TSC Combination

The TCR-TSC comprises usually n-series of TSC and single TCR that are connected in parallel. The capacitor can be switched in discrete steps, whereas continuous control within the reactive power span of each step is provided by TCR.

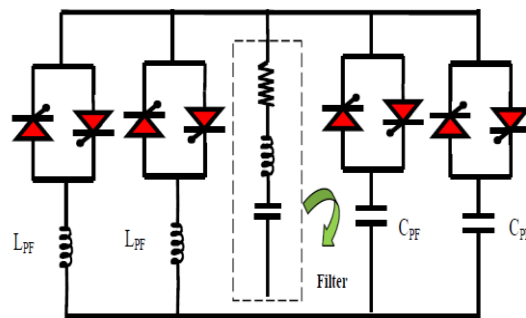


Fig 12: Circuit diagram of TCR-TSC Combination

As the size of TCR is small the harmonic generation is substantially reduced. The TSC branches are tuned with series reactor to different dominant harmonic frequencies. The main motivations in developing TCR-TSC were for enhancing the operational flexibility of the compensator during large disturbances and for reducing the steady-state losses. TCR-TSC can quickly operate to disconnect all the capacitor from the compensator, producing resonant oscillations.

Advantages of TSC-TCR Combination

The characteristics of a TSC/TCR combination are:

- Continuous control
- No transients
- Low generation of harmonics
- Low losses
- Redundancy
- Flexible control and operation

III MATLAB SIMULATION

MATLAB PARAMETERS

PARAMETERS	MEASUREMENT
Input Voltage of Photo Voltaic	161 volts
Output voltage of boost Converter	320 volts
Inductance for Boost converter	100e-6
Capacitance for Boost Converter	100e-6
Output of the Inverter	320 volts
Inductance for TCR	0.079812
Inductance for TSC	0.01497
Capacitance for TSC	78.2946e-6
Phase to Phase Voltage	250e-6
Nominal Frequency	50 HZ

Table 1: MATLAB Parameters

PROPOSED SIMULATION DIAGRAM

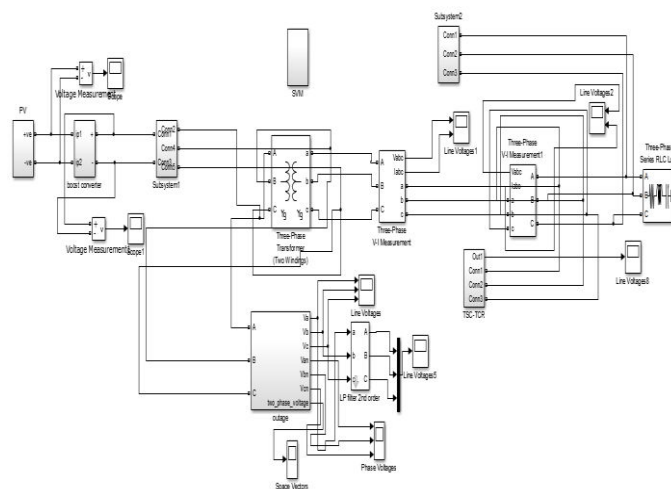


Fig 13: Grid connected PV System with TSC-TCR

Diagram of Boost Converter

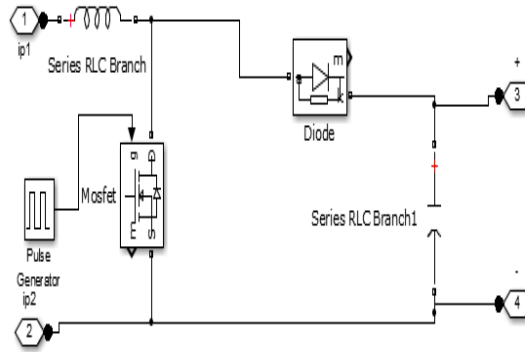


Fig 14: Boost Converter

Diagram of Three Phase Converter

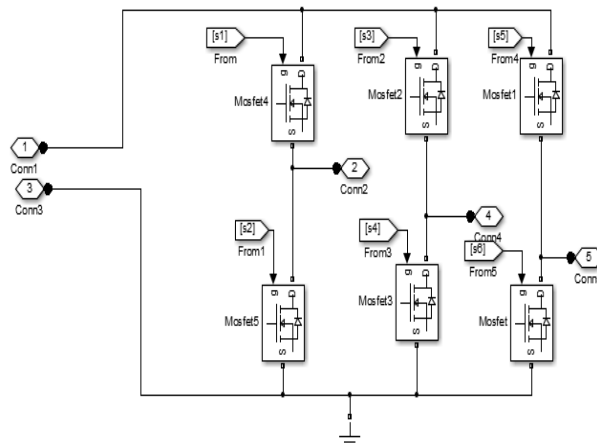


Fig 15: Three phase Inverter

Diagram of Three Phase Voltage to Line and Phase Voltage Conversion

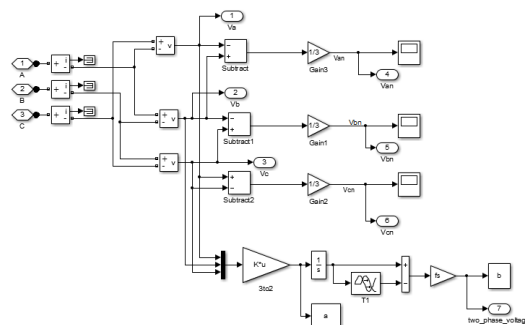


Fig 16: Three phase voltage to line and phase voltage conversion

Diagram of TSC-TCR Implementation

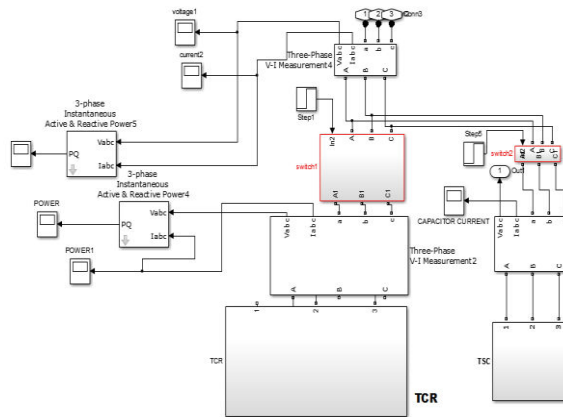


Fig 17: TSC-TCR implementation

Diagram of Pulse Generating Scheme for TSC-TCR

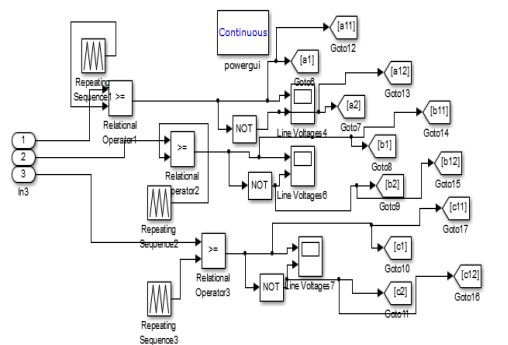


Fig 18: Pulse Generating Scheme for TSC-TCR

Output of SVPWM

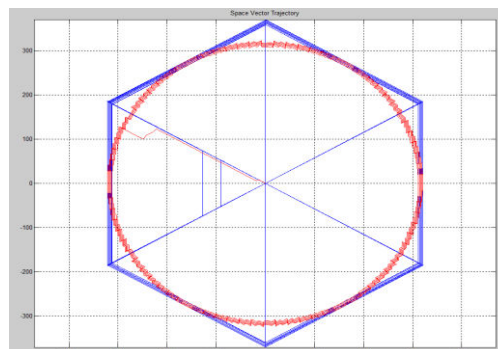


Fig 19: Output of SVPWM

Output of Inverter Line Voltage

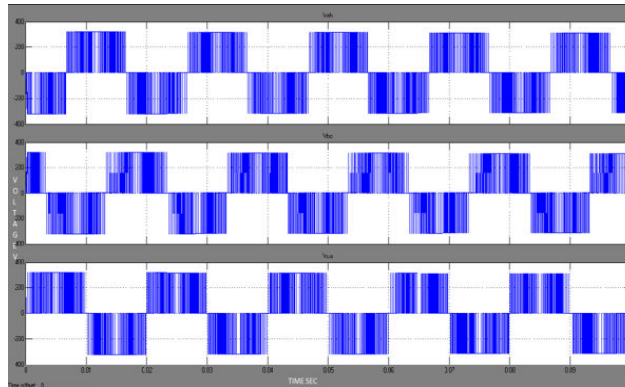


Fig 20: Inverter line voltage

Output of Inverter Phase Voltage

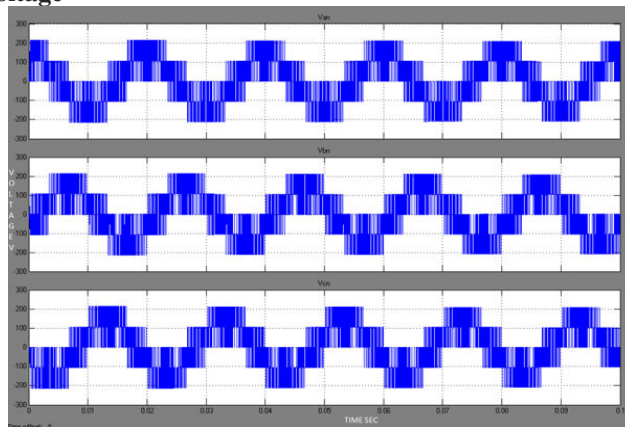


Fig 21: Inverter phase voltage

Approximate Grid Side Voltage

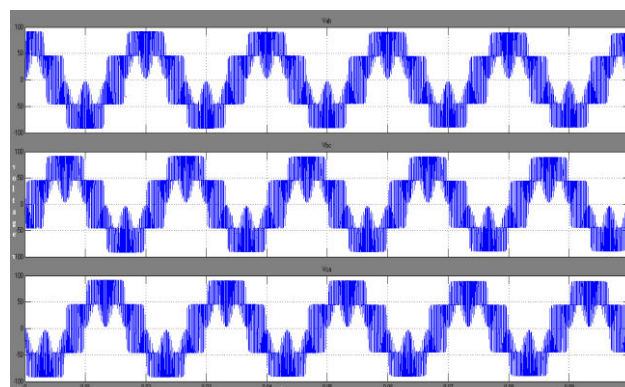


Fig 22: Approximate Grid Side Voltage

IV. CONCLUSION

The proposed system introduces a controlled topology for grid connected PV system using SVC system. To most widely used SVC devices TSC and TCR are used and simulated using MATLAB. The SVC TSC combination has

discontinuous mode operation, individual phase control is not possible and response time is low. The drawbacks of SVC TSC is overcome by TSC-TCR combination. The SVPWM is used for inverter control.

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