

STATCOM control by Induction generator using three-phase load & nonlinear load with WECS.

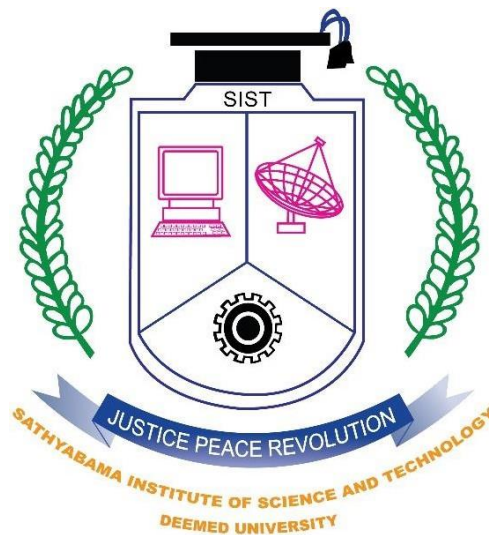
Submitted in partial fulfillment of the requirements for the award of

Bachelor of Engineering Degree in
Electrical and Electronics Engineering

by

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**DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
SCHOOL OF ELECTRICAL AND ELECTRONICS ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC

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MAY 2022



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Albin Philip Geevarughese (38140004)**, **Alshad Abdul Hassan (38140005)** who carried out the project "**STATCOM control by Induction generator using three-phase load & nonlinear load with WECS**" under my / our supervision from November 2021 to May 2022.

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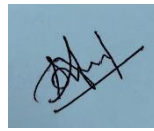
Internal Examiner

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DECLARATION

We, **ALBIN PHILIP GEEVARUGHESE (Reg. No. 38140004)** and **ALSHAD ABDUL HASSAN (Reg. No. 38140005)** hereby declare that the Project Report entitled **“STATCOM control by Induction generator using three-phase load & nonlinear load with WECS.”** done by us under the guidance of **Dr. M. KAVITHA** is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Electrical and Electronics Engineering.

1. 

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DATE: 28.04.2022

PLACE: Chennai

**SIGNATURE OF THE
CANDIDATES**

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ABSTRACT

Self-excited induction generators or SEIG, are wind energy-based conversion systems that are usually popular because it's exceptionally used as stand-alone loads at remote sites. The terminal voltage and frequency can be adjusted using VAR. The use of STATCOM and a fixed capacitor bank can be used as VAR in this given case. Furthermore, to reduce the harmonics caused by the SEIG, the use of harmonic compensation can be implemented. The combined use of these helps to maintain voltage at the rated values with very less harmonic distortion irrespective of the change in wind speed and load demand. The given system is found to be superior to those similar systems proposed in the early days.

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LIST OF SYMBOLS AND ABBREVIATIONS

IG	-Induction generators
STATCOM	-Static Synchronous Compensator
SEIG	-Self-excited induction generator
VSC	-Voltage source converter
SMC	-Sliding mode controller
WECS	-Wind energy conversion system
IC	-Integrated circuit
LCD	-Liquid crystal display
IGBT	-Insulated-gate bipolar transistor
LED	-Light Emitting Diode
RISC	-Reduced Instruction set computer
SSP	-Synchronous Serial Port
PSP	-Parallel Slave Port
USART	-Universal Synchronous Asynchronous Receiver Transmitter
VREF	-Voltage Reference
PWM	-Pulse Width Modulation
ICD	-In-Circuit Debug
APF	-Active Power Filters
HVDC	-High voltage direct current
POD	-Phase Opposition Disposition
APOD	-Alternative Phase Opposition Disposition
PD	-Phase Disposition

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

Power Generation, with its allied sectors, is unquestionably the largest important industry in the world that has been associated with our lives to make them simpler. Over the years, the decrease in the number of renewable sources and the cost of the extraction of these valuable resources has caused us to turn our heads towards renewable sources of energy especially the power generated from wind, which is wildly used all over the Indian subcontinent. Because the cost of producing electricity from this non-polluting source is quite low, wind energy has emerged as the best alternative. Small wind turbines (SWT, rating < 10 kW) have proved viable for meeting energy demand at stand-alone sites. High reliability, minimal maintenance requirements, easy excitation and control mechanisms, high efficiency, and cheap cost are all requirements for an electrical generator suited for such SWTs.

A STATCOM is a fast-acting device that regulates the voltage at the point of connection to a power grid by delivering or absorbing reactive current. Applications are in electric power transmission, electric power distribution, electrical networks of heavy industrial plants, arc furnaces, high-speed railway systems, and other electric systems, where voltage stability and power quality are of the utmost importance.

Power factor correction, reactive power management, dampening of low-frequency power oscillations (typically by reactive power modulation), active harmonic filtering, flicker mitigation, and power quality enhancements are all possible with STATCOMs.

1.2 LITERATURE SURVEY

Satpathy A.S et al.(2014) described currently the energy needed heavily relies on conventional sources. But the limited availability of fossil fuels and increase in the cost of conventional sources have changed the focus toward renewable energy sources. Wind energy is regarded to be one of the most well-established alternative

energy systems. A WECS is now being used to address both grid-connected and stand-alone load demands due to its low cost of power generation. The wind is also sporadic. As a backup, adequate storage technology is used to provide a continuous supply of power. This research has studied the long-term viability of a 4-kW hybrid wind-battery system to satisfy the demands of a 3-kW stand-alone dc load representing a base telecom station. A charge controller for the battery bank based on turbine maximum power point tracking and battery state of charge is created to ensure controlled charging and discharging of the battery. The pitch control approach ensures the mechanical safety of the WECS. Both control systems are combined, and their efficiency is verified in MATLAB/SIMULINK using varied load and wind profiles.

Singh B et al. (2014) showed how to generate single-phase electricity using a three-phase SEIG and a three-phase static synchronous compensator (STATCOM). The STATCOM is used to correct for imbalanced currents created by single-phase loads connected across the three-phase SEIG's two terminals. As a result, the SEIG can supply single-phase loads up to its rated power. Furthermore, the STATCOM controls the SEIG terminal voltage via reactive power compensation and suppresses harmonics injected by consumer loads. To create gating pulses for the three-phase STATCOM, a single-phase synchronous D-Q frame theory-based control technique is used. On a 3.7-kW, 230-V, Y-connected induction machine, the proposed method of single-phase power production from the three-phase SEIG is tested. The SEIG-STATCOM system's performance is assessed for both linear and nonlinear single-phase loads.

Kirtley J.L et al. (2013) describes that dynamic grid support must be integrated for distributed power systems connected to medium voltage grids. This paper provides a comprehensive control system for utility-scale photovoltaic (PV) power plants to improve fault ride-through (FRT) capability. The approach alleviates dc-bus double-line-frequency ripples, decreases voltage stress on inverter power switches and DC-link capacitors, and avoids undesired low-order voltage and current harmonics on the ac side using positive and negative sequence control approaches and PV features. The paper suggests a new feature that takes advantage of grid-tied inverters' overload capabilities to improve FRT performance. The test case includes a wind turbine induction generator, diesel engine driven

synchronous generators, and varied loads on a poor electric grid. In response to severe unbalanced voltage conditions caused by asymmetrical grid faults, a thorough simulation validated the suggested control methods' capacities to mitigate voltage dips, improve voltage response, and improve the overall stability of interconnected dispersed generation.

Chen W.L et al. (2010) describes that the mode shape and transient response of a STATCOM used as an exciter for induction generators are determined using a systematic technique based on eigen structure assignment in this paper (IG). The STATCOM has a physical control scheme that includes four control loops: ac voltage, dc voltage, ac active current, and ac reactive current controllers. To include these physical control loops in the output feedback channel, a synthetic approach is presented. The STATCOM active current and reactive current will no longer be guided by the same model but by new modes driven by proper oscillation mode design (eigen structure) in each state variable. According to modeling and actual data, the proposed mode decoupling STATCOM successfully regulates IG terminal voltage under various system disturbances.

Sekhar V.C. et al. (2016) showed how to use a DSTATCOM (Distribution Static Compensator) with a sliding mode controller (SMC) and a proportional and integral (PI) controller to improve current-induced power quality concerns and voltage regulation in three-phase self-excited induction generators (SEIG). The use of SMC to regulate the DC link voltage of a voltage source converter (VSC) functioning as DSTATCOM has several benefits, including a reduction in the number of sensors required to estimate reference currents and a stable DC link voltage during transient conditions. In steady-state settings, the use of a PI controller for terminal voltage control allows for error-free voltage profile tracking. The advantages of using SMC with a PI controller to operate DSTATCOM for an induction generator are single point voltage operation at the generator terminals and reactive power adjustment, which prevents the generator from being saturated. Balanced generator currents under any load condition, harmonic current suppression, constant DC link voltage, and a decreased number of sensors are among the other benefits offered. On a DSTATCOM, the SMC algorithm is successfully implemented for control of a three-phase SEIG feeding single-phase or three-phase loads. The proposed control algorithm's performance for voltage regulation and mitigation of power quality issues

such as reactive power compensation, harmonics reduction, and load balancing under nonlinear/linear loads has been determined to be good.

1.3 SCOPE OF THE PROJECT

The project scope is to reduce the harmonics caused during the generation of power in the grid. We use STATCOM to compensate for the loss in the voltage that occurs in the system

1.4 ADVANTAGES

- Reduction of power losses in the grid caused by active and reactive power in the system.
- The transient performance of the proposed system is comparatively better, thus stabilizing the grid.

1.5 APPLICATIONS

Applications are in the field of

- electric power transmission,
- electric power distribution,
- electrical networks of heavy industrial plants,
- arc furnaces,
- high-speed railway systems, and other electric systems (where voltage stability and power quality are of the most importance).

CHAPTER 2

PROJECT DESCRIPTION

2.1 BLOCK DIAGRAM EXPLANATION

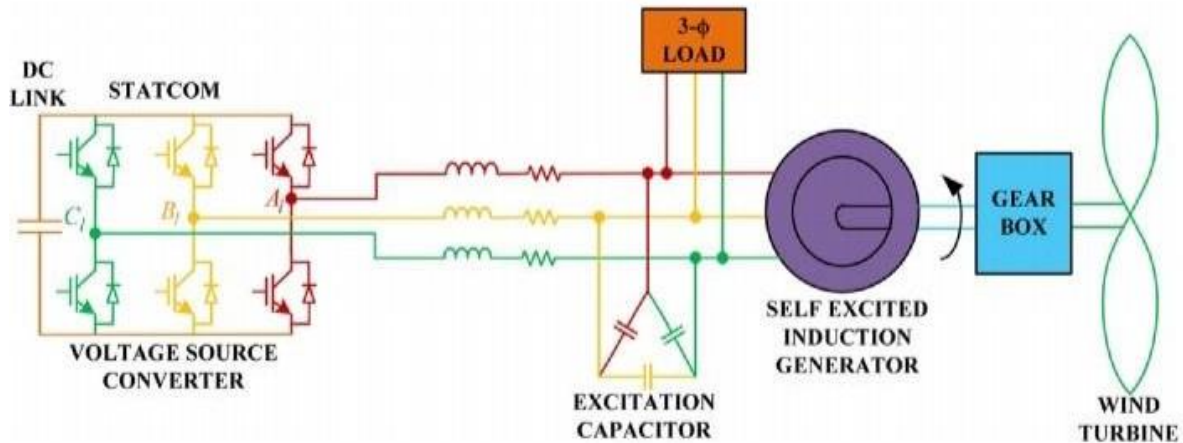


FIG 2.1: Block Diagram of STATCOM-assisted Self Excited Induction Generator-based Wind Energy Conversion System.

Fig 2.1 shows the schematic of a STATCOM-assisted Self Excited Induction Generator-based Wind Energy Conversion System. In the present system, a combination of a fixed capacitor bank and a STATCOM is chosen to maximize the energy output of the WECS over some time. A linear quadratic regulator is used to regulate the terminal voltage and frequency of the induction generator connected to balance three-phase loads.

2.2 ACTIVE AND REACTIVE POWER

The quantity of power used to create effective work, that is, the amount of power delivered to the load, such as a transformer, is referred to as active power or true power in AC electrical systems. The load draws this useable power as a result of energy being lost as heat. In an AC circuit or system, reactive power is the amount

of power that bounces back and forth between the source and the load, i.e. the power that cannot be employed for effective work.

2.3 HARMONICS

Electronic equipment with nonlinear loads that draw current in brief pulses produces harmonics. Short pulses can distort the current waveform, allowing harmonic currents to flow back into the grid. Harmonics in power systems have the primary effect of increasing the current in the system. This is especially true for the third harmonic, which generates a dramatic increase in the zero-sequence current and, as a result, an increase in the neutral conductor current.

CHAPTER 3

SIMULATION RESULTS

3.1 MATLAB SIMULATION

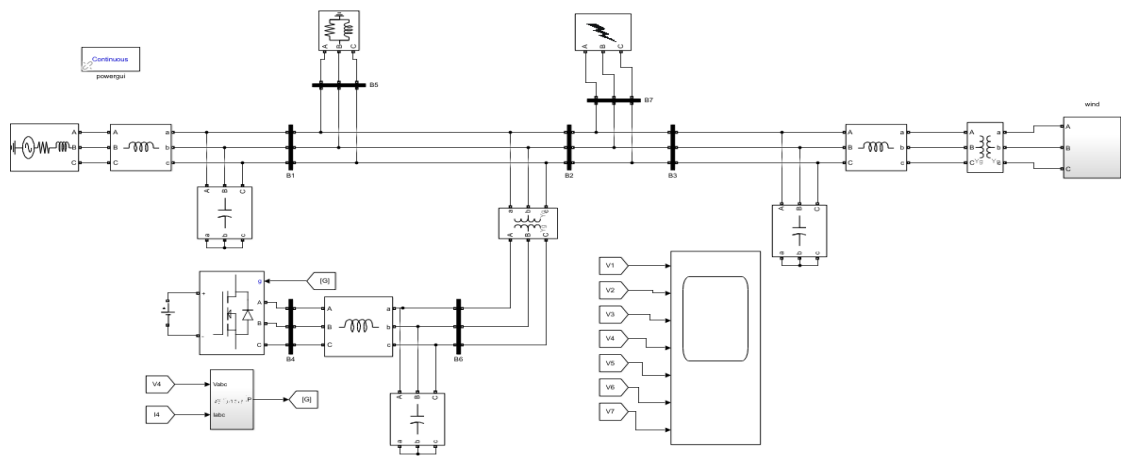


Fig 3.1: MATLAB Simulation

- There are three types of sources used for this simulation: three-phase source, linear phase source, and the energy generated from wind.
- Fault is being added to simulation to bring in the impedance in the system
- Wind Energy system acts as motor and generator in the given situation so we use an asynchronous machine (self-excited induction generator)
- All the three sources go through an LC circuit to rectify the leading and lagging power factor.
- The sign wave formed at every input and output is shown in the scope
- The V6 shows the compensated voltage in the system
- The sine wave shows the changes in the amplitude of the waves which shows the increase in power generated in the system

3.1.1 WIND ENERGY CONVERSIONS SYSTEM SUBSYSTEM

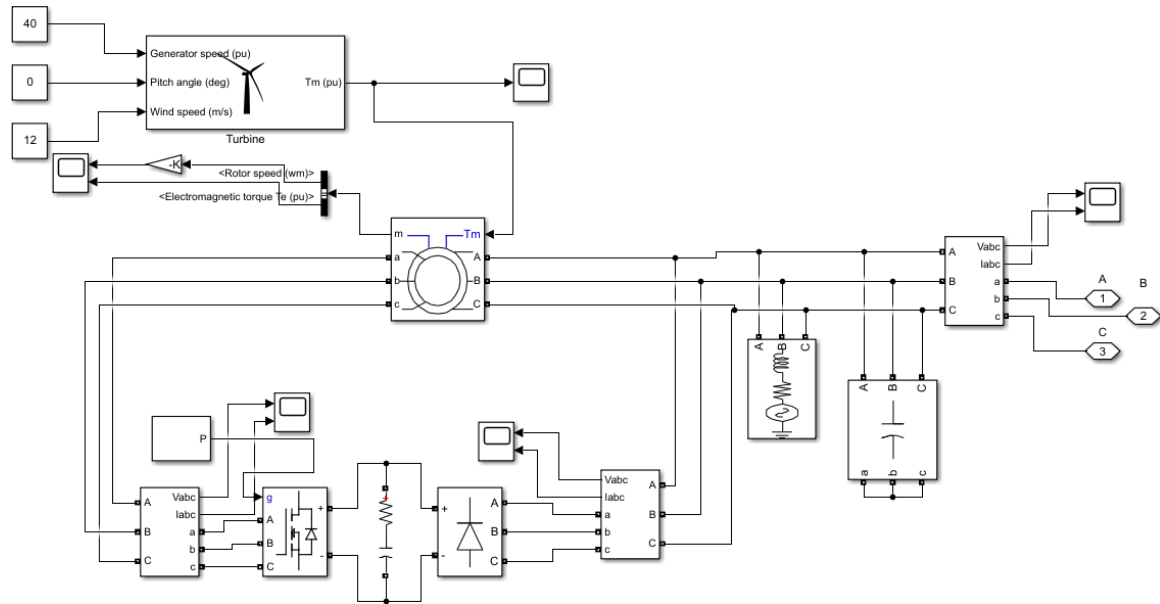


Fig 3.2: WECS Subsystem

- The above-shown SIMULINK simulation is for the Wind Energy Conversion System using a self-excited induction generator.
- The Self Excited Induction Generator works as a generator or as a motor depending on where the high voltage is being formed in the system.
- Under synchronous conditions, it works as a generator otherwise as a motor.
- The right side of the SEIG is where it is connected to the grid.
- The grid takes in DC voltage, it first gets passed through an LC filter and gets converted through the bridge rectifier as AC so it is easier to rectify the harmonics that form in the system
- The rectified power is passed through the universal bridge and given to SEIG.
- The left side of the SEIG is the wind energy system connected to the grid.
- In this case scenario, the value assumed for Generator speed is 40pu, Pitch angle to be 0°, and the wind speed to be 12 m/s.
- The torque produced by the wind energy system is given to the SEIG.

3.1.2 STATCOM SUBSYSTEM

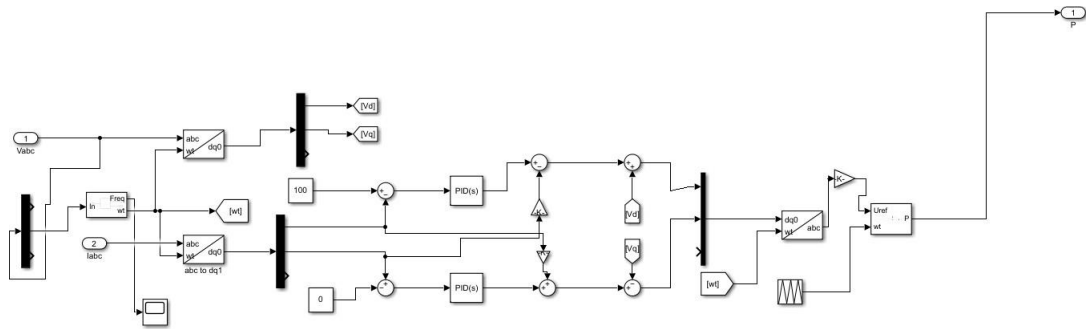


Fig 3.3: STATCOM Subsystem

- The above-shown SIMULINK simulation is for the Static Synchronous Compensator.
- It is used to produce the necessary gate pulse in the simulation and rectify the fault produced.

3.2 Performance Analysis

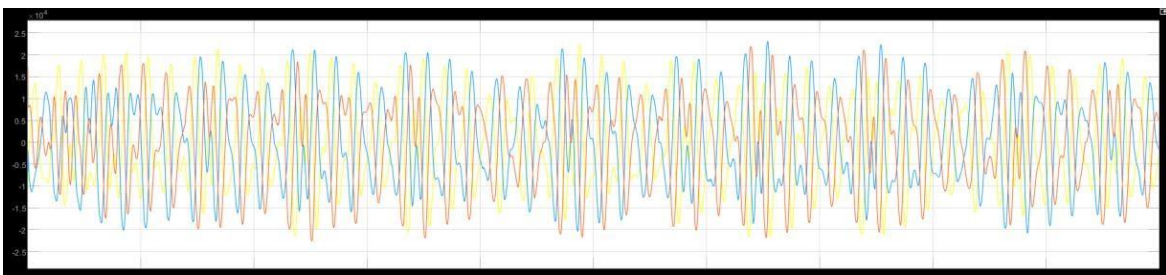


Fig 3.4: Output of Wind Energy Conversion System

The above-shown diagram is the waveform formed from the power produced by the wind energy conversion system.

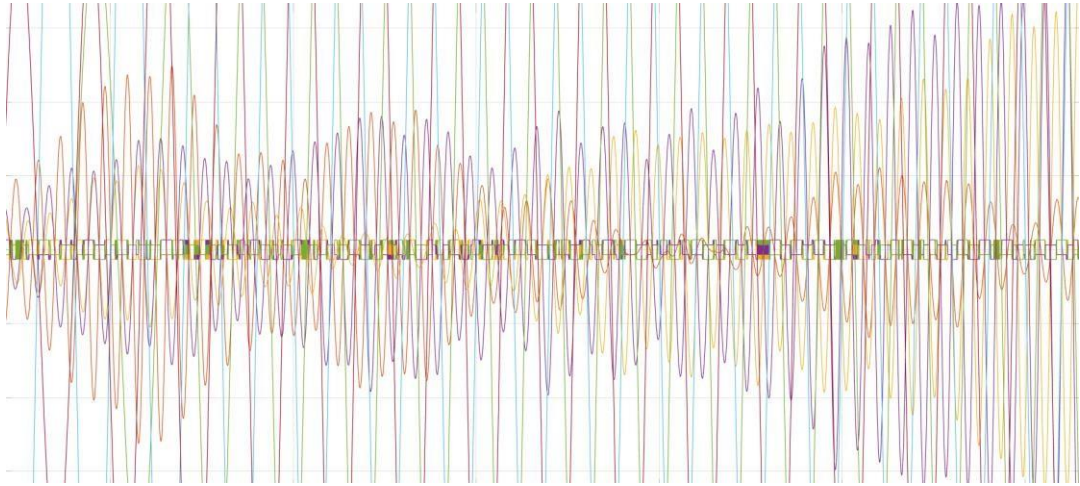


Fig 3.5: Output formed without STATCOM

Unstable three-phase waveforms are being formed in the system.

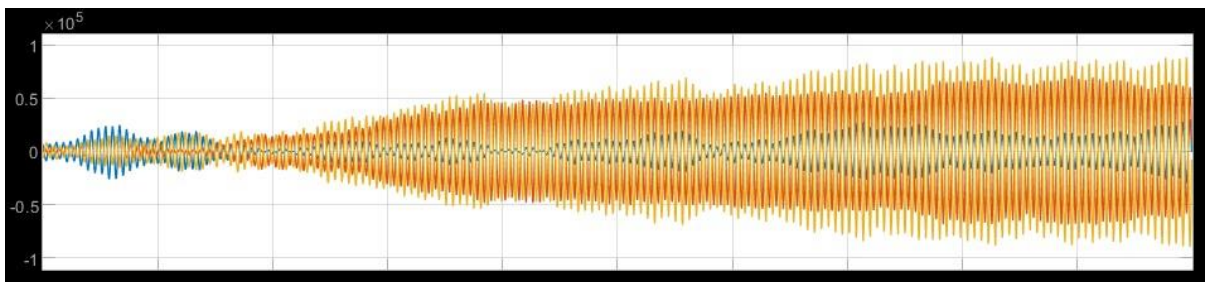


Fig 3.6: Compensated Amplitude

The above-shown diagram shows the compensated amplitude that is being produced in the grid with the help of STATCOM. The yellow waves are the compensated amplitudes

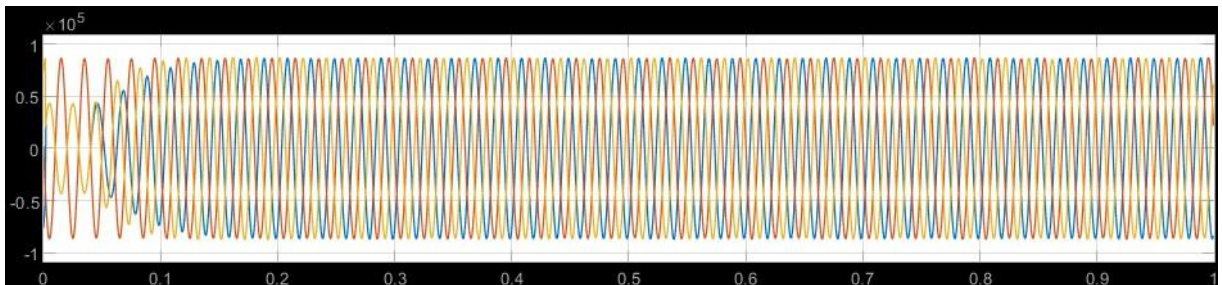


Fig 3.7: Rectification with STATCOM

In the beginning, there is a huge difference in the three different phase angle (3 different colors) presents in the diagram but after a minute, all the waveforms are at the same amplitude in the output.

The Sine Wave will reach the maximum amplitude possible with the help of STATCOM.

CHAPTER 4

HARDWARE DESCRIPTION

4.1 HARDWARE CIRCUIT DIAGRAM

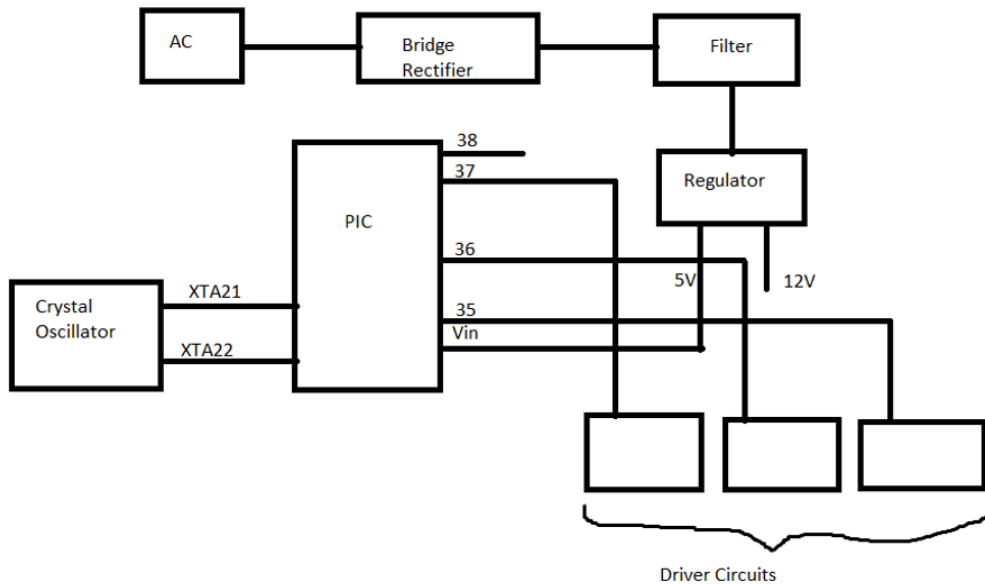


Fig 4.1: Hardware Circuit Diagram

The above-shown is the circuit diagram of the STATCOM part the of the prototype made

4.2 POWER SUPPLY

The ac voltage, which is usually 220V RMS, is linked to a transformer, which reduces the ac voltage to the desired dc output level. A diode rectifier produces a full-wave rectified voltage, which is then filtered by a capacitor filter to create a dc voltage. The resulting dc voltage frequently has some ripple or ac voltage variation. A regulator circuit reduces ripples and keeps the same dc value regardless of the input dc voltage or the load coupled to the output dc voltage. This voltage regulation is provided by one of the most prevalent voltage regulator IC modules.

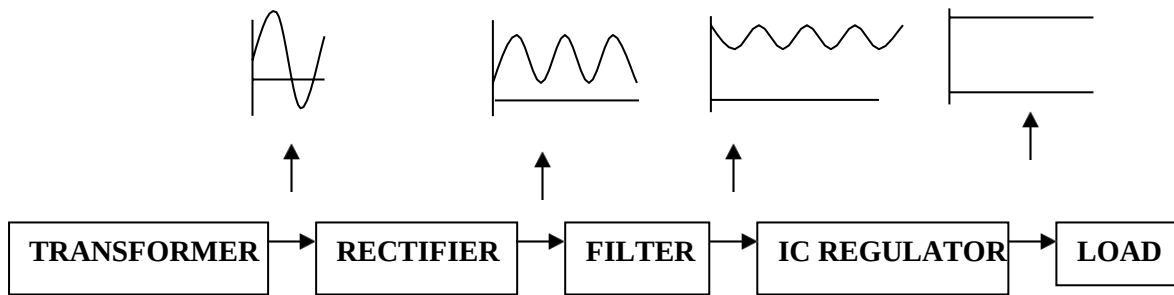


Fig 4.2: Block Diagram of Power supply

4.3 TRANSFORMER

The potential transformer will step down the power supply voltage (0-230V) to (0-12V) level.

4.4 VOLTAGE REGULATOR

Regulator IC units combine reference source, comparator amplifier, and overload protection circuitry into a single IC unit.

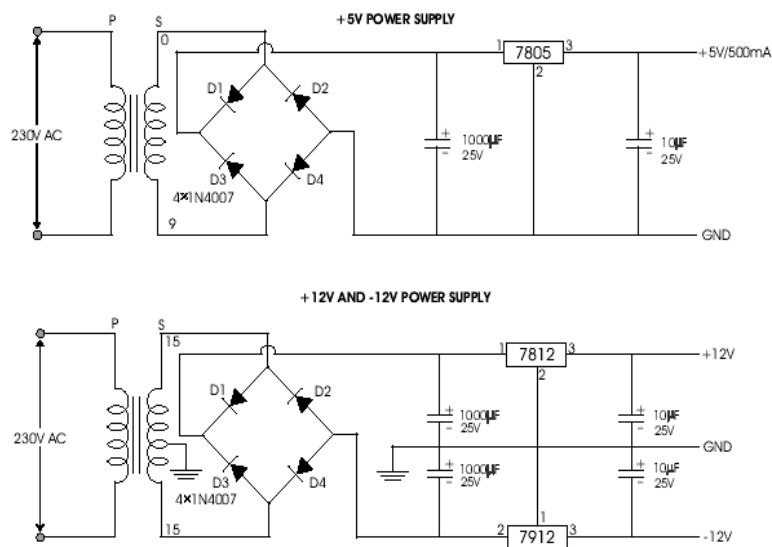


Fig 4.3: Transformer

The regulators can be configured to work with load currents ranging from hundreds of milliamperes up to tens of amperes, and power ratings ranging from milliwatts up to tens of watts. From 5 to 24 volts, the series 78 regulators provide fixed positive regulated voltages. From 5 to 24 volts, the series 79 regulators give set negative regulated voltages. An uncontrolled dc input voltage, V_i , is applied with one input terminal, a regulated dc output voltage, V_o , is applied to a second terminal, and the third terminal is linked to the ground in a fixed three-terminal voltage regulator. From 5 to 24 volts, the series 78 regulators offer fixed positive regulated voltages. The series 79 regulators, on the other hand, offer fixed negative regulated voltages ranging from 5 to 24 volts.

4.5 DRIVER CIRCUIT

In electronics, a driver is an electrical circuit or other electronic component used to control another circuit or component, such as a high-power transistor, liquid crystal display (LCD), and numerous others.

They are used to regulate the current flowing through a circuit or are used to control other factors such as other components, and some devices in the circuit. A specialized integrated circuit that controls high-power switches in switched-mode power converters is sometimes referred to as a high-power switch controller. An amplifier is also known as a loudspeaker driver or a constant voltage circuit that allows an attached component to operate over a wide range of input voltages. Typically, the driver stage(s) of a circuit requires different characteristics from other circuit stages. For example, To avoid or eliminate distortion in a transistor power amplifier, the driver circuit normally requires current gain, the capacity to discharge the following transistor bases quickly, and low output impedance.

The most typical usage of driver circuits in semiconductor devices is to magnify signals from controllers or microcontrollers to regulate power switches.

Isolating the control circuit from the power circuit, detecting malfunctions, storing and reporting failures to the control system, acting as a failsafe, evaluating sensor signals, and providing auxiliary voltages are all duties that driver circuits do.

4.6 Thyristor Driver Circuits

Appropriate control signals are employed in thyristor driver circuits to produce gate current pulses that actuate the thyristor. A transformer is used to separate the control circuit from the power circuit's high voltages.

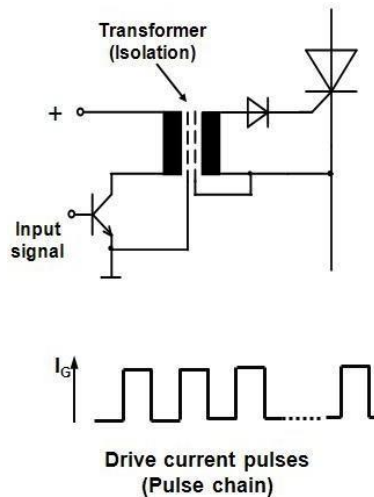


Fig 4.4: Principle of a thyristor driver circuit

To guarantee that the firing pulses surpass the thyristor's latching current, they are repeated numerous times. The minimal gate current necessary to trigger the thyristor is known as the latching current. The gate pulse must stay non-terminating until the current through the thyristor reaches the holding current, which is the minimum current needed for the thyristor to remain in the on-state.

4.7 MOSFET and IGBT Driver Circuits

IGBT and MOSFET drivers are very similar in that both components are controlled by a voltage (charging the gate capacitor). Table 1 below shows control voltages for the given both types of drivers:

Table 4.1: Typical control voltages for MOSFETs and IGBTs

	MOSFET	IGBT
Switch On	+10 V	+15 V
Switch Off	0 V	-8 V (-15 V)

The IGBT gate voltage in switch-off mode is generally approximately -8V to 15V to prevent an undesired capacitive switch on. The insulation between the gate and the emitter is made of thin silicon oxide. A maximum voltage of 20V to 25V must never be exceeded to ensure that the oxide layers remain intact.

4.8 Functions of Typical Driver Circuits

An IGBT half-bridge driver circuit is shown in the schematic below.

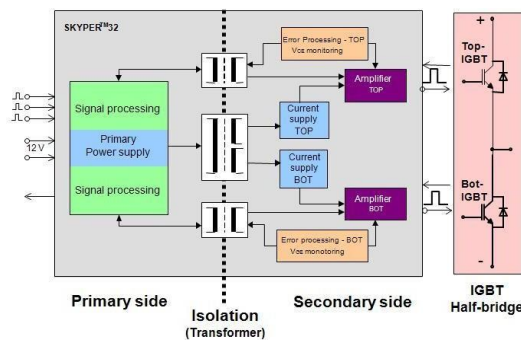


Fig 4.5: Outline of IGBT half-bridge driver circuit

On the primary side of the IGBT half-bridge driver circuit above, input signals are received and error signals are sent back to the controller.

Signal processing that takes place on the primary side of the driver circuit enables short pulse suppression to minimize glitches, prevention of both IGBTs in the half-bridge turning on simultaneously so to avoid short circuits, and monitoring of temperature and under voltages.

4.8.1 Isolation between primary and secondary sides

Isolation of primary and secondary sides of the driver circuit is generally accomplished by the use of transformers or optocouplers (LEDs and phototransistors). Typical driver circuits can withstand voltages of 2500 V between the primary and secondary sides.

Some simple driver circuits forego the isolation between the primary and secondary sides, leaving this task in the hands of the user.

4.8.2 The secondary side of the driver circuit

On the secondary side of the driver circuit, input signals are amplified and used to control the switching of the IGBTs. Overcurrent is monitored to detect shorts in the power circuit. This is done by either comparing the collector-emitter voltage V_{CE} to a preset threshold or by monitoring the signal of a current sensor.

If overcurrent occurs, the secondary side of the driver switches all the IGBTs off and sends an error signal to the primary side.

4.8.3 Isolation of the triggering signal using an optocoupler

Optocouplers are often used in place of transformers to isolate signals. An optocoupler is made up of an LED (Light Emitting Diode) and a light-sensitive transistor (phototransistor) all in one package.

In general, optocouplers are inferior to transformers since they display higher susceptibility than transformers, less durability, limited performance, and limited isolation voltage. These drawbacks are more apparent in low-cost optocouplers.

4.8.4 Output Stage of Driver Circuits

The driver charges and discharges the gate emitter capacitor via the gate resistor. The IGBT's switching speed is determined by this.

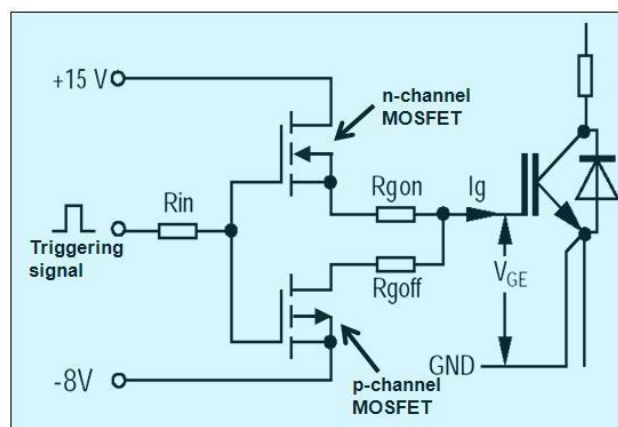


Fig 4.6: The output stage of a gate driver

In the diagram above, $R_{g\text{on}}$ represents the external gate series resistance at switch-on and $R_{g\text{off}}$ the external gate series resistance at switch-off. The higher R_g the slower the switching process.

4.8.5 Soft turn off

For many driver circuits, a switch to a higher $R_{g\text{off}}$ is made in the case of a short circuit, leading to a slower, or soft, turn-off. Overvoltages, which can result in high currents, and parasitic inductances, which could otherwise harm the module, are avoided in this method.

4.8.6 Maximum and average gate current

High currents flowing within a short time are required to charge or discharge the gate capacitor. The higher the switching speed and the bigger the IGBT surface, the higher the peak gate current (up to 10A).

The average driver current depends additionally on the clock frequency, that is the number of switching operations per second.

Maximum, as well as average gate currents, must be considered when selecting a driver circuit for a particular application.

4.9 PIC16F877A

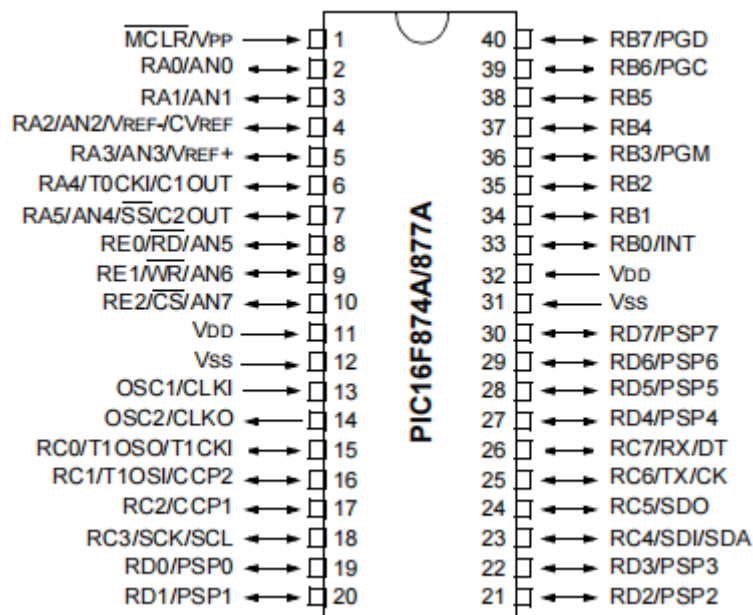


Fig 4.7: PIC16F877A Pin Diagram

4.9.1 High-Performance RISC CPU:

- To learn only 35 single words instructions
- Every single cycle instruction excluded program branches that are two cycle
- Operating speed: DC - 20 MHz clock input DC - 200 ns instruction cycle
- Up to 8K x 14 words of Flash Program Memory, up to 368 x 8 bytes of Data Memory (RAM), Up to 256 x 8 bytes of EEPROM Data Memory
- Pinout compatible with other 28-pin or 40/44-pin PIC16CXXX and PIC16FXXX microcontrollers

4.9.2 Peripheral Features:

- Timer0: an 8-bit timer or counter with 8-bit pre-scaler
- Timer1: a 16-bit timer or counter with a pre-scaler, can be incremented during Sleep via an external crystal/clock.
- Timer2: 8-bit timer/counter with 8-bit period register, Prescaler and postscaler
- Two Capture, Compare, PWM modules - Capture is 16-bit, max. resolution is 12.5 ns - Compare is 16-bit, max. resolution is 200 ns - PWM max. resolution is 10-bit
- Synchronous Serial Port (SSP) with SPI™ (Master mode) and I2C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) – 8 bits wide with external RD, WR, and CS controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

4.9.3 Analog Features:

- 10-bit, up to 8-channel Analog-to-Digital Converter (A/D)
- Brown-out Reset (BOR)

- Analog Comparator module with - Two analog comparators - Programmable on-chip voltage reference (VREF) module - Programmable input multiplexing from device inputs and internal voltage reference
- Comparator outputs are externally accessible

4.9.4 Special Microcontroller Features:

- 100,000 erase or write cycle enhanced flash program memory typical
- 1,000,000 erase/write cycle data EEPROM typical memory
- Data EEPROM retention > 40 years
- Self-reprogrammable under software control
- In-circuit serial programming (ICSP) via two pins
- Single-supply 5V In-circuit serial programming
- Watchdog Timer (WDT) with on-chip RC oscillator is used for reliable operation
- Programmable code protection
- Power-saving sleep mode
- Selectable oscillator options
- In-circuit debugs (ICD) via two pins CMOS Technology:
- Low-power, high-speed Flash/EEPROM technology
- Fully static design
- Wide operating voltage range that is from 2.0V - 5.5V
- Commercial and industrial temperature ranges
- Very low-power consumption

4.10 SHUNT ACTIVE FILTER

4.10.1 Shunt Active Power Filter:

Shunt active filters are by far the most widely accept and dominant filter of choice in most industrial processes. The active filter is connected in parallel at the PCC and is fed from the main power circuit. The objective of the shunt active filter is to supply opposing harmonic current to the nonlinear load effectively resulting in a net harmonic current. This means that the supply signals remain purely fundamental. Shunt filters also have the additional benefit of contributing to reactive power compensation and balancing of three-phase currents. Since the active filter is connected in parallel to the PCC, only the compensation current plus a small amount of active fundamental current is carried in the unit. For an increased range of power ratings, several shunt active filters can be combined to withstand higher currents.

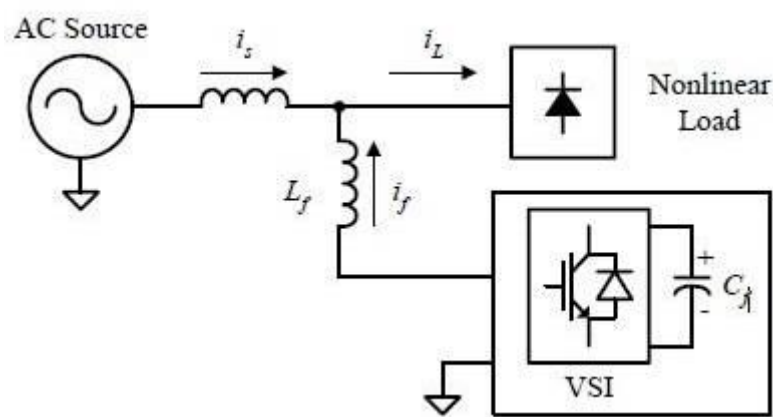


Fig 4.8: Principal configuration of VSI based shunt APF

If the nonlinear load current can be written as the sum of the fundamental current component ($i_{L,f}$) and the current harmonics ($i_{L,h}$) according to

$$i_L = i_{L,f} + i_{L,h} \dots \dots \dots (1)$$

then the compensation current injected by the shunt APF should be

$$i_f = i_{L,h} \dots \dots \dots (2)$$

the resulting source current is

$$i_s = i_L - i_f = i_{L,f} \dots \dots \dots (3)$$

From the above equation (3) the source current contains only the fundamental component of the nonlinear load current and is thus free from harmonics. When the shunt APF performs harmonic filtering, the ideal source current for a nonlinear load

is connected. In this way, the shunt APF completely cancels the current harmonics from the nonlinear load, thus resulting in a harmonic free source current.

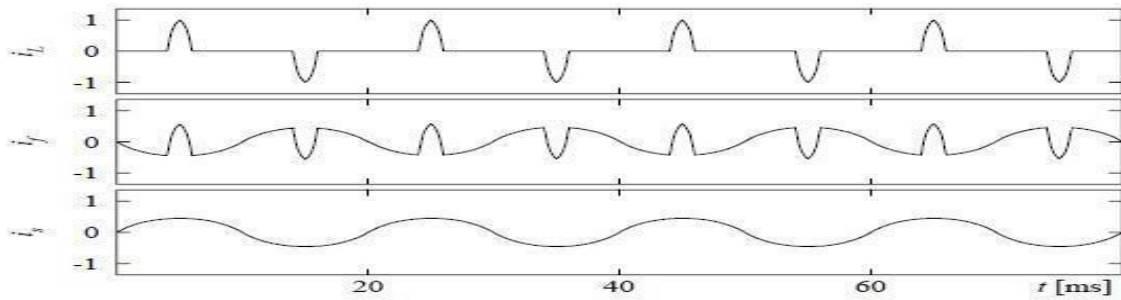
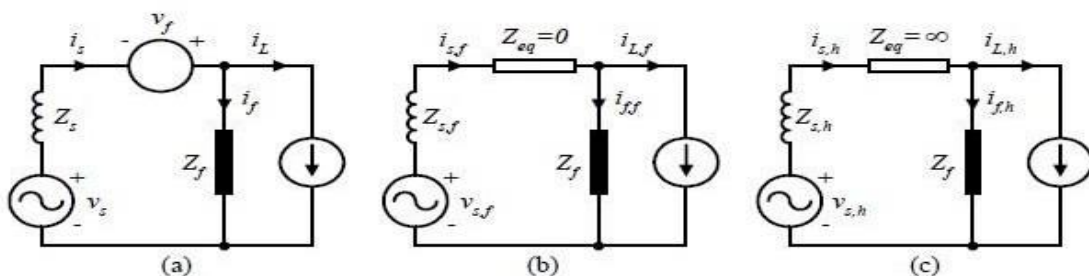


Fig 4.9: Operating principle of Shunt APF for harmonic filtering

4.10.2 Series Active Power Filter

The main objective of the series active filter is to maintain a pure sinusoidal voltage waveform across the load. This is achieved by producing a PWM voltage waveform which is added or subtracted against the supply voltage waveform. The choice of power circuit used in most cases is the voltage-fed PWM inverter without a current minor loop. Unlike the shunt filter which carries mainly compensation current, the series circuit has to handle high load currents. This causes an increased rating of the filter suitable to carry the increased current. Series filters offer the main advantage over the shunt configuration of achieving ac voltage regulation by eliminating voltage-waveform harmonics. This means the load contains a pure sinusoidal waveform only. The series APF can be thought of as a harmonic isolator. By proper control of this series APF there are no current harmonics that can flow from nonlinear load to source, and vice versa.



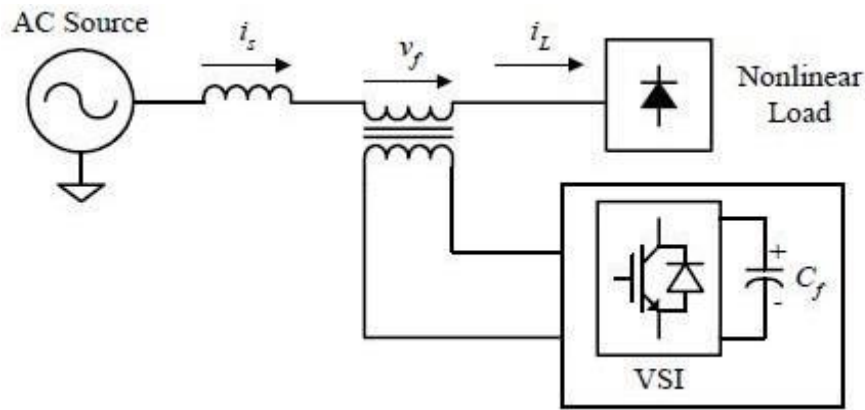


Fig 4.10: Principle configuration of VSI based Series

These series APFs are not commonly used in power systems like the shunt APF. As the load currents handled by the series APF are large. This high capacity of load currents makes the current ratings of series APF considerably compared with shunt APF, particularly on the secondary side of the interfacing transformer. Because of I^2R losses will increase. However, the main advantage of series APF when compared to shunt one is that they are ideal for voltage harmonic mitigation. It provides a pure sinusoidal waveform to the load, which is necessary for voltage-sensitive devices like power system protection devices. With this feature, series APFs are widely employed in improving the quality of the source voltage.

4.10.3 Hybrid Active Power Filter:

Previously, for APF exertion many of the nitriles are implemented based on analog circuits. Due to this, the performance of the APF is affected by the signal drift. Digital nitriles using DSPs or microcontrollers are referable, primarily due to their flexibility and immunity to noise. However, digital approaches do not properly filter high-order harmonics. This happens because of the hardware limitation of sampling rate in real-time application. Moreover, the utilization of fast switching power electronic switches (i.e. MOSFETs, IGBTs) in APF applications uses switching frequency noise to appear in the compensated source current. Additional filtering circuit is required to reduce this switching frequency noise and to prevent interference with other sensitive equipment's

The above problems discussed with APFs can be overcome with the help of hybrid APF configuration. These hybrid APFs are nothing but a combination of APFs and passive filters. Hence these hybrid APFs give the advantages of both the passive and APFs and provide improved performance and cost-effective solutions.

Hybrid APFs combinations are can be designed to compensate for higher powers without excessive sets for high-power switching. But the major disadvantage of this configuration is the fact that passive filters can only be tuned for a specific predefined harmonic and thus cannot be easily changed for loads that have varying harmonics.

This hybrid APF is a combination of shunt APF and a passive filter connected in parallel with the nonlinear load. Thus the objective function of the hybrid APF is divided into two parts i.e. the lower order harmonics are filtered by the shunt APF, while the higher-order harmonics are filtered by the passive high pass filter. The system configuration of hybrid series APF is the combination of series APF and shunt passive filter. By injection of nitrile harmonic voltage source, this hybrid series active filter is controlled to act as a harmonic isolator between the source and nonlinear load. This type of hybrid active filter is controlled in such a way that it offers zero impedance at the fundamental frequency and high impedance at all undesired harmonic frequencies. Passive filters are often easier and simple to implement and do not require any control circuit. This deserves to be most beneficial.

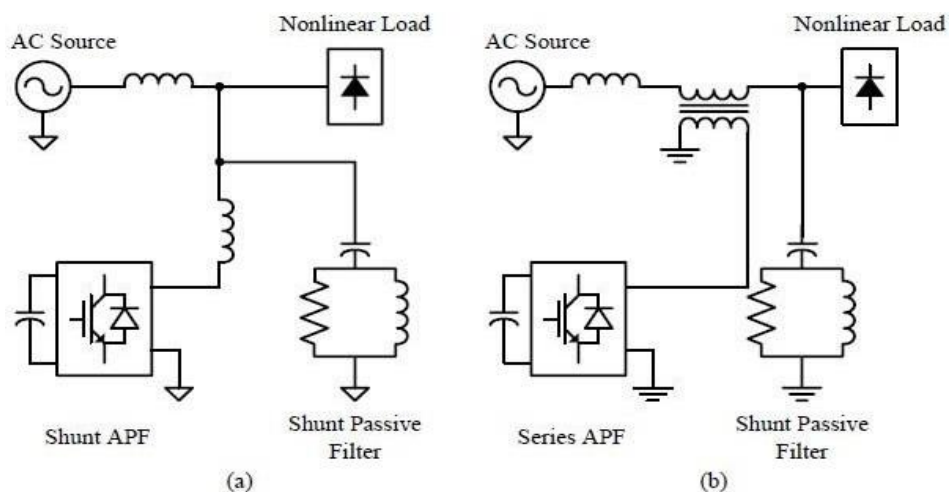


Fig. 4.11: Hybrid APFs

(a) Combination of Shunt APF and Shunt Passive Filter.

(b) Combination of Series APF and Shunt passive Filter.

4.10.4 Active power filter implementation :

Active power filters can be implemented as shunt type, series type, or a combination of shunt and series active filters (shunt-series type) depending on the reticular application or electrical problem to be solved. These filters can also be combined with passive filters to create hybrid power filters as given in Table (2.1).

4.10.5 Active filter application depending on power quality problems.

Table 4.2: Active Filter Connection

Active Filter Connection	Source of Problem	
	Load effect on AC Supply	AC Supply effect on Load
Shunt	Current Harmonic Filtering	
	Reactive current Compensation	
	Current Unbalance	
	Voltage Flicker	
Series	Current Harmonic Filtering	Voltage Sag/Swell
	Reactive Current Compensation	Voltage Unbalance
	Current Unbalance	Voltage interruption
	Voltage Flicker	Voltage flicker
	Voltage Unbalance	Voltage notching
Series-shunt	Current Harmonic Filtering	Voltage Sag/Swell
	Reactive Current Compensation	Voltage Unbalance
	Current Unbalance	Voltage interruption
	Voltage Flicker	Voltage flicker
	Voltage Unbalance	Voltage notching

4.11 INVERTER:

An inverter is electronic equipment that converts direct current to alternating current. It does not produce any power. The power is provided by the DC source.

The input and output voltage, frequency, and overall power handling depend on the design of the specific device or circuitry.

A power inverter can be entirely electronic or maybe a combination of mechanical effects and electronic circuitry. In the conversion process, static inverters do not employ moving parts.

4.11.1 Input voltage

A typical power inverter device or circuit requires a relatively stable DC power source capable of supplying enough current for the intended power demands of the system. The input voltage depends on the design and purpose of the inverter.

Examples include:

- 12 VDC- For smaller consumer and business inverters that are powered by a 12V lead-acid battery that can be recharged. 24 and 48 VDC- Common standards for home energy systems.
- 200 to 400 VDC- When power is from photovoltaic solar panels.
- 300 to 450 VDC- When power is from electric vehicle battery packs in vehicle-to-grid systems.
- Hundreds to thousands of volts- Where the inverter is part of a high voltage direct current power transmission system.

4.11.2 Output waveform

Depending on the circuit design, an inverter can produce a square wave, modified sine wave, pulsed sine wave, or sine wave.

There are two basic designs for producing household plug-in voltage from a lower-voltage DC source. The first of which uses a switching boost converter to produce a higher-voltage DC and then converts to AC. The second method converts DC to AC at the battery level and uses a line-frequency transformer to create the output voltage.

4.11.2.1 Square wave

This is one of the most basic waveforms that an inverter may produce, and it can be useful in some situations.

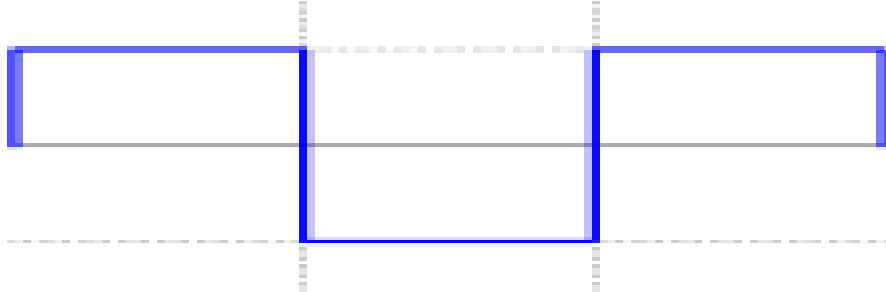


Fig 4.12: Square Wave

4.11.2.2 Sine wave

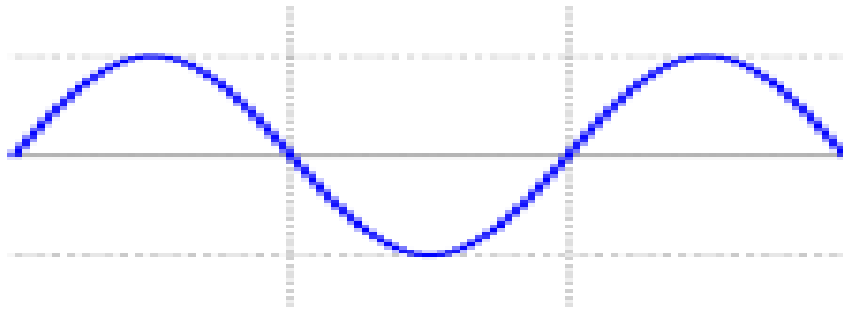


Fig 4.13: Sine Wave

A sine wave inverter is a power inverter device that produces a multiple-step sinusoidal AC waveform. To distinguish the inverters with outputs of much less distortion than the "modified sine wave" (three-steps) inverter designs, the manufacturers often use the phrase pure sine wave inverter. Almost all consumer grade inverters that are sold as a "pure sine wave inverter" do not produce a smooth sine wave output at all, just a less choppy output than the square wave (one step) and modified sine wave (three-steps) inverters. In this sense, the phrases "pure sine wave" or "sine wave inverter" are misleading to the consumer. However, this is not critical for most electronics as they deal with the output quite well.

Where power inverter devices substitute for standard line power, a sine wave output is desirable because many electrical products are engineered to work best with a

sine wave ac power source. The standard electric utility power attempts to provide a power source that is a good approximation of a sine wave.

Sine wave inverters with more than three steps in the wave output are more complex and have a significantly higher cost than a modified sine wave, with only three steps, or square wave, (one step), types of the same power handling. Switch-mode power supply (SMPS) devices, such as personal computers or DVD players, function on quality modified sine wave power. AC motors directly operated on non-sinusoidal power may produce extra heat, may have different speed-torque characteristics, or may produce more audible noise than when running on sinusoidal power.

4.11.2.2.1 Modified sine wave

The non-square waveform of a "modified sine wave" inverter is a useful rough approximation of a sine wave for power translation purposes.

In commercially available modified-sine-wave inverters, the waveform is a square wave with a delay before the polarity transition, and the outputs just need to cycle through a three-position switch at the pre-determined frequency. Positive, negative, and zero voltage switching states are created according to the patterns in the switching Table 2. When compared to a sine wave, the peak voltage to RMS voltage does not preserve the same connection. To compensate for DC bus voltage variation, the DC bus voltage can be actively adjusted or the "on" and "off" periods can be changed to keep the same RMS value output up to a DC bus voltage. With a technique known as PWM, the ratio of on to off time can be altered to vary the RMS voltage while maintaining a constant frequency. The generated gate pulses are distributed by the created pattern to each switch, resulting in the output.

The output harmonic spectrum is determined by the pulse width and modulation frequency. Voltage harmonics are not a major concern when operating induction motors, nevertheless, harmonic distortion inside the current waveform causes additional heating and can result in pulsating torques.

Numerous electrical equipment will operate significantly well on modified sine wave power inverter devices, especially in a load that is resistive such as a traditional incandescent light bulb.

Due to the harmonic content, most AC motors will run on MSW inverters with a 20% efficiency drop. They may, however, be rather noisy. A fundamental frequency-tuned series LC filter could help.

4.11.3 Output frequency

The AC output frequency of a power inverter device is usually the same as the standard power line frequency, 50 or 60 hertz.

If the output of the device or circuit is to be further conditioned (for example stepped up) then the frequency may be much higher for good transformer efficiency.

4.11.4 Output voltage

The AC output voltage of a power inverter device is often the same as the standard power line voltage, such as household 120VAC or 240VAC. This allows the inverter to power numerous types of equipment designed to operate off the standard line power.

The designed-for output voltage is often provided as a regulated output. That is, changes in the load the inverter is driving will not result in an output voltage change from the inverter.

In a sophisticated inverter, the output voltage may be selectable or even continuously variable.

4.11.5 Output power

A power inverter will often have an overall power rating expressed in watts or kilowatts. This describes the power that will be available to the device the inverter is driving and, indirectly the power that will be needed from the DC source. Smaller popular consumer and commercial devices designed to mimic line power typically range from 150 to 3000 watts.

Not all inverter applications are primarily concerned with brute power delivery in some cases, the frequency and or waveform properties are used by the follow-on circuit or device.

4.11.6 Three-Phase Inverters

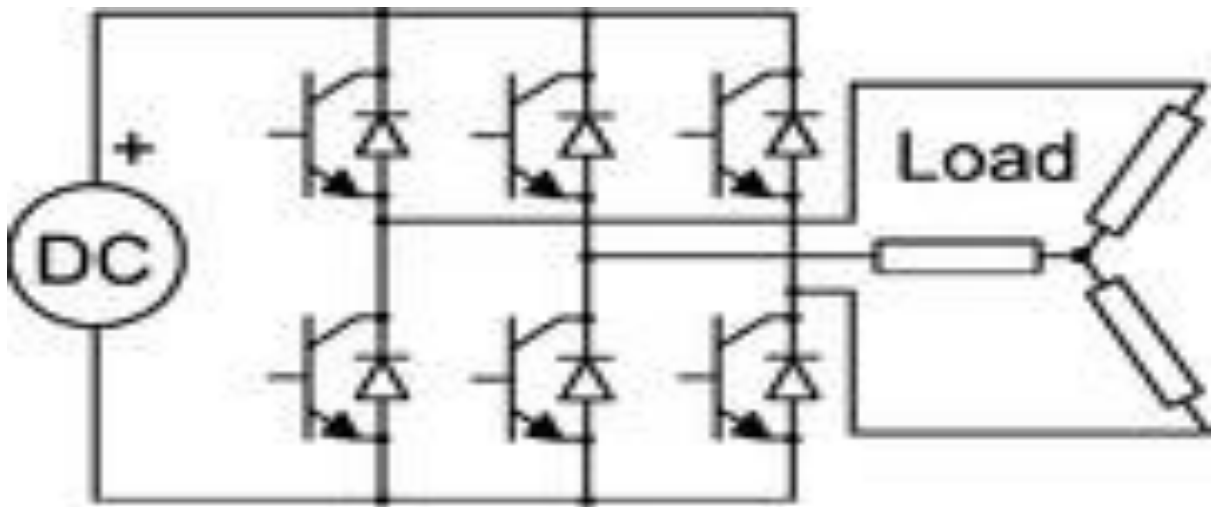


Fig 4.14: Three-phase inverters

Three-phase inverters are used for variable-frequency drive applications and high power applications such as HVDC power transmission. A basic three-phase inverter consists of three single-phase inverter switches each connected to one of the three load terminals. For the most basic control scheme, the operation of the three switches are coordinated so that one switch operates at each 60-degree point of the fundamental output waveform. This creates a line-to-line output waveform that has six steps. The six-step waveform has a zero-voltage step between the positive and negative sections of the square wave such that the harmonics that are multiples of three are eliminated as described above. When carrier-based PWM techniques are applied to six-step waveforms, the basic overall shape, or envelope, of the waveform is retained so that the 3rd harmonic and its multiples are canceled.

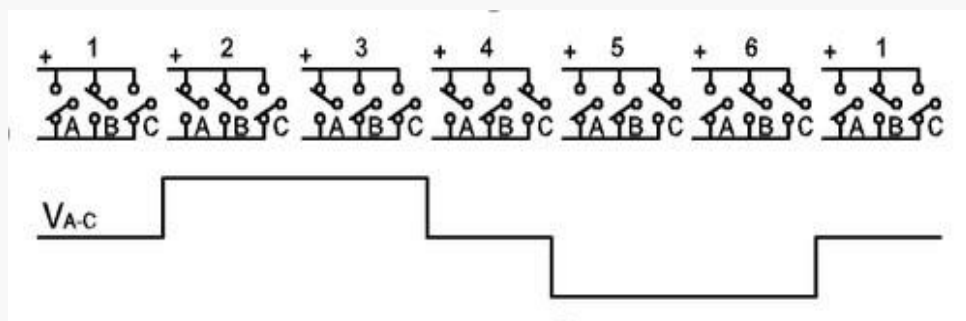


Fig 4.15: 3-phase inverter switching circuit showing 6-step switching sequence and waveform of voltage between terminals A and C (2^3-2 states)

To construct inverters with higher power ratings, two six-step three-phase inverters can be connected in parallel for a higher current rating or in series for a higher voltage rating. In either case, the output waveforms are phase-shifted to obtain a 12-step waveform. If additional inverters are combined, an 18-step inverter are obtained with three inverters, etc. Although inverters are usually combined to achieve increased voltage or current ratings, the quality of the waveform is improved as well.

4.11.7 Application:

4.11.7.1 DC power source utilization

An inverter converts the DC electricity from sources such as batteries or fuel cells to AC electricity. The electricity can be at any required voltage in particular, it can operate AC equipment designed for mains operation, or rectified to produce DC an any desired voltage.

4.11.7.2 Uninterruptible power supplies

An uninterruptible power supply (UPS) uses batteries and an inverter to supply AC power when main power is not available. When the main power is restored, a rectifier sulkies DC power to recharge the batteries.

4.12 DIODE:

Power diodes provide uncontrolled rectification of power and are used in applications such as electroplating, anodizing, battery charging, welding, power supplies (dc and ac), and variable frequency drives. They are also used in feedback and the freewheeling functions of converters and snubbers. Shows the diode symbol and its volt-ampere characteristics. In the forward biased condition, the diode can be represented by a junction offset drop and a series-equivalent resistance that gives a positive slope in the V-I characteristics. The typical forward conduction drop is 1.0 V. This drop will use conduction loss, and the device must be cooled by the appropriate heat sink to limit the junction temperature. In the reverse-biased condition, a small leakage current flows due to minority carriers, which gradually increase with voltage. If the reverse voltage exceeds a threshold value, lulling the breakdown voltage, the device goes through avalanche breakdown, which is when

the reverse current becomes large and the diode is destroyed by heating due to large power dissipation in the junction.

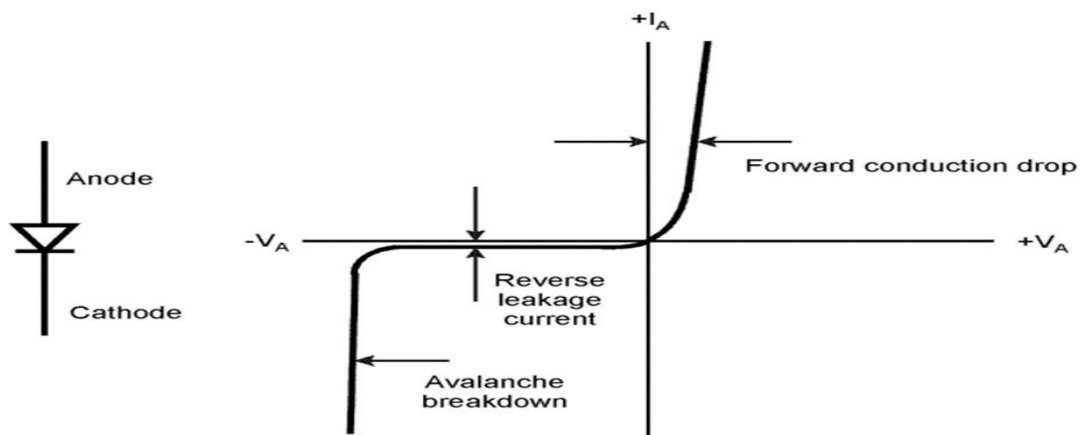


Fig 4.16: PI characteristics of a Diode

4.13 VOLTAGE REGULATOR:

The LM 78XXX series of the three-terminal regulations is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on-card regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, and other solid-state electronic equipment. Although these devices are generally designed as fixed voltage regulators, they can be utilized with external components to achieve variable voltages and currents. The LM78XX series is available in aluminum to 3 packages which will allow over 1.5A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. The LM 78XX is available in the metal 3 leads to 5 and the plastic to 92. For this type, with adequate heat sinking. The regulator can deliver a 100mA output current. The advantage of this type of regulator is, it is easy to use and minimizes the number of external components. The following are the features of voltage regulators:

- a) Output current over 1.5A for 78 and 78L series
- b) Internal thermal overload protection
- c) No external components are required
- d) Output transistor safe area protection

e) Internal short circuit current limit.

4.14 CAPACITOR

A capacitor (originally known as a condenser) is a passive two-terminal electrical component used to store energy electrostatically in an electric field. The forms of practical capacitors vary widely, but all contain at least two electrical conductors (plates) separated by a dielectric (i.e. insulator). The conductors can be thin films, foils or sintered beads of metal or nonductile electrolyte, etc. The nonconducting dielectric acts to increase the capacitor's charge capacity. A dielectric can be glass, ceramic, plastic film, air, vacuum, paper, mica, an oxide layer, etc. Capacitors are widely used as parts of electrical circuits in many common electrical devices. Unlike a resistor, an ideal capacitor does not dissipate energy. Instead, a capacitor stores energy in the form of an electrostatic field between its plates.

When there is a potential difference across the conductors (e.g., when a capacitor is attached across a battery), an electric field develops across the dielectric, using positive charge $+Q$ to collect on one plate and negative charge $-Q$ to collect on the other plate. If a battery has been attached to a capacitor for a sufficient amount of time, no current can flow through the capacitor. However, if a time-varying voltage is applied across the leads of the capacitor, a displacement current can flow.

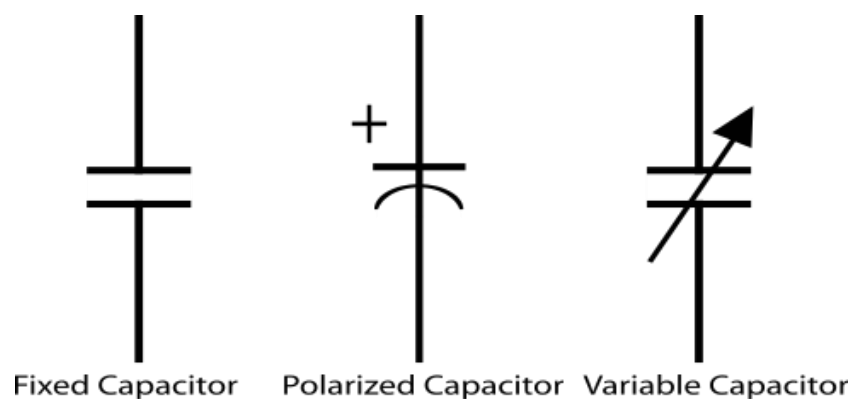


Fig 4.17: Types of Capacitors

4.15 RECTIFIER

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification. Physically, rectifiers take several forms, including vacuum tube diodes, mercury-arc valves, copper, and selenium oxide rectifiers, semiconductor diodes, silicon-controlled rectifiers, and other silicon-based semiconductor switches. Historically, even synchronous electromechanical switches, and motors have been used. Early radio receivers, called crystal radios, used a "cat's whisker" of fine wire pressing on a crystal of galena (lead sulfide) to serve as a point-contact rectifier or "crystal detector".

Rectifiers have many uses but are often found serving as components of DC power supplies and high-voltage direct-current power transmission systems. Rectification may serve in roles other than to generate direct current for use as a source of power. As noted, detectors of radio signals serve as rectifiers. In gas heating systems flame rectification is used to detect the presence of a flame.

Because of the alternating nature of the input AC sine wave, the process of rectification line produces a DC that, though unidirectional, nonsuits of pulses of current. Many applications of rectifiers, such as power supplies for radio, television, and computer equipment, require a steady constant DC (as would be produced by a battery). In these applications, the output of the rectifier is smoothed by an electronic filter (usually a capacitor) to produce a steady current.



Fig 4.18: Rectifier

4.16 BRIDGE RECTIFIER

A diode bridge is an arrangement of four (or more) diodes in a bridge circuit configuration that provides the same polarity if output for either polarity of input. When used in its most common application, for conversion of an alternating current (AC) input into a direct current (DC) output, it is known as a bridge rectifier.

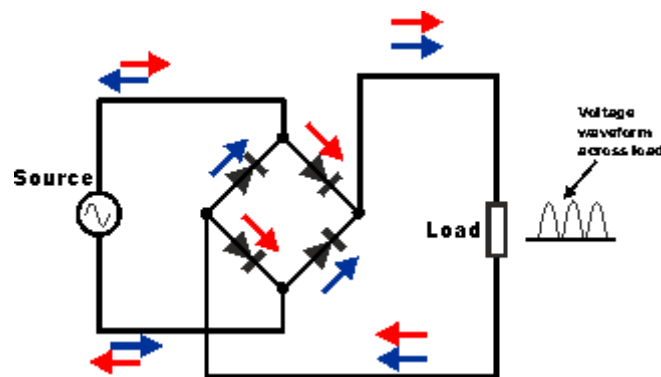


Fig 4.19: Bridge Rectifier

According to the conventional model of current flow (originally established by Benjamin Franklin and still followed by most engineers today), the current is defined to be positive when it flows through electrical conductors from the positive to the negative pole. In actuality, free electrons in a conductor nearly always flow from the negative to the positive pole. In the vast majority of applications, however, the actual direction of current flow is irrelevant.

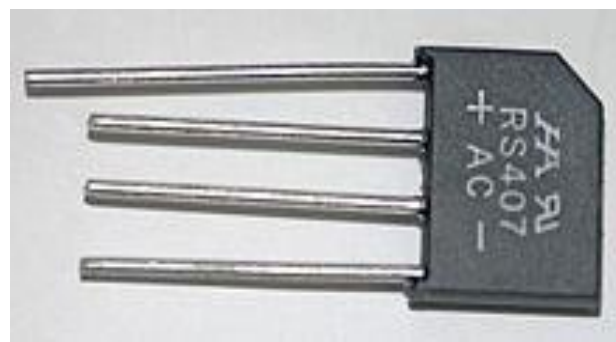


Fig 4.20: IR sensor

The IR Sensor-Single is a general-purpose proximity sensor. It is typically used for collision or obstacle detection. An IR emitter & IR receiver pair make up the module.

An IR signal is always detected by the high-precision IR receiver. There are 358 comparator ICs in the module. The sensor's output is high when the IR receiver gets an IR signal; otherwise, it is low. The sensor's status may be checked without the use of any additional hardware thanks to the onboard LED indicator. This module has a low power consumption. It gives a digital output.

FEATURES:

- General Purpose Proximity Sensor.
- IR emitter and IR receiver pair.
- LED indicator for sensor output.
- Very compact.
- Low power consumption.
- LM358 for Digital Output.

4.17 HARDWARE KIT DIAGRAM

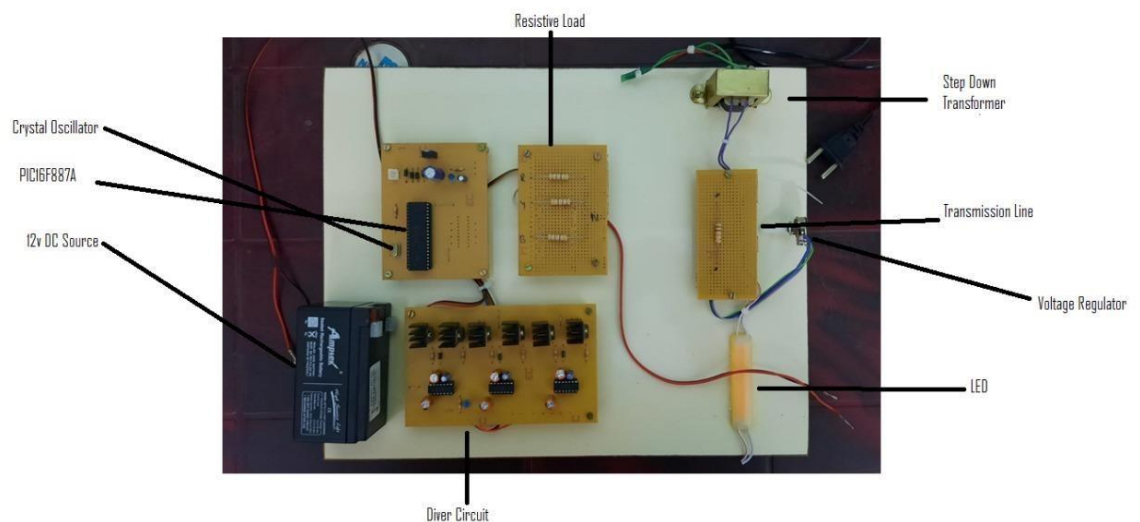


FIG 4.21: Hardware Kit Diagram

Main Components Used:

- Controller: Peripheral Interface Controller (PIC16F877A)
- Crystal Oscillator
- Capacitor - 470 microfarad
- Driver - Optocoupler
- Transformer - 230 to 12 v (0.5 amp)
- Load resistor - 50 ohm
- Battery - 12-volt Li-ion (DC Source)
- 10K resistor 5%

4.18 PROTOTYPE

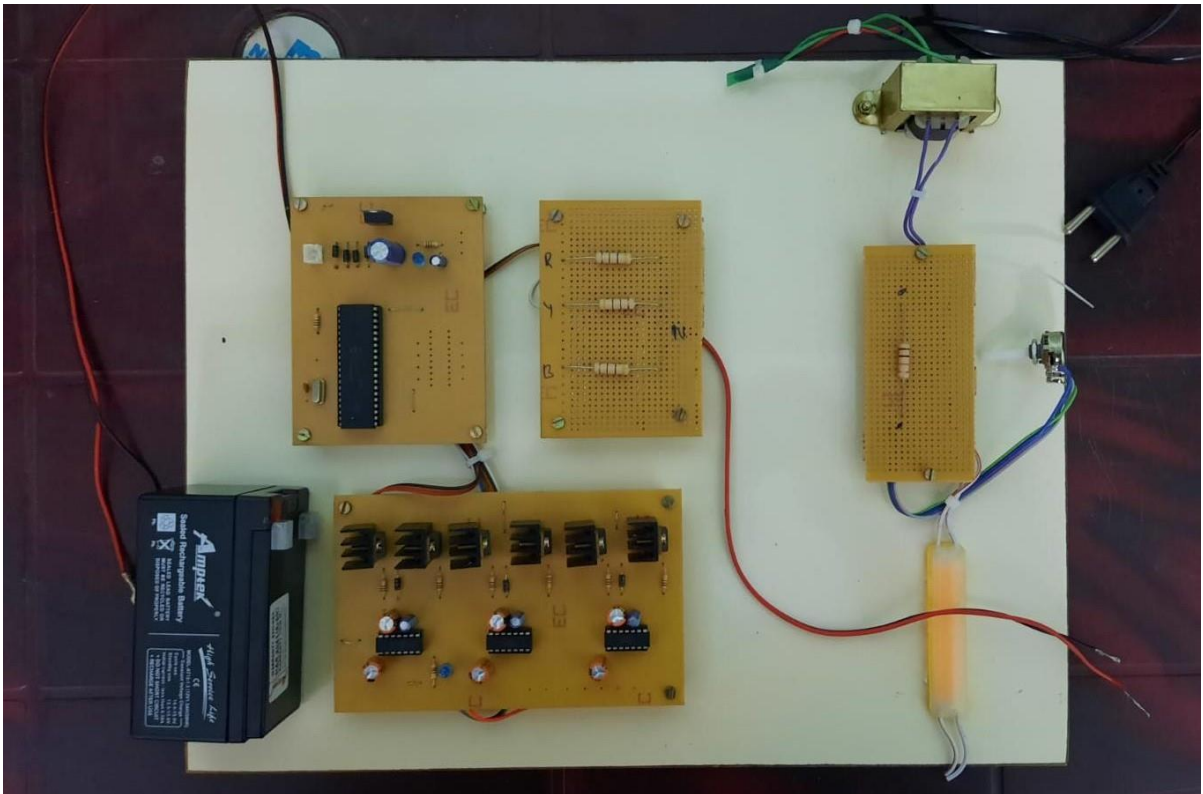


Fig 4.22: PROTOTYPE

Working of Prototype:

- A DC source (12V battery) is connected to the circuit on the left side
- The battery source helps to power the microcontroller and the crystal oscillator
- The crystal oscillator helps to generate stable clock signals or pulse width modulation signals in the form of sine wave
- The sine wave is then amplified using a driver circuit (the driver circuit used here includes MOSFET, diodes, transistor, etc.)
- The artificial three-phase load formed is given to the grid
- On the right side which is considered to be the grid, the voltage is taken from a three-phase load of 230V and converted to 12V using a step-down transformer
- This 12V is then passed through a load resistor of 50ohm, and the LED connected on the other end of the resistor gets turned ON.
- The artificial load is connected to the load resistor as a parallel connection.
- When this load is also added to the grid, the LED glows brighter thus stabilizing the power given to the grid.

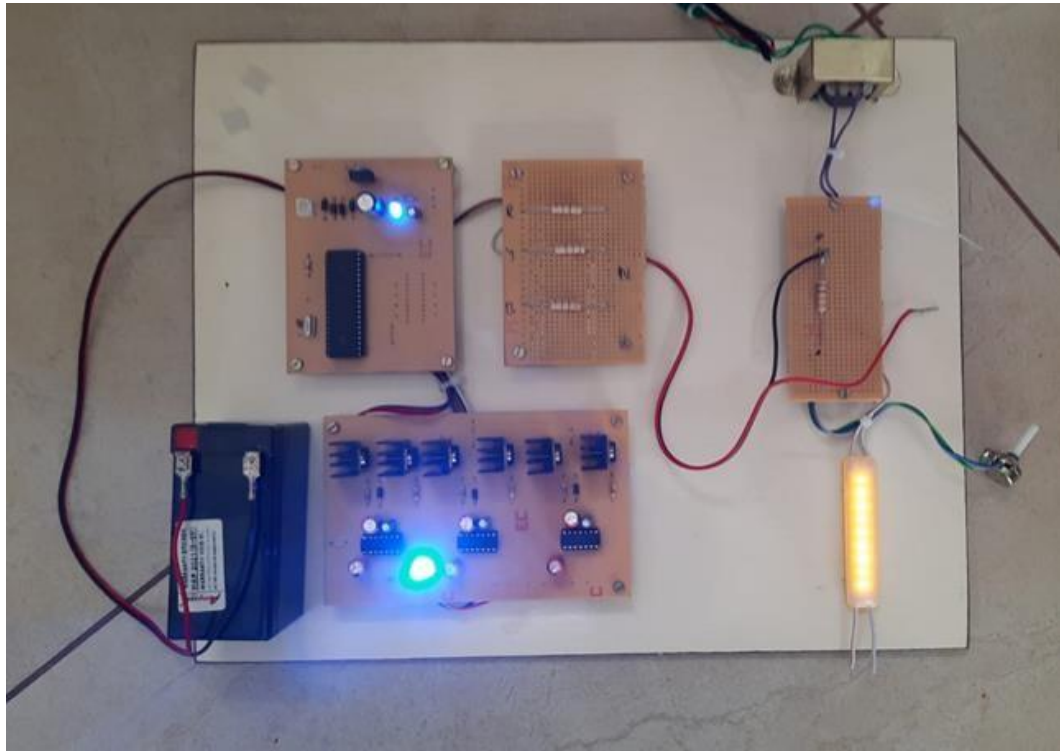


Fig 4.23: Without STATCOM connection

In the above-shown diagram, the STATCOM part is not connected to the grid, so the only power in the system is the one taken from the grid at 240v and then converted to 12v using the step-down transformer in the circuit. The voltage regulator connected with the transmission line helps reduce the voltage given to the LED, otherwise, the LED would glow at maximum capacity.

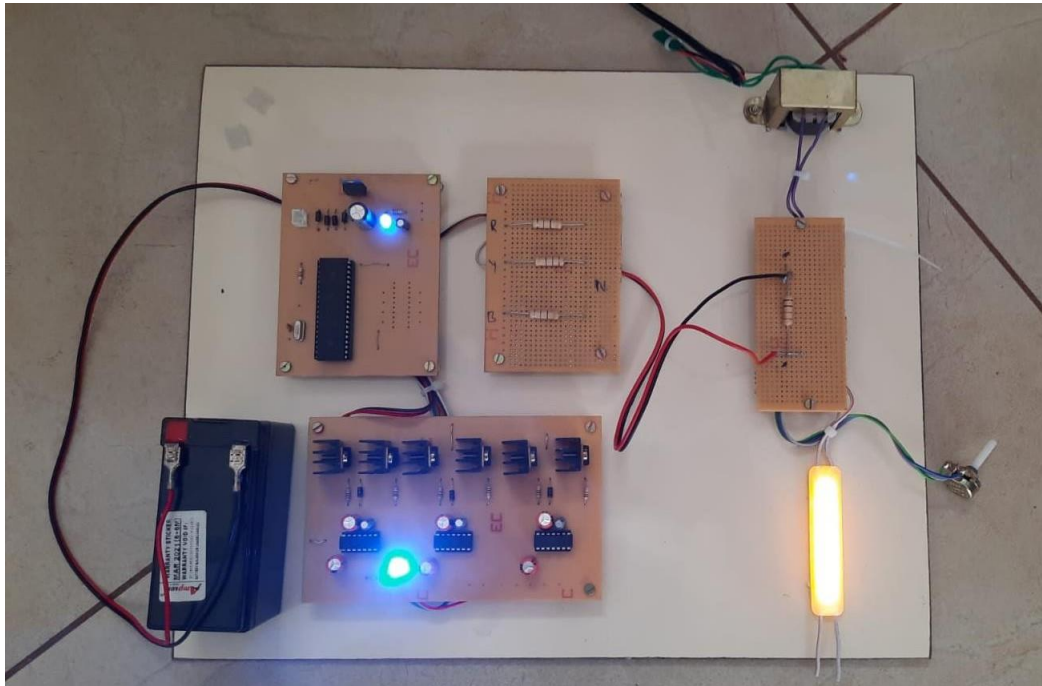


Fig 4.24: With STATCOM connection

The STATCOM part of the system is connected to the grid through the resistive load to the transmission line, the LED then glows brighter when the power from the STATCOM is added to the grid to rectify the harmonics created by the grid to some capacity.



Fig 4.25: Hardware Output

A compensated variable voltage of approximately 7.7V can be measured through the multi-meter that is connected on either side of the transmission line.

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY:

STATCOM is used to reduce the harmonics in the grid. The given prototype stabilizes the grid when the artificial load is connected to the grid generated by using a PWM generator and amplified using an optocoupler and then given to the grid.

5.2 CONCLUSIONS:

A SEIG requires capacitive VAR for excitation, which can be given by a combination of fixed shunt capacitance and a STATCOM. The proposed control scheme's transient performance during a load and wind speed transient is compared to that of existing control methods described in the literature. The proposed control technique improves the WECS's transient performance (in terms of terminal voltage and frequency deviation) as compared to conventional controllers. When the WECS is connected to nonlinear loads, particularly single-phase nonlinear loads, the performance of the state feedback controller diminishes. An indirect harmonic compensation approach, in combination with state feedback control, is proposed to ensure the WECS's reliable performance while supplying single and three-phase nonlinear loads. The scheme is designed without sensing the load currents which enhance the system reliability and reduces cost. The control performance is tested with both single-phase and three-phase nonlinear loads. The scheme is created without the use of load current sensors, which improves system reliability and lowers costs. Both single-phase and three-phase nonlinear loads are used to test the control performance.

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