B. TECH PROJECT REPORT

On

Single Phase Smart PV Inverter

BY

Divyanshu Arya
Dipankar S Shrivastava

DISCIPLINE OF ELECTRICAL ENGINEERING

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Single Phase Smart PV Inverter

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degrees

of
BACHELOR OF TECHNOLOGY
in

ELECTRICAL ENGINEERING

Submitted by:
Divyanshu Arya
Dipankar S Shrivastava

Guided by:
Dr. Amod C Umarikar,
Associate Professor,
Electrical Engineering,
IIT Indore

INDIAN INSTITUTE OF TECHNOLOGY INDORE
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CANDIDATE'S DECLARATION

We hereby declare that the project entitled **"Single Phase Smart PV Inverter"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'ELECTRICAL ENGINEERING' completed under the supervision of **Dr. Amod C Umarikar, Associate Professor, Discipline of Electrical Engineering,** IIT Indore is an authentic work.
Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

Signed:

Divyanshu Arya	Dipankar S Shrivastava
(160002015)	(160004013)
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CERTIFICATE

This is to certify that the B.Tech Project entitled, "**Single Phase Smart PV Inverter**" and submitted by Divyanshu Arya and Dipankar S Shrivastava in partial fulfillment of the requirements of B.Tech Project embodies the work done by them under my supervision.

Dr. Amod C Umarikar,
Associate Professor,
Discipline of Electrical Engineering,
IIT Indore

Preface

This report on “Single Phase Smart PV Inverter” is prepared under the guidance of Dr. Amod C Umarikar.

Through this report, we have tried to give the design for a Single-Phase Grid Connected Photovoltaic Inverter and then simulate the operation by connecting the inverter to a grid carrying 230V AC.

We have explained the various control strategies in detail, their mathematical operations, block diagrams and actual implementations made in PSCAD software. In the end, we have displayed the output of the inverter at various stages in form of output waveforms.

Divyanshu Arya, Dipankar S Shrivastava
B.Tech. IV Year
Discipline of Electrical Engineering
IIT Indore

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Divyanshu Arya, Dipankar S Shrivastava
B.Tech. IV Year
Discipline of Electrical Engineering
IIT Indore

Abstract

This report discusses the design of a Single-Phase Grid Connected Photovoltaic Inverter and the control strategies used in the design. Solar energy is an excellent source of renewable energy, but the systems need to be efficient in conversion and control of solar energy.

To optimize the voltage and current of PV Panels, Maximum Power Point Tracking (MPPT) algorithm is used to obtain reference voltage for operation of panels (Voltage Controller). This is then used to calculate reference current and fed to current controller, which provides the Modulation Index to PWM Module which controls the firing of IGBTs in the full-bridge configuration inverter.

The voltage generated by the inverter needs to be in synchronization with the grid voltage. In order to achieve this, Phase Locked Loop (PLL) system is used, which gives the phase of the grid to control system which matches it, in order to establish synchronization between inverter and grid.

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Chapter 1

Introduction

1.1 Background

- Solar energy is the energy received from the thermo-nuclear fission reactions happening in the core of the sun. This energy is predominantly used by the plants for photosynthesis but due to the realization of its huge potential during the twentieth century, nations are now aggressively developing technology to harness it into electrical energy.

- It is unarguably a crucial source of renewable energy, however converting it to electrical energy comes with its own sets of challenges. There are two types of techniques namely, Active Solar Techniques and Passive Solar Techniques. The former includes use of technological devices such as Photovoltaic Systems, Piezo-electric crystals which go under thermal stress due to sunlight and hence causing deformation in the lattice and hence producing electricity. Passive Solar Techniques include constructing buildings so that they face the sun.

- The large amount of solar energy available makes it an immensely popular source of electricity. Around 30% of the received solar energy is reflected back to space while the rest is absorbed by clouds, oceans and land.

- Grid connected PV Systems have gained popularity in recent times and so has the need to make it more efficient and robust. With India aiming to produce 90 Gigawatts by the year 2022, it is necessary to design a system suitable for these requirements.

1.2 Motivation

2 Solar energy has contributed towards reducing the greenhouse effect and global waming.

3 The use of solar power is not harmful to the planet, at the same time being cost effective.

4 Power form a PV inverter can be stored in batteries or supplied onto the grid, we have considered the latter.

5 Grid connected PV inverter systems are very helpful in reduction of consumption of power generated by traditional methods (Thermal Power etc), while reducing the monthly bills as well.

6 Solar inverters and predominantly the multifunctional ones are the ones with the highest throughput. They convert DC to AC which requires the least amount of later-on conditioning.

7 Solar Inverters are much more cost-effective then generators as they produce energy free of cost and become free eventually as the running cost is zero.

1.3 Overall Objective

- Synthesize a solar inverter which converts the solar energy to AC energy, along with appropriate circuitry for filtering and conditioning of the generated AC energy.

- Propose a control strategy for maximum power extraction from the solar inverter while maintaining the voltage at the grid.

1.4 Software Used

- PSCAD
- Simulink

Chapter 2

Preliminary Concepts

2.1 Solar Cell

A photovoltaic cell or simply put a solar cell is a conglomerate of cells which generate free electrons by the incident light of appropriate frequency (the frequency of the incident light should be equal or more than the threshold frequency for the phenomenon to occur). The potential difference generated per cell is generally in the range of 0.5 to 0.7 volts. Using a bus configuration provides the same effect as using a battery. When put in series the potential differences add up producing the desired output-voltage. Also for reliability people can use a parallel configuration as well.

Photovoltaic cells irrespective of the source of energy (whether natural i.e. sun or artificial) are always termed as solar cells. Besides using them for energy generation they are also used as Light detectors. An application could be to produce a moving escalator which automatically detects when a person is about to step depending whether there is an incident light on the detector.

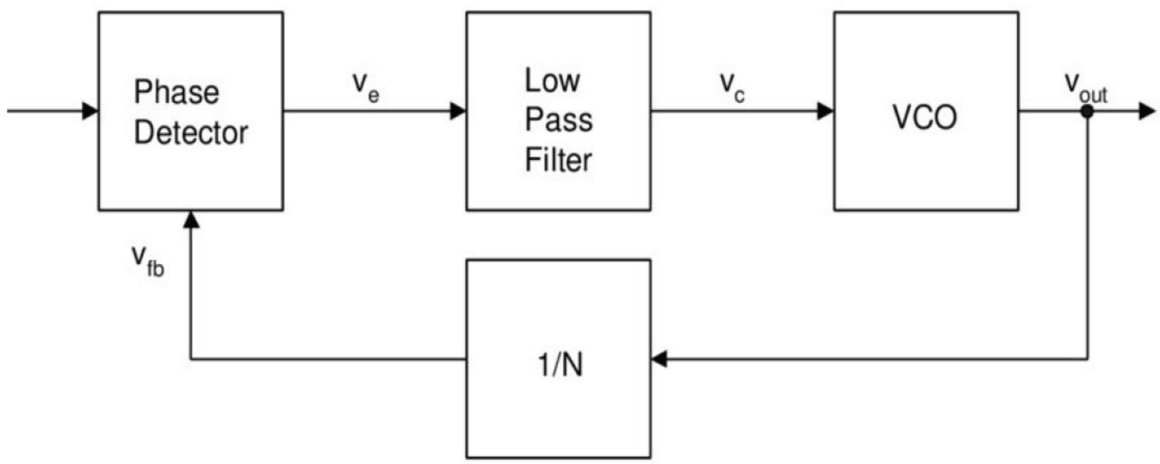
The working of a photovoltaic cell depends on these basic criteria:

- The basic requirement is of a source of light being incident on the photovoltaic cell
- The frequency of incident light should be greater than the threshold frequency of the material.
- The amount of power generated by the photovoltaic cell depends on external factors such as:
    - Ambient temperature
    - Solar Irradiation
    - Relative humidity

2.2 Inverter

An inverter is a circuit which converts a DC power into an AC power at desired output voltage and frequency. The AC output voltage could be fixed or variable voltage and if we wish to connect the solar (PV) inverters to the grid, we need to make sure that the voltage produced by the inverter is in synchronization with the grid it is being connected to. This is achieved by the use of PLL.The figure below shows a generalised diagram for a PLL.

Figure 2.1: Generalised PLL Block Diagram



- In order to implement PLL, we need signal in the α-β form, which is achieved using Clarke Transformation. In our case, we don't need a frequency divider as for our purpose N is 1. We use a circuit implementation of Clarke-Park Transform to be used as a Phase Detector.
- The purpose of Low Pass Filter is to supply a clean DC voltage to the VCO which would then produce the signal with the required frequency. An input with ripples to the VCO would destabilise the output, hence the functioning of the Low Pass Filter is very essential.
- A VCO (which stands for Voltage Controlled Oscillator) is a circuit which produces a signal with a frequency proportional to the input voltage.

  The phase detector internally implements a simple dq transform. Dq transform changes the frame of reference which converts AC to DC as the frame of reference rotates with the same frequency as the AC signal. The transformation procedure is shown:

Figure 2.2: Clarke Transform

$$\begin{bmatrix} U_\alpha \\ U_\beta \end{bmatrix} = U \begin{bmatrix} \cos(\omega t + \theta_0) \\ -\sin(\omega t + \theta_0) \end{bmatrix}$$

Figure 2.3: Clarke-Park Transform

$$\begin{bmatrix} U_{d1} \\ U_{q1} \end{bmatrix} = \begin{pmatrix} \cos(\theta_{pll}) & \sin(\theta_{pll}) \\ -\sin(\theta_{pll}) & \cos(\theta_{pll}) \end{pmatrix} \begin{bmatrix} U_{a1} \\ U_{b1} \end{bmatrix}$$

The final circuit and its implementation on PSCAD is shown:

Figure 2.4: PLL for System

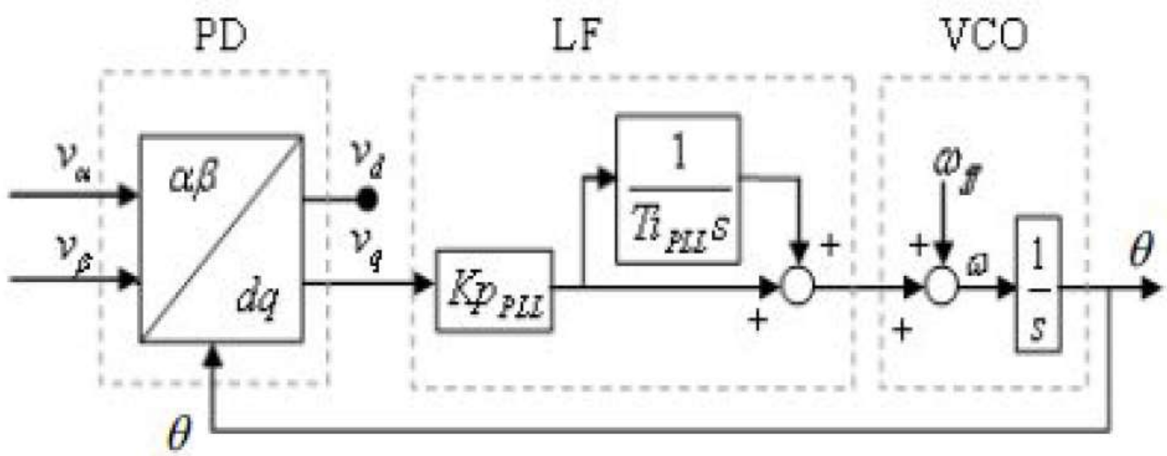
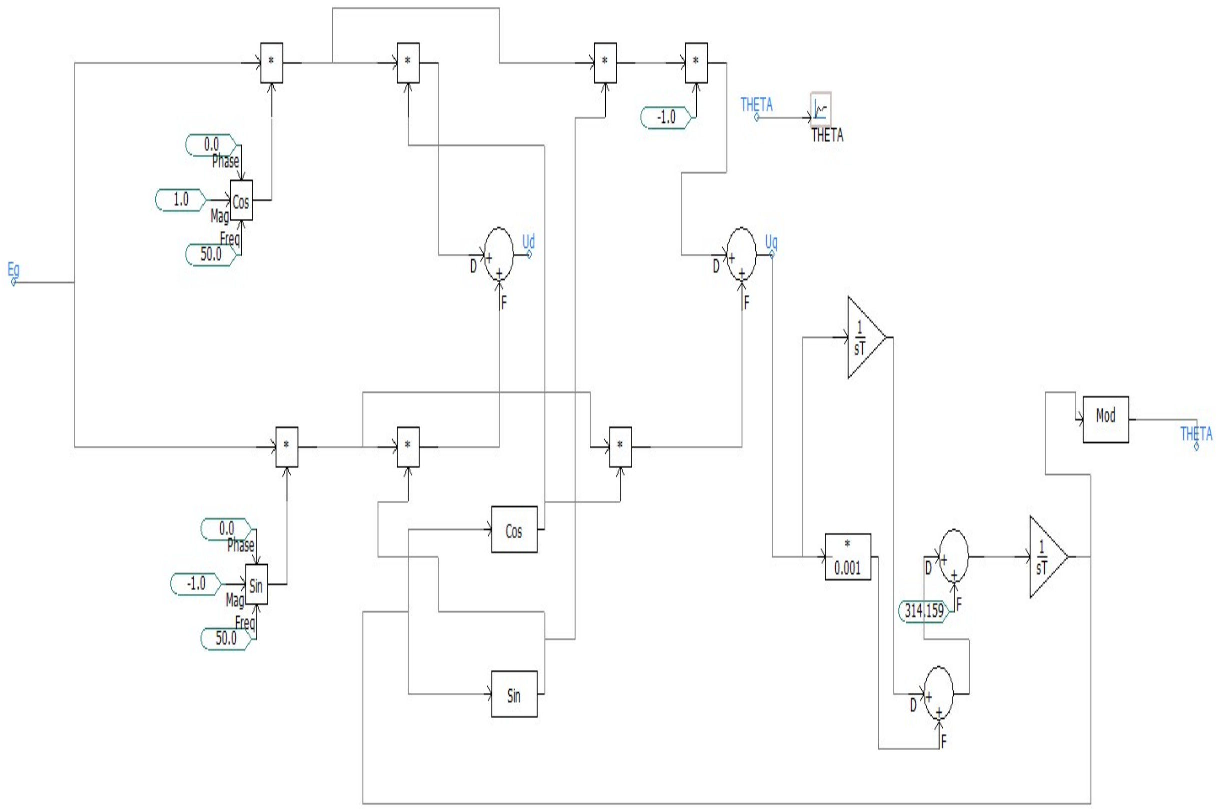


Figure 2.5: PLL Circuit designed in PSCAD



Chapter 3

Control Strategy

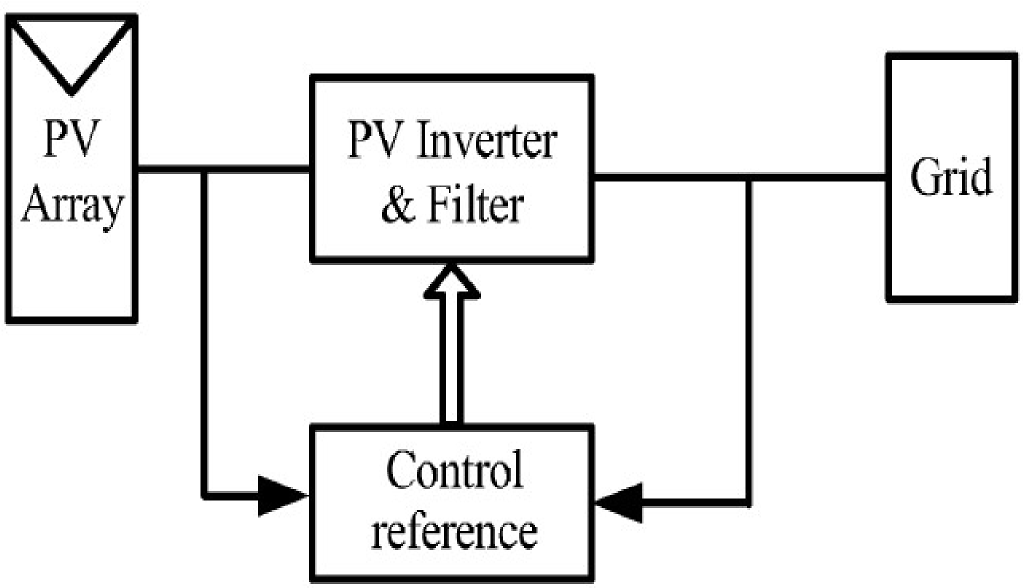
3.1 Classification of Components

All the components of the circuit can be classified into 4 categories which are:

1. PV Array
2. PV Inverter and Filtering Circuit
3. Grid
4. Control Strategy implementation

A figure for the same is shown below:

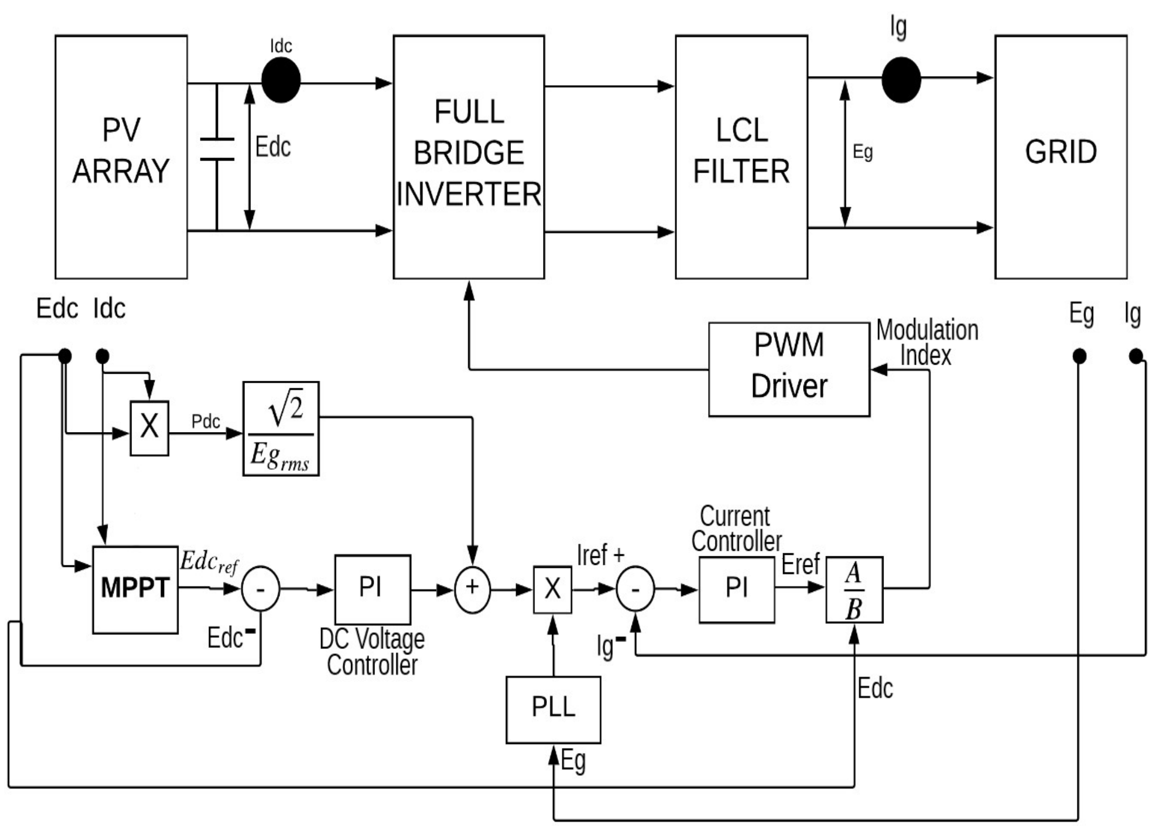
Figure 3.1: Components of PV Inverter



As we can see, PV Array converts the solar energy to electrical energy in the form of a DC voltage. The PV Inverter then converts it to a sinusoidal voltage which is then conditioned by the LCL filter. This voltage is fed to the Grid. The function of the Control Reference is to sense the voltage and current being supplied from the PV Array followed by sensing the same being received by the Grid. It then makes appropriate corrections so as to draw maximum power from the PV Array while maintaining 230V RMS, 50Hz at the Grid.

3.2 Complete System for Single Phase Grid Connected PV Inverter along with Control Strategy

Figure 3.2: Block Diagram of the PV Inverter

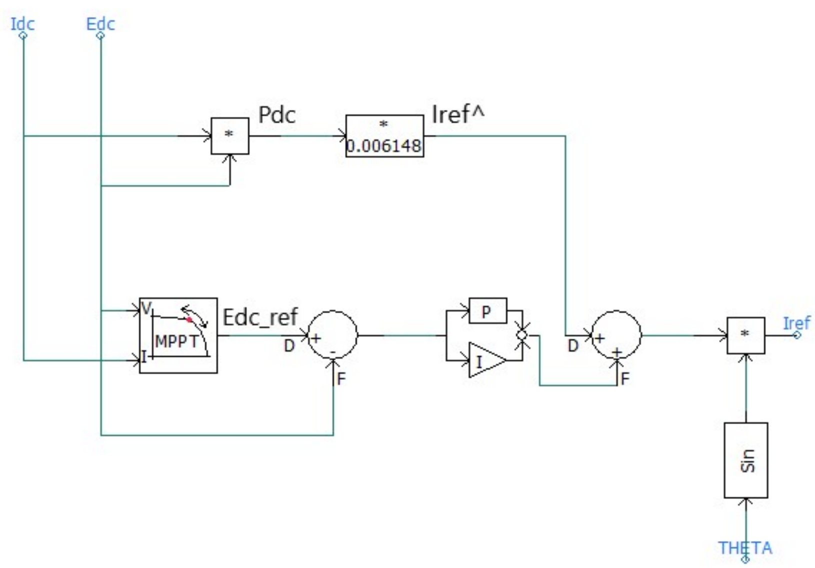


3.2 Complete System for Single Phase Grid Connected PV Inverter along with Control Strategy

- Internally the PV array produces DC voltage which is filtered by a capacitor for removing harmonics.
- Then the Inverter converts it to AC voltage which again is filtered by a 3rd order LCL filter from here on the cleaned AC voltage is supplied to the grid.
- The function of the Controlling Circuit is to “see” what the PV array is supplying, what the grid is getting and then after taking these parameters into consideration it should drive the inverter.

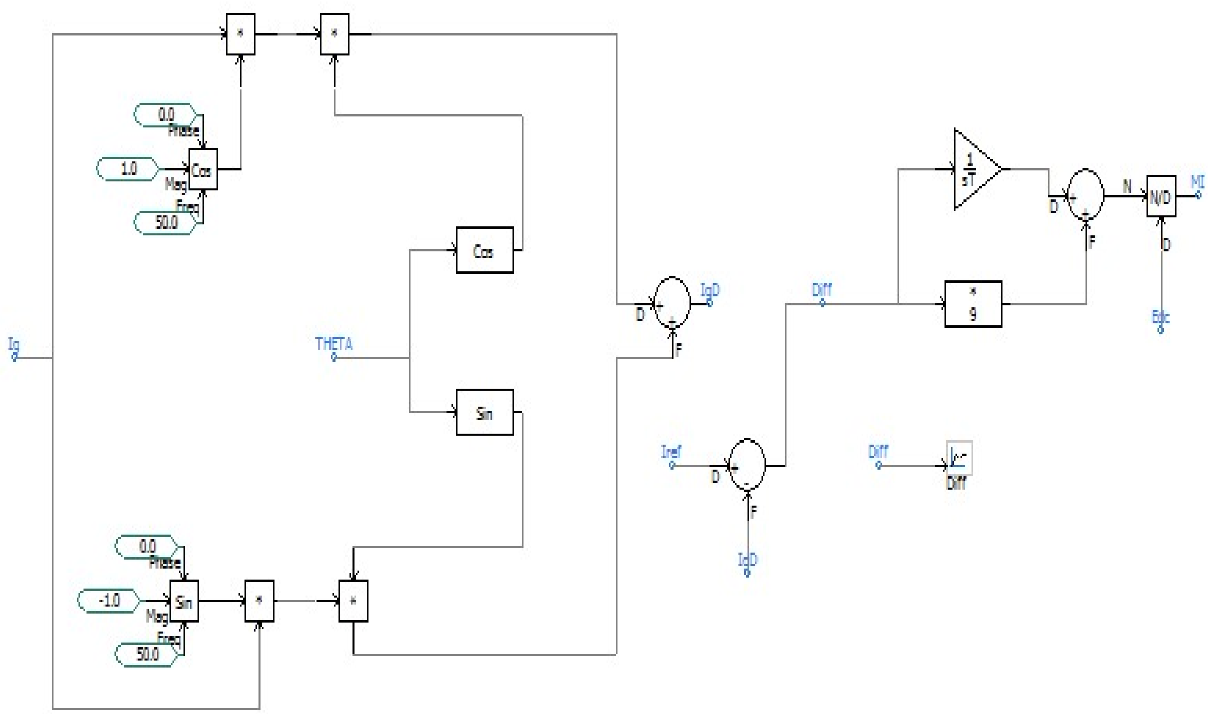
The process starts by MPPT sensing the voltage and current supplied by the PV array. The algorithm used by MPPT is Incremental Conductance Algorithm. The output of MPPT is the reference voltage at which maximum power gets transferred from the PV Array. This reference voltage is then compared with the current voltage across the PV panels and then an error signal is generated. After this, a voltage controller is used to obtain the requisite current. The figure for this process is shown:

Figure 3.3: MPPT & Voltage Controller Circuit designed in PSCAD



We know that the amount of power generated by the grid is equal to the power generated by the Inverter. So, we compute the reference current using the Power supplied by the PV Array and the RMS voltage at the grid. This reference current is then added to the one obtained from the voltage controller which gives us the Reference Current Amplitude. Now to synchronise it with grid we used a PLL whose sine value was multiplied to get the final Reference Current. . This is sent in a Current Controller as shown:

Figure 3.4: Current Controller Circuit designed in PSCAD



The Current Controller gives the reference voltage which is compared with the DC voltage across the PV Array to give the Modulation Index given to the comparator to drive the Inverter.

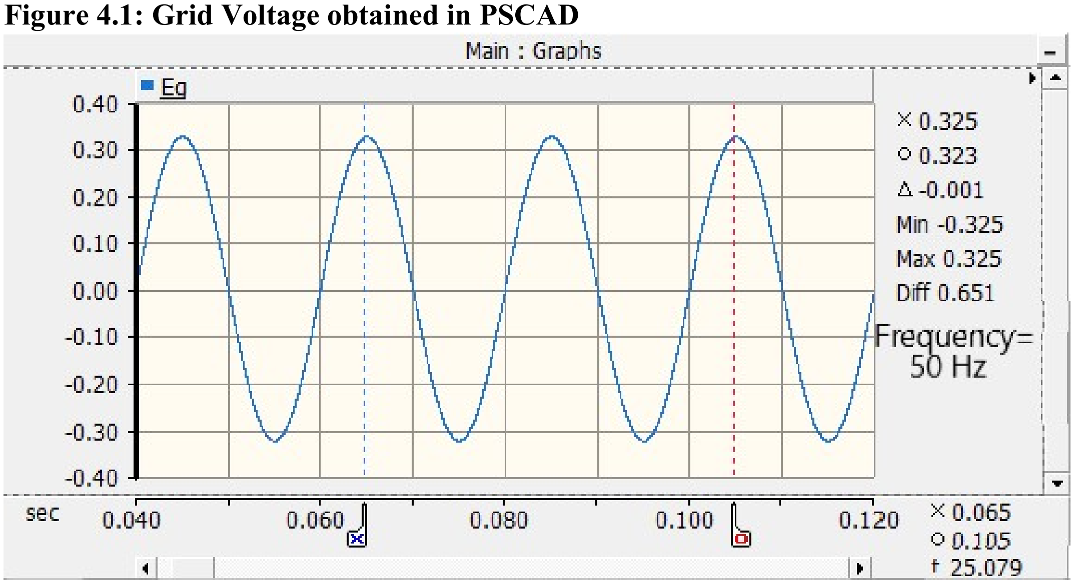
Chapter 4

Results

4.1 Grid Voltage

The figure below shows the voltage received by the Grid, As can be clearly seen the frequency is 50Hz with 230V RMS.

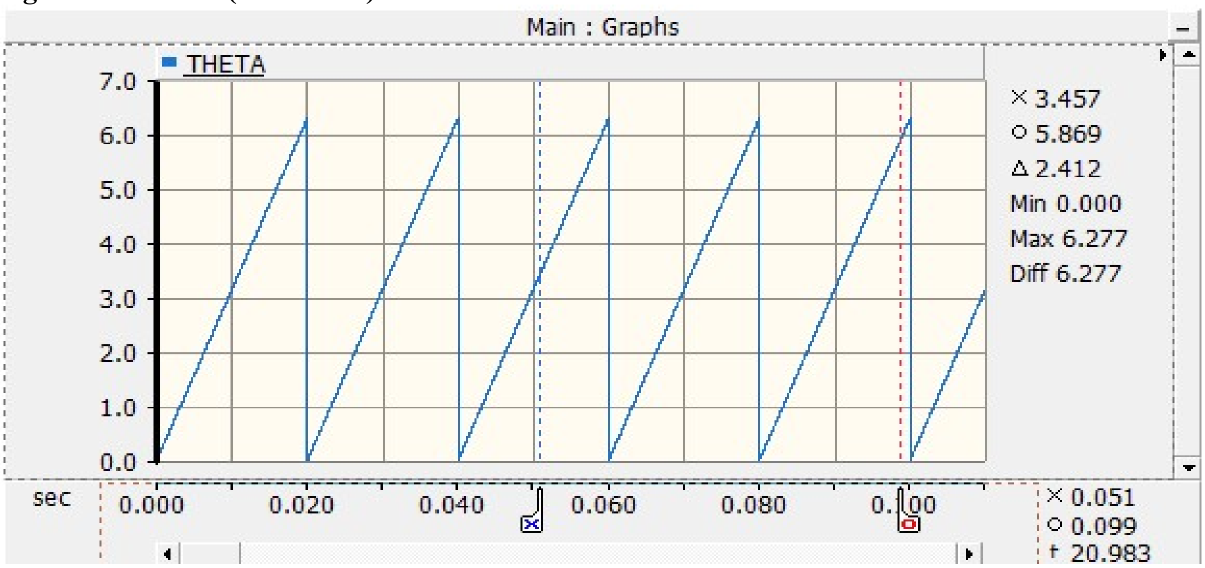
Figure 4.1: Grid Voltage obtained in PSCAD



4.2 Theta Obtained from PLL

As can be seen the peak value is twice of pi and the time period is 0.02 seconds which translates to 50Hz frequency hence achieving Grid synchronization.

Figure 4.2: Theta (from PLL) obtained in PSCAD



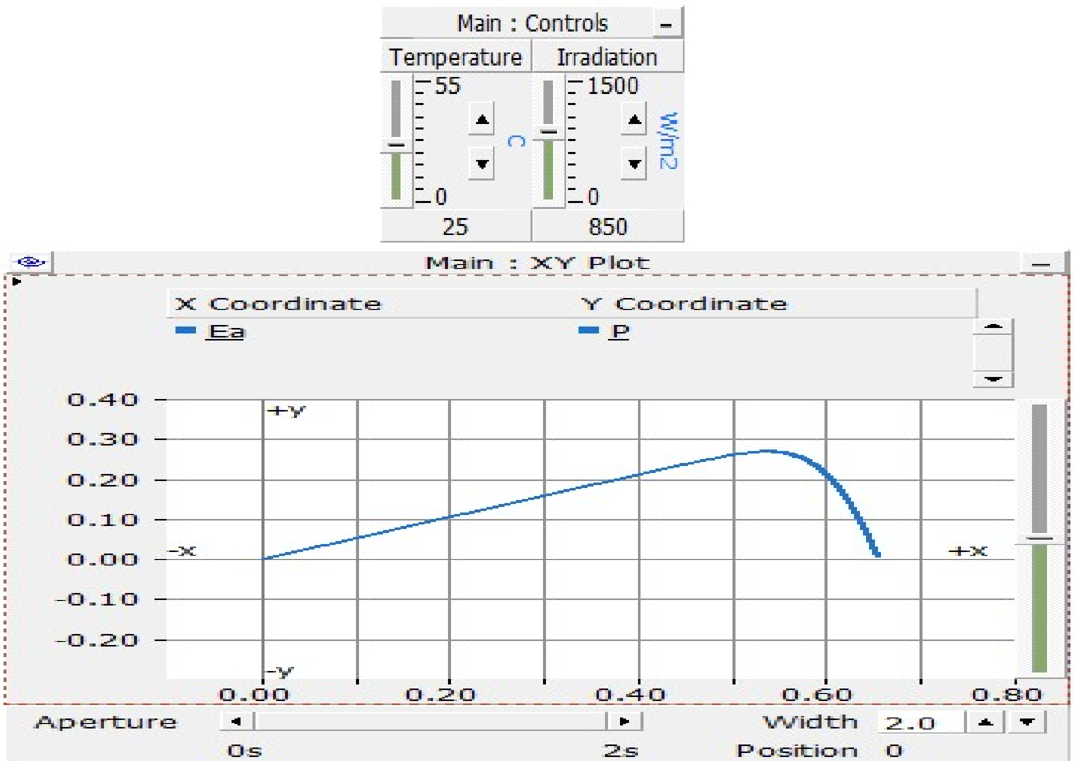
4.3 MPPT & Power Transfer in the System

4.3.1 Case 1:

Ambient Temperature = 25ºC   Solar Irradience = 850 W/m^2

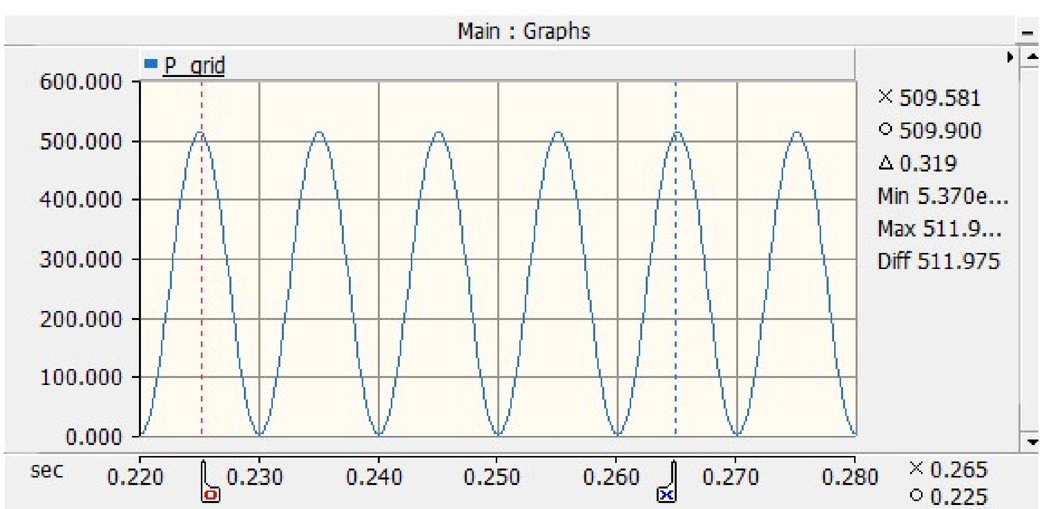
Maximum Power from PV Panel possible (MPPT) = 0.2668 kW

Figure 4.3: PV conditions & MPPT (Case 1) in PSCAD



Power Curve on the output side: (We can see the PEAK power is twice of the power transferred from the input side) .**Here, Pmax = 0.511 kW**

Figure 4.4: Power Output (Case 1) obtained in PSCAD

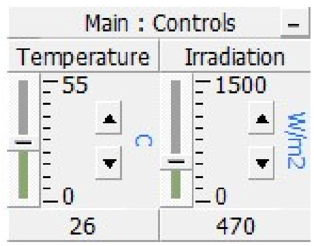


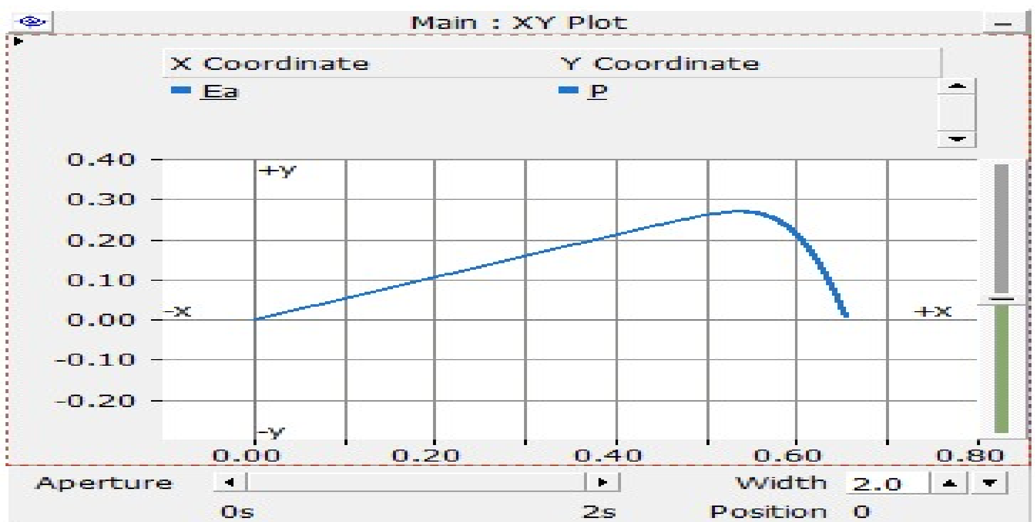
4.3.2 Case 2:

Ambient Temperature = 26ºC   Solar Irradience = 470 W/m^2

Maximum Power from PV Panel possible (MPPT) = 0.1507 kW

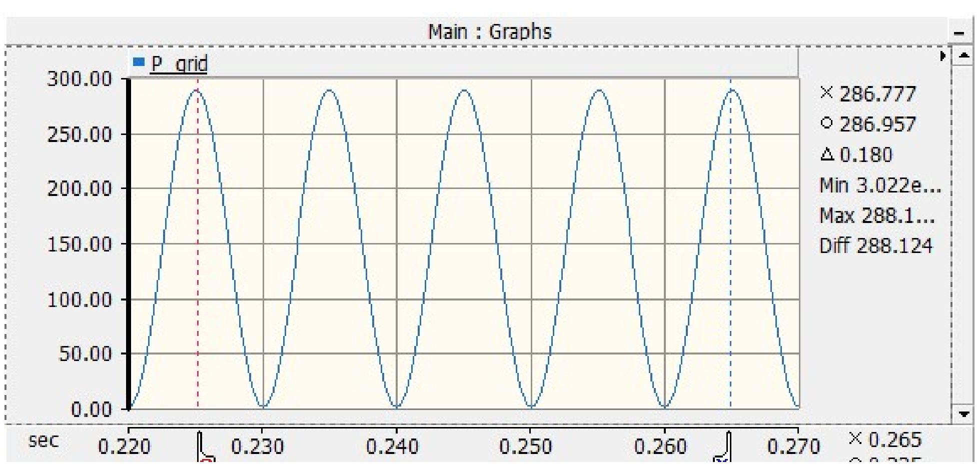
Figure 4.5: PV conditions & MPPT (Case 2) in PSCAD





Power Curve on the output side: (We can see the PEAK power is twice of the power transferred from the input side) .**Here, Pmax = 0.288 kW**

Figure 4.6: Power Output (Case 2) obtained in PSCAD



Chapter 5

Conclusions and Future Scope

- We can conclude that the circuit obtained is capable of grid connectivity and extracting maximum power from the photovoltaic arrays under varying conditions (Temperature and Irradiation).

- The power obtained at the grid corresponds to the power output obtained by the MPPT Plot, showing the proper functioning of MPPT.

- Output of the PLL (Theta) shows proper sensing of the phase of the grid, ensuring synchronization between inverter and grid.

- Smart Functionalities can be added to the inverter in the future. Some of the smart features are:

    - Low Voltage Ride Through (LVRT): This feature keeps the inverter connected to the grid (for short durations) in case of faults on the grid.

    - Constant Power Generation (CPG): This feature enables us to set a maximum limit of power that can be generated by the inverter, as the inverter shouldn't be run at maximum capacity for prolonged periods.

    - VAR Operation at Nights: During the night, when solar irradiance is zero, there is no active power available to supply to the grid. But, the inverter can supply reactive power to the grid at this time, which can be used to stabilize the grid voltage.

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