COMPUTER AIDED DESIGN FOR A PV SYSTEM AND INVESTIGATION OF 3 PHASE THYRISTOR CONVERTER

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# BACKGROUND STUDY

## PV System and Principle of operation

A photovoltaic cell converts energy from the sunlight into electricity. The radiation from the sun is made up of tiny particles of energy called photons. As these photons impact on the cell, some of them are absorbed into the cell. The energy from the photons on impact causes electrons to be free [2]. The movement of the free electrons is what generates electricity.

A PV system is made up of a combination of many cells. Since a PV module is made up of cells combined in series and parallel, the equivalent circuit can obtained by first doing an analysis on a single cell. The equivalent circuit for a PV cell is given below

[1]

Figure : Equivalent Circuit of PV cell

RL

D

Rsh

Rs

Isc

V

Ish

ID

The circuit comprises of a Current source which delivers short circuit current ISC , A shunt diode connected across the current source with current ID  representing diffusion current across the P-n junction and internal series and parallel resistances RS and RSH respectively

Mathematical Representation

Using Shockley’s diode equation



[1]

Where Is is reverse saturation current, q is charge of one electron, Tc is the cell temperature in Kelvin, V is output voltage, A is junction power factor which determines diode deviation from ideal p-n junction



The photocurrent Isc is given by [1]

Where Tr is the reference temperature, ISCR is the short circuit current at reference temperature, ki is temperature coefficient and G is irradiance in mW/cm2.

Reverse saturation current is given by

From figure 1 the cell current can be expressed as



## Boost converter

A boost converter is a DC/DC switching converter which is normally used where a higher output voltage then what is supplied by the source is needed by the load [3]. The efficiency of the boost converter is usually very high [3]. A typical boost converter circuit is shown in figure (2) below.

[3]

Figure : Boost Converter

Vin

L

D

Co

Vout

When switch is on voltage applied to inductor is

This can also be written as

Where K and Tpare duty ratio and switching period respectively. [1]

When switch is OFF,

For the inductor, the rise in current is equal to the fall in current therefore

Di= [1]

## Brief discription of a thyristor

A thyristor is a switching semi conductor device that is unidirectional, that is to say it can only conduct in a single direction [7]. It is also referred to a silicon controlled rectifier whose principle of operation could be described using the circuit below

[6]

Figure : Symbol and Schematic diagram of thyristor

**TX1**

**P**

**N**

**P**

**N**

**P**

**N**

**TX2**

TX2

TX1

**P**

**N**

Cathode

Anode

Anode

Cathode

Gate

Gate

The physical and schematic diagrams of thyristor are shown Figure 1a and 1b respectively.. It can be seen that a thyristor is basically a combination of PNP and NPN bipolar transistors. To make the thyristor conduct a voltage is applied at the gate which turns on the NPN transistor which in turn makes the PNP to start conducting. Once both transistors are ON, they remain ON until turned OFF. The thyristor could also be turned ON by applying sufficient voltage between the anode and cathode to make one of the transistors break down and begin to conduct. Once one of the internal transistors starts conducting there would be sufficient amount of base current at the second transistor to make it conduct .[6]

The thyristor can turn off by reducing the current flowing in the internal transistors until one of them stops conducting. This can be achieved by applying a negative voltage to the gate [6].

## 3 phase thyristor rectifier

Due the mode of operation and behaviour as described earlier, thyristors are used in 3 phase rectified circuits. This type of rectifier using thyristors is referred to as line commutated controlled rectifier. An example of a 3 phase thyristor converter is shown below.

[4]

Figure :Three phase thyristor rectifier

T6

T5

T4

T3

T2

T1

**Id**

**Va**

**Vb**

**Vc**

n

**ic**

**ib**

**ia**

**Vd**

The 3 phase rectifier shown in figure (4) above has 6 thyristors connected in two groups of 3 each. The first group has a common cathode connection and the second group have a common anode connection. The thyristors are fired at an interval of 1200. The firing sequence for the thyristors is 16,62,24,43,35 and 51.Each thyristor is fired after 600 of the previous thyristor being fired. This means at point (because it is 3 phase starting point is not ) T1 is triggered while T5 is still conducting and between 600 and 1200 both T1 and T5 would conduct together and the line to line voltage Vab=Van – Vbn would appear across the load. At 1800 thyristor T6 is fired and thyristor T5 is reversed biased thereby switching off. At 2400 T2 is triggered and T1 is switched off. The process continues for the rest of the sequence with the triggering action of one thyristor switching off the previous thyristor.[4]

## PI Controller

A PI controller is a combination of a proportional controller and integral controller. By combining both controllers, the setbacks in one is corrected by the other. For example a proportional controller has non zero steady state error while a proportional integrator forces the steady state error to zero by accumulating all the errors

# PART A

## AIMS AND OBJECTIVES

To be able to understand and implement the construction of a PV system with control scheme using simulink in mat lab. To know how the different blocks that make up the PV system can be constructed separately and connected together to make a complete PV system.

To understand how simulink tool boxes can be used in implementing a dc to dc converter that is used to control a PV system.

## RESULTS AND DISCUSSION

### Boost converter model

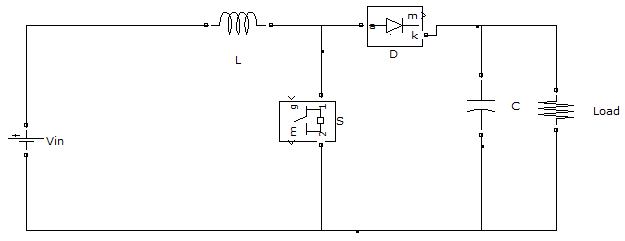
****[8]

Figure : Model of Boost Converter

The figure (4) shows a boost converter model made up of an input Dc source, an inductor at the input to keep the current steady and reduce current ripples, a Mosfet switch, a capacitor at the output to keep the voltage steady and reduce voltage ripples and a resistive load .

### A dynamic PWM generator

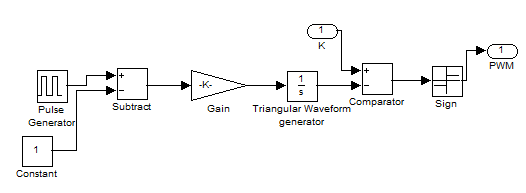
[8]

Figure :PWM generator

Figure (5) above shows the PWM generator that has been created by a combination of various function blocks. The PWM is made up a of a pulse generator for input pulses of amplitude 2. In other to get desired amplitude of 1 and -1 for the pulse with to be generated, a constant block is added and together with pulse generator fed into the input of a subtractor. The output from the subtractor is amplified by a gain of 50e-6 and this is fed into an integrator to obtain a triangular waveform. The triangular waveform at the output of the integrator is compared to a constant duty ratio of 0.5. The results of the comparison is square wave which is positive when the triangular wave is less than the duty ratio an negative when the triangular wave is greater than the constant duty ratio as illustrated in the figure (6) below.

Figure :PWM

### Subsystem

A subsystem is used to make a model more compact. The PWM generator in figure (5) is converted into a subsystem as shown in figure (7)

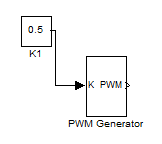
[8]

Figure : Sub System for PWM generator



Figure : Waveform of PWM generator

As can be seen from figure (8) the entire PWM generator system has been converted to a single box. Figure (9) shows the pulse width waveform at the output of the signal generator

Connecting the PWM generator model to the previously designed Boost converter gives the model shown in figure (10).2 oscilloscopes have been added to measure the output voltage response across the load and the current response in the inductor.

These measurements are plotted using the “to file” block component which saves the responses as vector variables under a file name.

Figure (10) shows the load voltage of the boost converter. It can be observed that the voltage has ripples and the magnitude is increased. The increase in voltage magnitude is due to the converter being a step up (boost) converter.

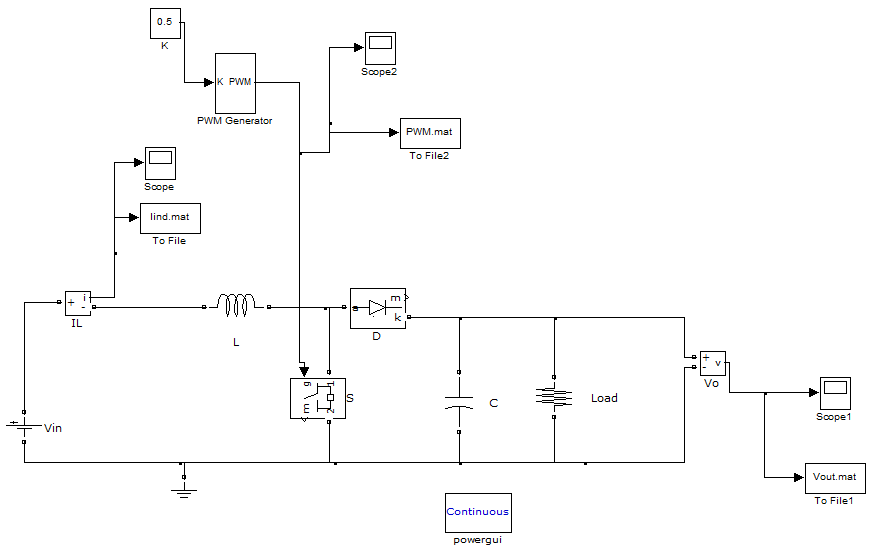
[8]

Figure : Boost Converter with PWM generator



Figure : PV voltage of Boost Converter



Figure :Amount of ripple



Figure : Inductor current of boost converter

### S function for pv model

The S-function processes input signals as states and generate outputs from these signals. Both the input and output signals are in vector form. The S-function is made of several call functions which are used by simulink during simulation.

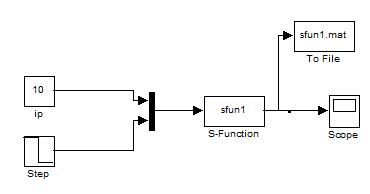
[8]

Figure : S function

Figure (14) above shows how an S function is integrated into a model. The S- function block is obtained from user defined functions in the simulink library. The name of the block is then changed to the same name that the S-function code was saved in, for this case it is named sfun1.

Two inputs are fed into the S-function block. The first is from a constant block of magnitude 10 and the second from a step block which changes from 0.5 to -0.5 in 0.025 seconds. The S-function block then computes the product of these two inputs at every time interval. The response is shown in figure (14)



Figure : S -function outputwit step and constant block inputs

It can be observed that the response changes from 5 to -5 in 0.025 seconds. This is because

When the step input is 0.5, the S-function computes the output as 0.5 X 10 = 5. And the amplitude remains 5 until the step input changes to -0.5, then the output becomes -0.5 X 10 = -5.

### Implementing s-function block in pv-model

The PV simulation code is put in the S-function code. The S-function is then implemented in PV\_model as shown in figure 16.

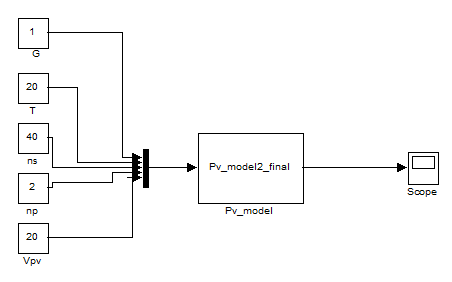
[8]

Figure : PV Model Implementation in simulink



Figure : Current plot for PV model

Figure (17) above shows the current plot for the PV model. The plot is a straight line because the current is from a constant source.



Figure : I-V Characteristic of a PV Array

Comparing current plot of the PV model and I-V characteristic of PV array, it can be seen that at a voltage of values are approximately equal.

Table : Relationship between Irridiation and Current

|  |  |
| --- | --- |
| Irradiation G (kw/m2) | Current (A) |
| 1 | 5.75 |
| 0.8 | 4.46 |
| 0.6 | 3.16 |
| 0.4 | 1.89 |

From table 1 above it can be observed that irradiance has a significant effect on the PV current. A slight decrease in the irradiation would lead to a large drop in current. For maximum current, maximum irradiation would be needed.

Table : Relationship between Temperature and current

|  |  |
| --- | --- |
| Temperature (0C) | Current (A) |
| 18 | 5.76 |
| 19 | 5.78 |
| 20 | 5.75 |
| 21 | 5.68 |
| 22 | 5.58 |

From table 2 it can be observed that the temperature is inversely proportional to the PV current supplied. But the effect of temperature change on current is not as significant as in the case of irradiation.

Table : Relationship between Voltage and Current

|  |  |
| --- | --- |
| Voltage (V) | Current(A) |
| 18 | 6.29 |
| 19 | 6.09 |
| 20 | 5.75 |
| 21 | 5.10 |
| 22 | 4.09 |

From table 3 it can be observed that the PV voltage is also inversely proportional to the PV current. This is due to the need for balance of power as can be seen from the I-V characteristics where at maximum current (short circuit current) voltage across the panel is zero and at maximum voltage (open circuit voltage), current through the panel is zero.

### Pv system connected to a boost converter with MPP tracking capabilities

#### PV Model with boost converter

The PV model was connected to a boost converter to regulate the PV voltage as shown in figure (22). Capacitor and Inductor values to limit the current and voltage ripple to 5% were calculated using the formulas below.

and

For 5% voltage ripple and 5% current ripple

Where TS=50μs, K=0.5,Vpv=20 , substituting in equation (9) and (10) gives C=55.83nF and L=2.2mH.

Simulating using the values of Capacitor and Inductor obtained above did not still satisfy the requirements. This is because it was assumed that current and voltage are constant. But practically the current and voltage are not constant. Bigger values of capacitor (10μF) and Inductor(8mH) were used based on the recommended range.



Figure :Inductor Current



Figure : PV voltage

From figure (19) and (20) it can be observed that the voltage and current ripples have been significantly reduced with the new values of capacitor and inductor.

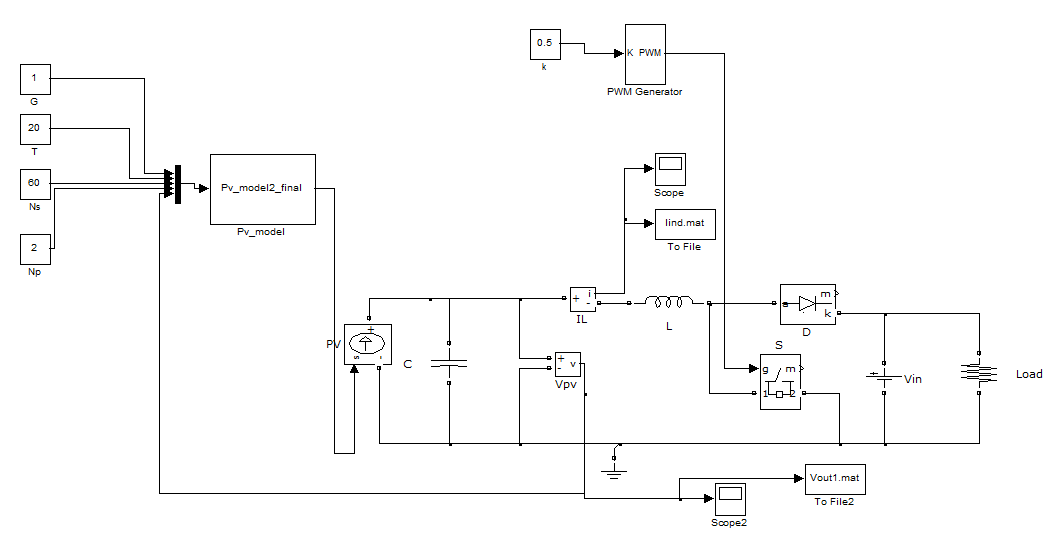
[8]

Figure 22 :PV Model with Boost Converter

Several simulations were run for different weather conditions and the results were tabulated as follows

Table : Effect of Varying k

|  |  |  |
| --- | --- | --- |
| Duty ratio K | Voltage Cpv (V) | Current (A) |
| 0.5 | 25.38 | 6.14 |
| 0.6 | 20.3 | 6.48 |
| 0.7 | 15.22 | 6.53 |
| 0.8 | unstable | unstable |

From the table 4 above it can be observed that as the duty ratio is increased, the PV voltage decreases and inductor current increases. Also as the duty ratio was increase the transient response time increased until at a duty ratio of 0.8 the voltage and current responses were unstable with continuous oscillations.

Table : Effect of varying Irridiation G

|  |  |  |
| --- | --- | --- |
| Irridiation G(Kw/m2) | Voltage Cpv (V) | Current (A) |
| 1 | 25.38 | 6.14 |
| 0.9 | 25.38 | 5.49 |
| 0.88 | 25.38 | 5.36 |
| 0.86 | 25.38 | 5.23 |

From table 5 above it can be seen a change in the irradiation leads to a significant change in current. A change in irradiation does not affect the transient response of the PV voltage and current.

Table : Effects of varying Temperature

|  |  |  |
| --- | --- | --- |
| Ambient temperature | Voltage Cpv (V) | Current (A) |
| 16 | 25.38 | 6.20 |
| 18 | 25.38 | 6.18 |
| 20 | 25.38 | 6.14 |
| 23 | 25.38 | 6.07 |

From table 6 above, it can be seen that as the ambient temperature was increased, the current increased but not significantly as in the case of varying irradiance. The change in temperature did not have any effect on PV voltage due the presence of a feedback. The output voltage is maintained by measuring the present voltage and sending it as reference.

From the value of voltage obtained in table 4 ,5 and 6, it can be said that power to the load would be supplied by the battery because at the weather and duty ratio conditions shown the battery voltage (50V) is higher than the PV supply. The battery would therefore discharge until it gets below 25.38 (provided the conditions are maintained constant). When the PV voltage is greater the battery would start charging and power to the load would be supplied by the PV generator.

#### PV Model with boost converter and PI controller

A PI controller was designed as shown in figure (20) and added to the PV model as shown in figure (21).

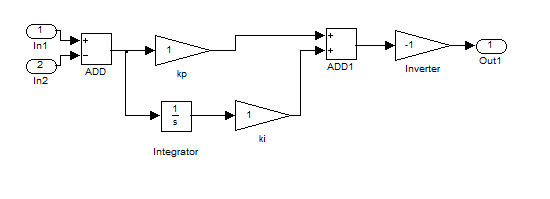


Figure : PI controller

In figure (20) above it can be observed that an inverter is placed at the output of the PI controller. This is because the output of ADD1 block would always be negative since the gain of the integral controller is negative and greater than the gain from the proportional controller. The function of the inverter is to give a positive output

The values of proportional controller gain Kp and integral controller gain were adjusted such that the overshoot and under shoot did not exceed 20%.

The final values of Ki and Kp chosen were 75 and 0.1 respectively . The response is shown in figure 24

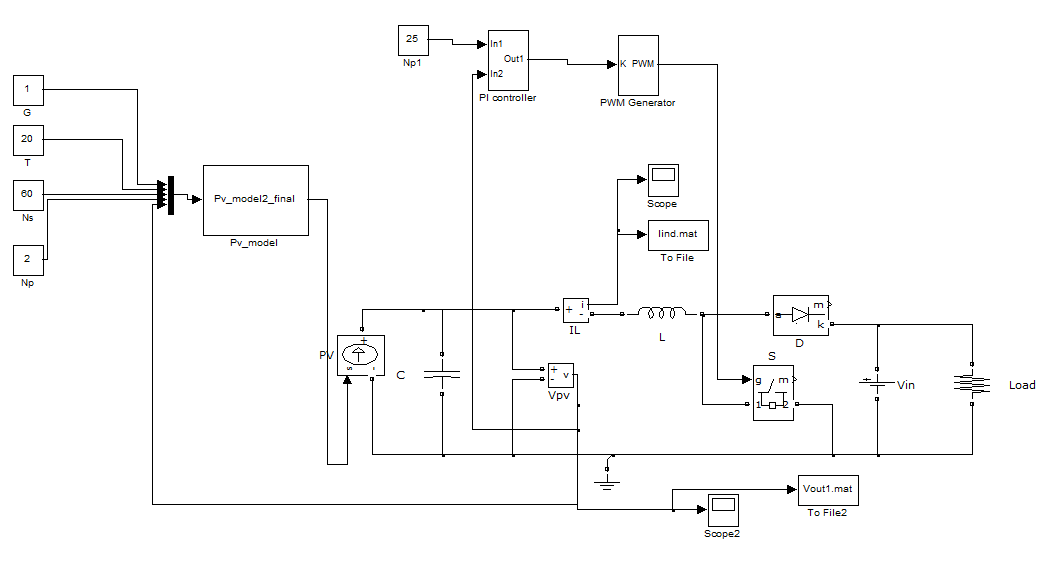


Figure : PV Model with Boost converter and PI controller



Figure : Closed loop response with adjusted Ki and Kp

From the figure above it can be observed that with kp and ki set to 0.1 and 75 respectively, the undershoot has been completely removed. The settling time is less than 3 milliseconds.

Table : Effect of varying weather condition on Pv sysem with PI Control

|  |  |  |
| --- | --- | --- |
| Irridiance G(kw/m) | Temperature | PV voltage |
| 1 | 25 | 25.06 |
| 0.8 | 23 | 24.99 |
| 0.8 | 18 | 24.96 |
| 1 | 18 | 24.96 |

It can be observed from table 7 that a slight change weather conditions results in very little change to the PV voltage due to the PI controller.

# PARTB

## AIMS AND OBJECTIVES

To understand the principle of operation of a 3 phase thyristor converter. To know how a combination of thyristors can be used for rectification of a 3 phase Ac supply.

To study the effect of firing angle on the voltage and current waveforms of the thyristor converter. To know how the output voltage and current waveforms behave when the firing angle of the thyristor is varied from 0 to 180o.

## RESULTS AND DISCUSSION

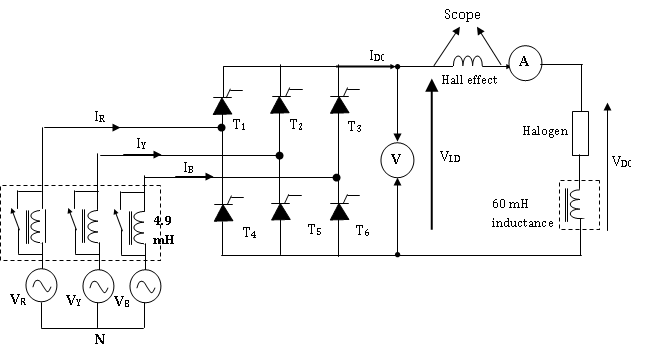
[8]

Figure : Diagram of experiment connection

Connections were made as shown in the figure (19). The function of the Oscilloscope is to observe and record the ac voltage waveforms as the firing angle is varied. The Voltmeter and ammeter are to measure the values of dc voltage and dc current.

The resistance of the lamp was measured to be 8Ω. The power supply was then switched ON. Phase angle control knob was adjusted changing the firing angle from 900 to 00.

Since the control knob was not calibrated, the measurement of firing angle was done by comparing the waveform to the time division. With a reference vertical line set at 2.50ms, a second measurement line was set to be proportional to the voltage waveforms and varying the firing angle changed the position of the line.

# C:\Users\LENOVO\Desktop\3 phase rectifier\TEK0003.JPG

Figure : Voltage Waveforms with firing angle set 900

Figure (20) above shows the voltage waveforms with the firing angle set 900. It can be observed with the dc voltage obtained that half of the supply voltage is transferred to the load. Therefore half of the power supplied would be transferred to the load. The two vertical orange lines are used to measure the firing angle.

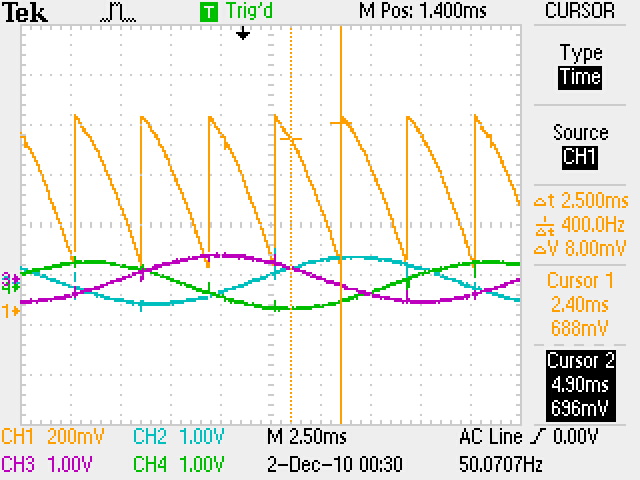


Figure : Voltage waveforms with firing angle α set to 450

Figure (21) shows the waveform when the delay angle is reduced to 450.At this delay angle it is observed that there is an increase in the power transferred to the load due to increase in DC voltage and current values. This is because the thyristors conduct for a longer period than when the delay angle was set to 900

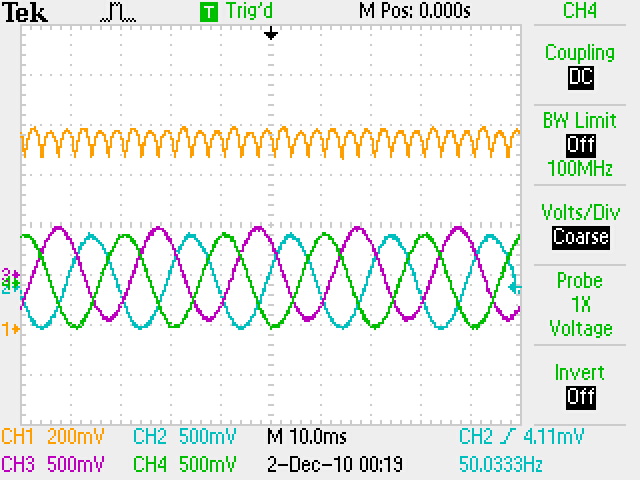


Figure : Voltage waveforms with firing angle set to zero

Figure (22) shows the waveforms when the there is no delay angle. At this point maximum power is transferred from supply to the load as can be observed from the DC voltage (orange waveform).

The calculations for DC voltage and and current depend on the firing angle and are solved as follows:

For a Resistive load

When 



When 



Where VPH represents the room mean square voltage Vrms  and is the peak voltage

Table 8: below shows the relationship between the comparison between the measured values and the calculated values

Table : Table of Results

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **R Load** | | | | | | | | |
| **Firing Angle** | **Delay**  **Time (ms)** | **Calculated** | | | | | **Measured** | | | |
| **VDC mean (V)** | **IDC**  **mean**  **(V)** | **VDC**  **r.m.s.**  **(V)** | **IDC**  **r.m.s**  **(A)** | **P (W)** | **VDC mean (V)** | **VDC**  **r.m.s.**  **(V)** | **IDC**  **r.m.s.**  **(A)** | **P (W)** |
| 0° | 0 | 151.57 | 0.80 | 151.58 | 2.29 | 347.12 | 147.00 | 146.60 | 2.70 | 395.82 |
| 45° | 2.5 | 107.18 | 0.60 | 112.24 | 1.70 | 190.81 | 103.00 | 109.40 | 2.35 | 257.09 |
| 90° | 5 | 20.31 | 0.28 | 52.98 | 0.80 | 42.38 | 23.80 | 33.80 | 1.45 | 49.01 |

From table 8 it can be seen that the measured values of voltage and current are smaller than the calculated values. This is because for the calculated values an ideal situation is considered where there are no losses. But for the measured values there are losses such as power(I2R) losses due to internal resistance of the supply as well as increased resistance due to rise in temperatures. Power loss would affect the amount of power supplied to the load.

# CONCLUSION

A PV system can be made to track maximum power point by incorporating a PI controller into the PV system. The PI controller adjusts the PV voltage based on the maximum power point. With properly tuned values of proportional gain and integral gain, the PI controller reduces ripples and improves transient response.

For a PV system with varying weather conditions, the irradiation G (KW/m2 has a significant effect on the current supplied by PV generator and is directly proportional to the current. Therefore a slight decrease in the irradiation would lead to a significant decrease in current. How large the decrease would be is dependent upon other weather conditions such as ambient temperature.

For a PV system with varying weather conditions, change in ambient temperature has a significant effect on the PV terminal voltage. For a slight drop in temperature would lead to a significant increase in the terminal voltage. Also how large the increase of terminal voltage would be is determined by the other weather conditions such Irradiance. Duty ratio of the boost converter also affects the terminal voltage. The higher the duty ratio the lower the terminal voltage. If duty ration is made to high the terminal voltage becomes unstable.

In thyristor 3 phase rectified circuits the amount of power supplied to the load is determined by the delay angle of the thyristors. The maximum delay angle that can be achieved is 1800 and when there is no angle of delay (delay angle=0), maximum power is transferred to the load.

In a 3 phase thyristor rectifier using 6 thyristors, the thyristors are triggered it sequence resulting in the formation of 6 pulse DC voltage waveforms.

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# APPENDIX