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Design Of Grid-Connected Photovoltaic Inverter Digital Control Module

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Abstract:

This paper presents the design of control module of grid connected photovoltaic system. photovoltaic array is being widely used nowadays. Sun energy could be utilized by the use of photovoltaic systems. But the photovoltaic array output is highly non-linear to be directly connected to the utility grid. Hence the output is applied through DC-DC boost converter. Output of converter is converted to AC using an inverter. Both the converter and the inverter is controlled by the digital control module. Control module generates PWM signals to operate the MOSFET switches of the inverter. PWM signal is in phase with the utility grid voltage. Hence the AC output voltage of the inverter also will be in phase with the grid voltage. Digital controller includes MPPT module and PI controller. MPPT algorithm makes sure that the photovoltaic output is taken at the maximum power point. PI controller stabilizes the output PWM signal. The controller is implemented using dsPIC30f.Tool used is MPLAB. Use of renewable resource makes the project highly attractive.

Key words: *Maximum power point tracking(MPPT) method,Pulse width modulated(PWM) signal,Grid,synchronization*

1.Introduction

Implementation of the Photo-Voltaic system is costly because of the higher cost solar cells. Efficiency of the system should be improved to get maximum utilization of resources and more algorithms have been developed in this field.

Even though the solar energy is available in infinite amount, problem arises in making it physically available for human use. Major method to generate energy from sun is using photovoltaic system (PV system). Grid connected PV system supply solar electricity through an inverter directly to the household and to the electricity grid if the system is providing more energy than the house needs. The output from the solar panel should be taken at the maximum power point (MPP) to get maximum efficiency. Solar panel delivers the maximum energy at maximum power point. This point of operation should be tracked throughout the period of operation of the PV system.

The grid-connected PV power system can offer a high voltage gain and guarantee the used PV array voltage is less than 50 V, while the power system interfaces the utility grid. he proposed system can not only be applied to the string or multi string inverter system, but also to the module-integrated inverter system in low power applications. On the other hand, the non isolation PV systems employing neutral-point-clamped topology, highly efficient reliable inverter concept topology, H5 topology, etc., have been widely used especially in Europe. Although the transformer less system having a floating and no earth-connected PV dc bus requires more protection, it has several advantages such as high efficiency, lightweight, etc.

Generated power from the PV module should be converted to a form suitable to be given to the utility grid. The PV module generates a DC voltage. Whereas the grid voltage is 50 Hz AC. From this, it is evident that the PV output should not be connected directly to the utility grid. It should be first boosted to grid voltage level, and then converted to AC which is exactly synchronized to the grid voltage. All these processes need very efficient and accurate control. The control module implemented with a dsPIC30f.It generate PWM signal which controls the operation of the converter and inverter. The digital controller also takes care of the MPPT and synchronization.

2.Evolution Of Solar Power Systems

2.1.Log Cabin System

This was a simple system which supplies power for 12v or less dc equipments. PV array generates low power and it was directly connected to appliances having matching power requirements as shown in the figure. The PV output is charging a battery, which is connected to the load. Unregulated charging currents alter the battery life. Power generated is only less than hundred watts. This was not connected to grid due to the above described reasons.

2.2.Urban Home System

Larger panels providing 200-400 volts are connected to an inverter to yield 120/240VAC at medium power levels (2-10kW). This system is connected to AC power lines (i.e., connected to the grid) . The customer sells power to the power company during the day and buys power from the power company during the night. The grid connected approach eliminates expensive and short lived batteries. A couple of issues exist with this system. One, the inverter has potential as a single point of failure; and two, non-optimal power harvesting from the solar panels, especially in partial shading conditions.

2.3.Single Inverter With Multiple DC/DC Converters

The use of DC/DC converters per string provide enhanced power harvesting from solar panels. The DC/DC converters may be separate modules or reside within the inverter module. This method is still susceptible to single-point-failure of the inverter, and involves the distribution of high voltage
DC power – a potentially dangerous situation because direct current power fusing is difficult to achieve.

2.4.Urban Home System With String Inverters

Panels providing 200-400 volts are connected to multiple inverters to yield 120/240 VAC at medium power levels (2-10kW). The inverters are connected to the grid. Use of multiple inverters provides enhanced power harvesting from solar panels and also provides enhanced system reliability.

2.5.Module Incorporated Inverters

Each solar panel module incorporates its own inverter. Module-incorporated inverters are also known as micro inverters.The incorporation of inverters into the solar panels greatly reduces installation labor costs, improves safety, and maximizes the solar energy harvest.

3.Control Module For Grid-Connected Photovoltaic System

A grid-connected photovoltaic (PV) power system is proposed, and the steady-state model analysis and the control strategy of the system are presented. A full-bridge inverter is used as the second power-processing stage, which can stabilize the dc-bus voltage and shape the output current. The block diagram of the grid connected PV system employing the digital controller is

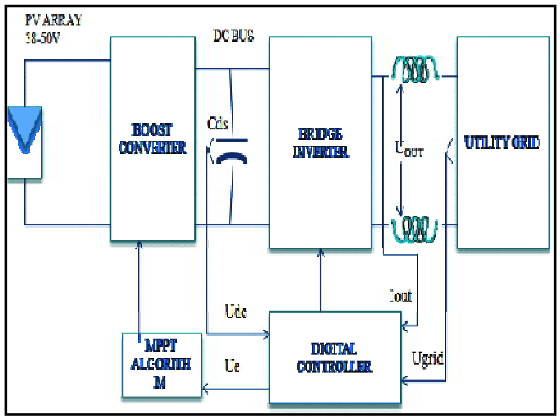


Figure 1: Block diagram of grid connected PV system

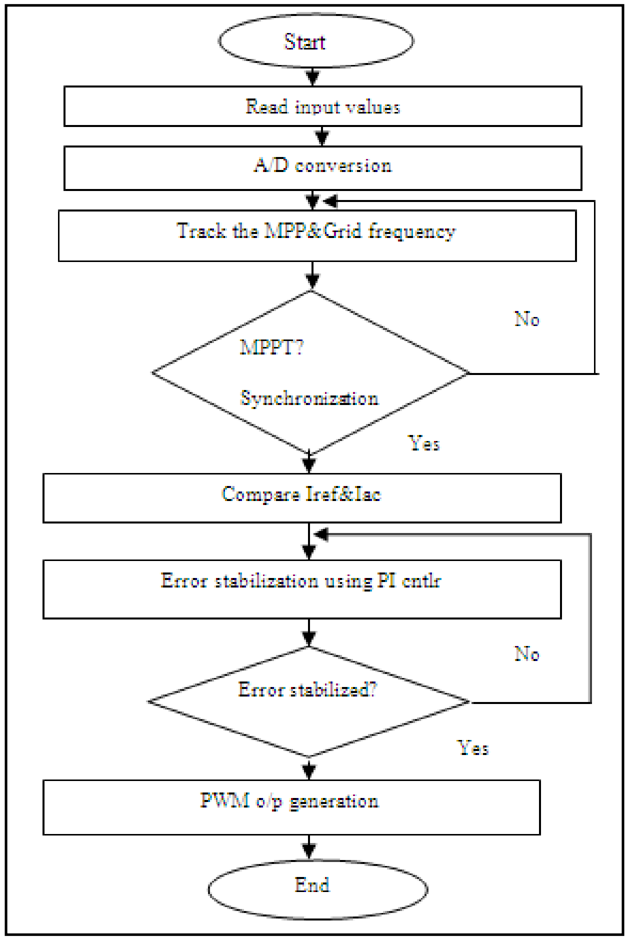
shown. Interfacing a solar microinverter module with the power grid involves two major tasks. One is to ensure that the solar microinverter module is operated at the Maximum Power Point (MPP). The second is to inject a sinusoidal current into the grid. These inverters must be able to detect an islanding situation, and take appropriate action in order to prevent bodily harm and damage to equipment connected to the grid. Two compensation units are added to perform in the system control loops to achieve the low total harmonic distortion and fast dynamic response of the output current. Furthermore, a simple maximum-power-point-tracking method based on power balance is applied in the PV system to reduce the system complexity and cost with a high performance.

3.1.Inverter

The word 'inverter' in the context of power-electronics denotes a class of power conversion (or power conditioning) circuits that operates from a dc voltage source or a dc current source and converts it into ac voltage or current. The 'inverter' does reverse of what ac-to-dc converter (rectifier) does. A power inverter, or inverter, is an electrical power converter that changes direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries. The inverter performs the opposite function of a rectifier. A grid tie inverter (GTI) is a sine wave inverter designed to inject electricity into the electric power distribution system. Such inverters must synchronize with the frequency of the grid. They usually contain one or more Maximum power point tracking features to extract the maximum amount of power, and also include safety features. It is a special type of power inverter that converts direct current (DC) electricity into alternating current(AC) and feeds it into an existing electrical grid. GTIs are often used to convert direct current produced by many renewable energy sources, such as solar panels or small wind turbines, into the alternating current used to power homes and businesses. The technical name for a grid-tie inverter is "grid-interactive inverter". Grid-interactive inverters typically cannot be used in standalone applications where utility power is not available. During a period of overproduction from the generating source, power is routed into the power grid, thereby being sold to the local power company. During insufficient power production, it allows for power to be purchased from the power company.

Residences and businesses that have a grid-tied electrical system are permitted in many countries to sell their energy to the utility grid. Electricity delivered to the grid can be compensated in several ways. "Net metering", is where the entity that owns the renewable energy power source receives compensation from the utility for its net outflow of power. So for example, if during a given month a power system feeds 500 kilowatt-hours into the grid and uses 100 kilowatt-hours from the grid, it would receive compensation for 400 kilowatt-hours. In the US, net metering policies vary by jurisdiction. Another policy is a feed-in tariff, where the producer is paid for every kilowatt hour delivered to the grid by a special tariff based on a contract with Distribution Company or other power authority. In the United States, grid-interactive power systems are covered by specific provisions in the National Electric Code, which also mandates certain requirements for grid-interactive inverters.

4.System Flow Chart



System flow chart is shown above. The analog inputs are read. They are converted to digital. Maximum power point tracking is done to find out the maximum power output. Synchronization with the grid signal is ensured. Error between AC reference signal and generated signal is reduced using a PI controller. When the error is minimized, a PWM signal corresponding to the sinusoidal signal is generated.

5.Control Module

The Grid-Connected Solar Microinverter Reference Design is controlled by a single dsPIC DSC device, as shown in the system block diagram. The functions of the dsPIC DSC can be broadly classified into the following categories:

- All power conversion algorithms
- Inverter state machine for the different modes of operation
- Maximum Power Point Tracking (MPPT)
- Digital Phase-Locked Loop (PLL)
- System islanding and Fault handling

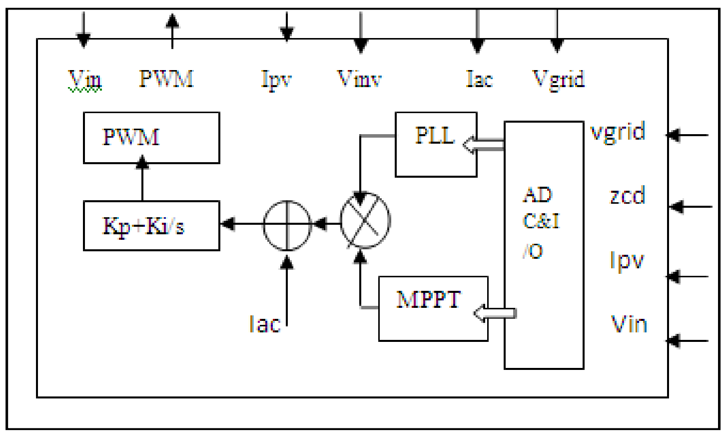


Figure 2: Control module of the grid connected PV system

The dsPIC DSC device offers intelligent power peripherals specifically designed for power conversion features that applications. These intelligent power peripherals include the High-Speed PWM, High-Speed 10-bit ADC, and High-Speed Analog Comparator modules. These peripheral modules include ease the control of any Switch Mode Power Supply with a high-resolution PWM, flexible ADC triggering, and comparator Fault handling. dsPIC DSC also provides built-in peripherals for digital communications including I2C, SPI and UART modules that can be used for power management and housekeeping functions.

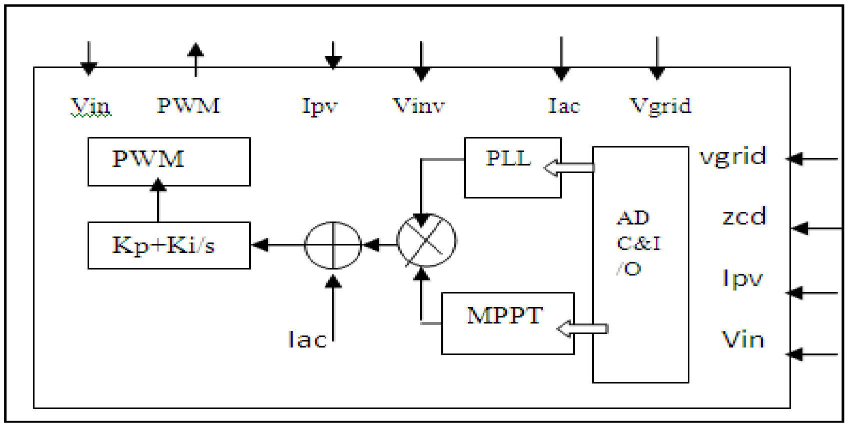


Figure 3: Control loop block diagram

6.1.10-Bit A/D Converter

The 10-bit A/D converter can have up to 16 analog input pins, designated AN0-AN15. In addition, there are two analog input pins for external voltage reference connections. These voltage reference inputs may be shared with other analog input pins. The analog inputs are connected via multiplexers to four S/H amplifiers, designated CH0-CH3. One, two or four of the S/H amplifiers may be enabled for acquiring input data. The analog input multiplexers can be switched between two sets of analog inputs during conversions. An Analog Input Scan mode may be enabled for the CH0 S/H amplifier. A Control register specifies which analog input channels will be included in the scanning sequence. The 10-bit A/D is connected to a 16-word result buffer. Each 10-bit result is converted to one of four 16-bit output formats when it is read from the buffer. The A/D module has six Control and Status registers. These registers are:

- ADCON1: A/D Control Register 1
- ADCON2: A/D Control Register 2
- ADCON3: A/D Control Register 3
- ADCHS: A/D Input Channel Select Register
- ADPCFG: A/D Port Configuration Register

6.2.Algorithm For A/D Conversion

6.2.1.<u>Configure The A/D Module</u>

• Select port pins as analog inputs ADPCFG<15:0>

• Select voltage reference source to match expected range on analog inputs ADCON2<15:13>

• Select the analog conversion clock to match desired data rate with processor clock ADCON3<5:0>

• Determine how many S/H channels will be used ADCON2<9:8> and ADPCFG<15:0>

• Determine how sampling will occur ADCON1<3> and ADCSSL<15:0>

• Determine how inputs will be allocated to S/H channels ADCHS<15:0>

• Select the appropriate sample/conversion sequence ADCON1<7:0> and ADCON3<12:8>

• Select how conversion results are presented in the buffer ADCON1<9:8>

• Select interrupt rate ADCON2<5:9>

• Turn on A/D module ADCON1<15>

6.1.2.<u>Configure A/D Interrupt (If Required)</u>

• Clear ADIF bit

• Select A/D interrupt priority

6.2.MPPT Loop

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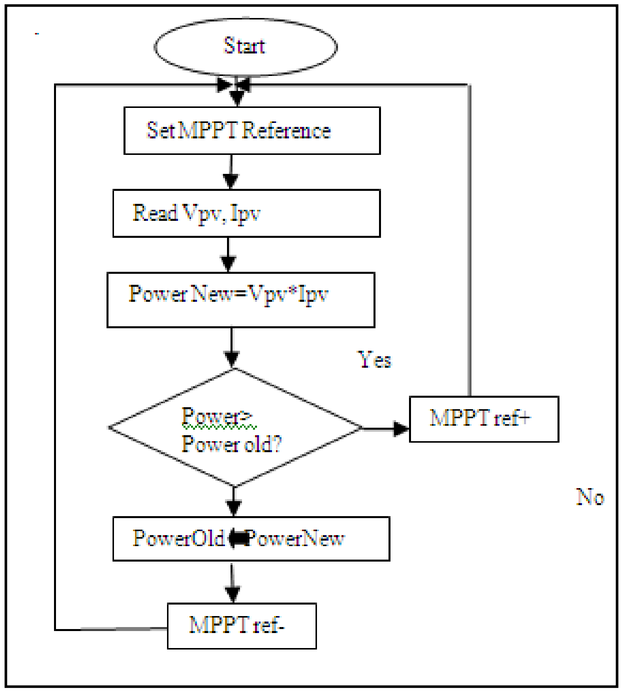

6.3.MPPT Control Loop Block Diagram

Two algorithms are commonly used to track the MPPT: the Perturb and Observe (P&O) method and the Incremental Conductance (IncCond) method The reference design uses the P&O method for MPPT. Figure4 presents the control flow chart of the P&O algorithm. The MPP tracker operates by periodically incrementing or decrementing the solar array voltage. If a given perturbation leads to an increase (decrease) the output power of the PV, the subsequent perturbation is generated in the same (opposite) direction. In Figure4, Set MPPT reference denotes the perturbation of the solar array voltage, and MPPT ref+ and MPPT ref- represent the subsequent perturbation in the same or opposite direction, respectively.

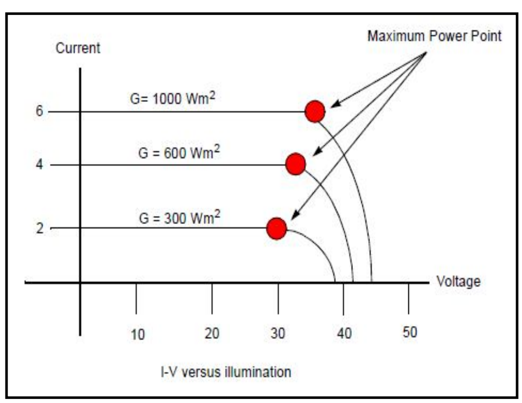

Figure 4

A set MPPT reference decides the peak value of sine reference current generated by the PLL. Therefore, the PV voltage is being continuously checked at every zero-crossing of the grid voltage and its value is compared with previous zero-crossing sample of the PV voltage.

From the I-V Vs illumination characteristics we know that the relationship between the voltage or current and different parameters are complex. Here according to the illumination, the I-V curve level increases with illumination. In each curve, the maximum power point, at which, the PV array delivers maximum power, is tracked.

6.4.Digital Phase Lock Loop(PLL)

In systems connected to the grid, a critical component of the converter's control system is the PLL that generates the grid voltage's frequency and phase angle for the control to synchronize the output to the grid.. As such, PLL systems that can synchronize to the grid parameters accurately and as quickly as possible are of vital importance; otherwise, inaccurate and potentially harmful control of power factor angle, harmonics, and the determination of system mode of operation can result. The grid-connected solar microinverter PLL has been implemented by hardware as well as software zerocrossing detect of grid voltage. In software, grid voltage is sampled at every ADC trigger and the polarity of the grid voltage is stored in a register. In every sample grid voltage polarity has been checked. If there is change in grid voltage polarity, software sets the zero voltage detect flag. The period value determines the phase angle increments for sine table reference generation from the sine table. The sine table consists of 512 elements for generating 0-90 degrees of sine reference. As 90-180 degrees of sine waveform is a mirror image of 0 to 90 degrees. Therefore, 0-180 degree, half sine reference is generated in phase and is synchronized with the grid voltage. The PLL circuit is implemented using the zero crossing detector.

6.5.Zero Corssing Detector Circuit

Inverter output should be in phase and in the same frequency as the grid voltage to feed current with a high power factor. Zero cross detect circuitry detects the grid voltage state and changes the dsPIC DSC port (Port B15) state accordingly. As the grid voltage state changes from negative to positive, it changes the state of PORTB15 from low-to-high and vice - verse

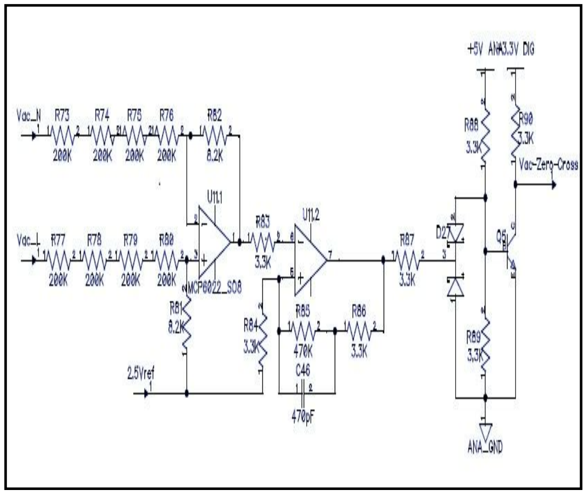

Figure 5: ZCD circuit diagram

High voltage AC signals (grid voltage) are de amplified and an offset of 2.5V is added using the differential amplifier U11.1. The output of the differential amplifier U11.1 is compared with the 2.5V reference by comparator U11.2. The comparator U11.2 output drives the transistor Q5 base, as shown in Figure .To avoid false triggering of the comparator, a hysteresis band of ~10 mV is added using R85, R86 and C46.

6.6.PI Controller

Proportional-Integral (PI) algorithm computes and transmits a controller output (CO) signal every sample time, T, to the final control element (e.g., valve, variable speed pump). The computed CO from the PI algorithm is influenced by the controller tuning parameters and the controller error, e(t).

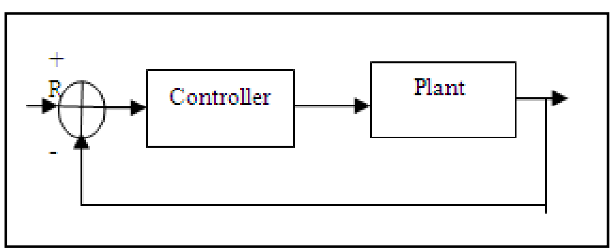

Figure 6: PI controller block diagram

Characteristics of PI Controllers are

- Proportional Controller Kp

_ reduces the rise time

– reduces but never eliminates steady-state error

- Integral Controller Ki

_ eliminates steady-state error

_ worsens transient response

7.Comparison Of PWM Signal, Generated By Discreet Components And Dspic

PWM signal generated by dsPIC is having many advantages such as precise dead time control and the number of control signals generated, when compared to that generated by a discreet component circuit. We can use TL494 for generating PWM signals.

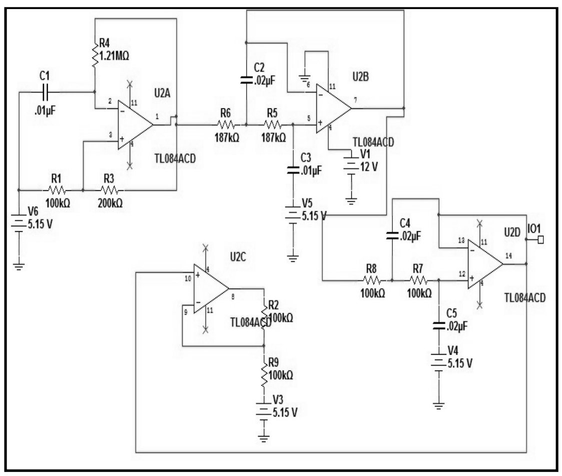

Figure 7: Sine Wave Generator

The above shown sine wave generater generates uses TL084 quad opamp IC to generate sine wave.

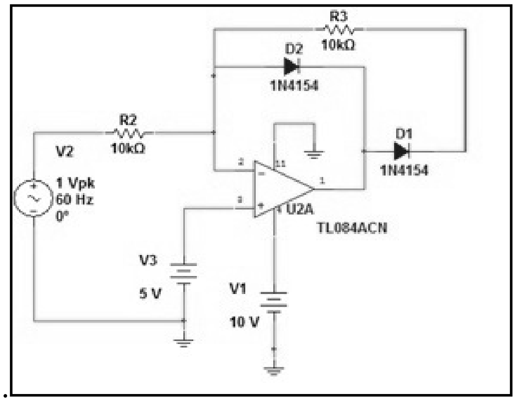

Figure 8: Precision Rectifiers for Half-Wave Generation

The generated sine wave is rectified first using TL084 itself. Both positive and negative half cycles are rectified and used as the input to TL494.

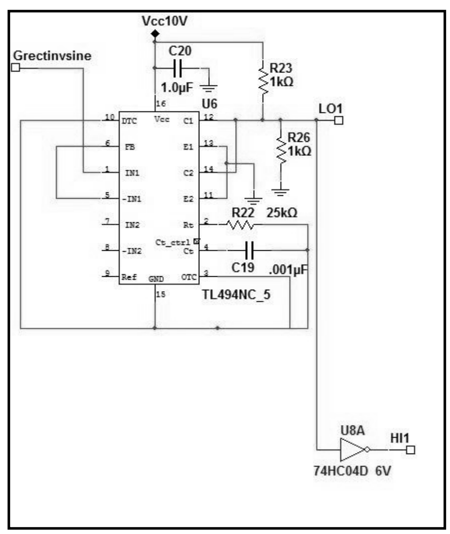

Figure 9: TL494 Configuration

Rectified sine wave is given as the input to the TL494. TL494 has sawtooth wave generated internally. The rectified sine wave is compared with internally generated sawtooth waveform and PWM signal is generated. This is compared with the PWM generated by dsPIC.

8.Simulation Results

Simulation using Matlab was done and the results obtained are discussed below

8.1.Electrical Characteristics Of Solar Cells

PV cells are semiconductor devices, with electrical characteristics similar to a diode. A PV cell will behave differently depending on the size of the PV panel or type of load connected to it and the intensity of sunlight (illumination). This behavior is called the PV cell characteristics. When the cell is exposed to sunlight and is not connected to any load, there is no current flowing and the voltage across the PV cell reaches its maximum. This is called an open circuit (Vopen) voltage. The current is maximum when the two terminals are directly connected with each other and the voltage is zero. The current in this case is called a short circuit (ISC) current.

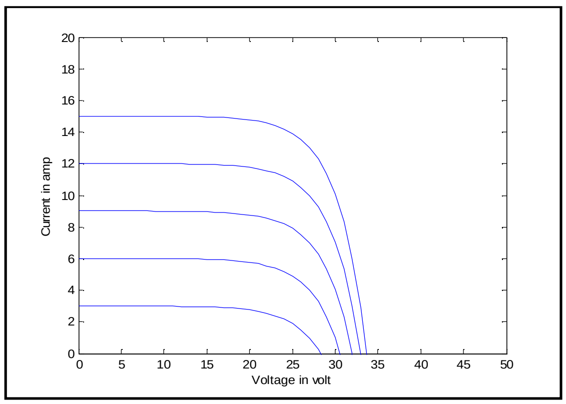

Figure 10: PV output Current Vs Voltage

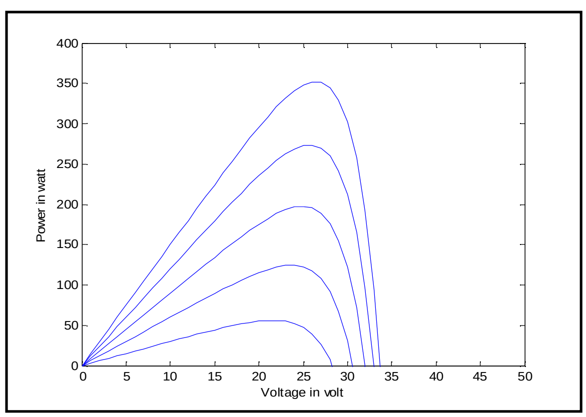

Figure 11: PV output Power Vs Voltage

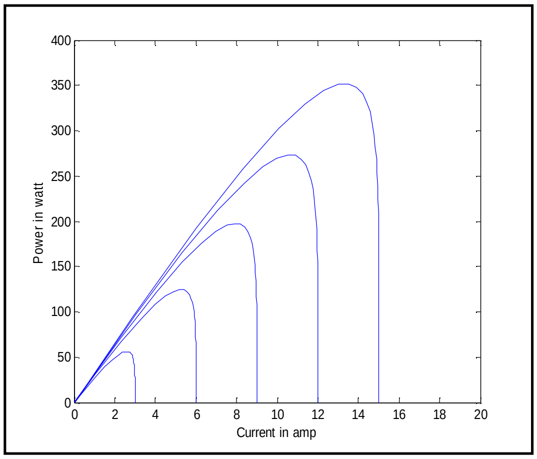

Figure 12: PV output Power Vs Current

8.2.PWM Output Waveform

A modulated sine PWM generates modulated sine primary MOSFET current, producing the diode secondary diode current. The output of the inverter is synchronized with the grid by digital PLL. The MPPT controls the magnitude/rms of the output current. The shape of the output current is controlled by current control loop.

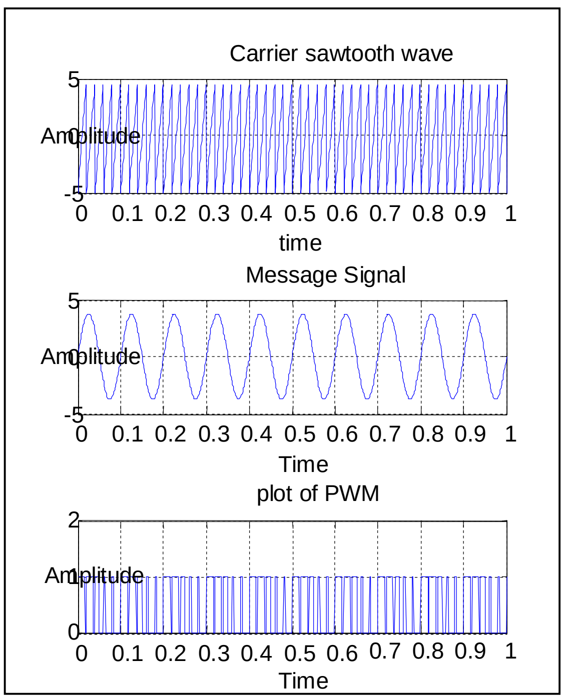

Figure 13

8.3.PID Controller Output Waveforms

PId controller is used to minimize the error between the reference AC signal and the one which is in synchronization with the grid voltage. The output of a system with and without PID controller is shown below

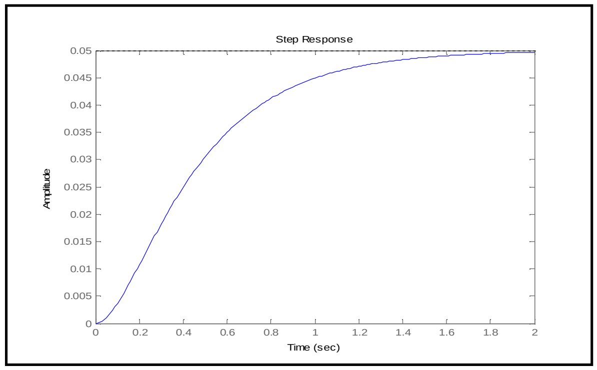

Figure 14: System output without PID controller

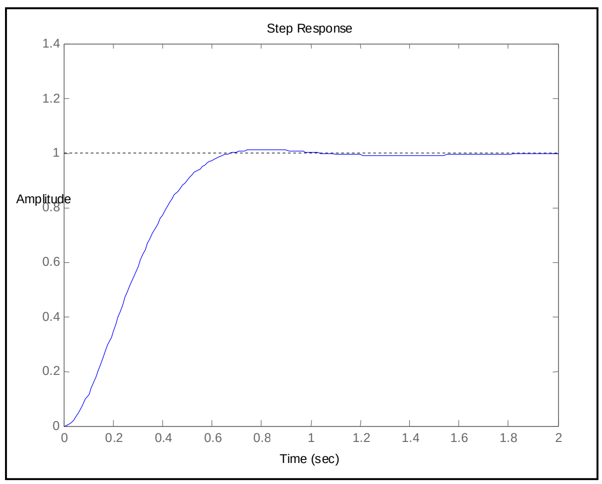

Figure 15: System output with PID controller

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