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Modeling of Solar Based Grid Tie Dual Converter Using Absolute Active Power Control

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Abstract *— In a PV System of power generation it is always preferred to operate it at maximum possible power level. With a continuous increase in the grid-connected PV systems there is a very major problem of large amount of power fluctuations faced which is to be taken care of. During the peak power production period, the grid is overloaded working alone with the existing Maximum Power Point Tracking (MPPT) strategy; which reduces the inverter reliability due to thermal loading of the power devices. As an advanced power-controlling or power-limiting strategy the Absolute Active Power Control (AAPC) can satisfactorily solve the problem of grid overloading by limiting the maximum power to a certain level (P_{limit}). This active power control strategy makes sure that the power level stays to the left side of the maximum power level which actually reduces the power level than the available power (P_{mpp}). There is a drawback of power loss while applying the active power control strategy therefore it is implemented on the system in an optimized way making the power loss within permissible limits. This will solve the overloading problem of the grid which results in increase in inverter reliability due to reduced thermal loading of the power devices after applying Absolute Active Power Control method. The Absolute Active Power Control can be easily applied to the existing PV System as it requires just a minor software change to the existing controlling algorithm of the system. The algorithm will work in such a way that if the power crosses the P_{limit} the system will work in AAPC mode and in MPPT mode otherwise. This paper contains PV cell modeling, DC to DC converter and then MPPT along with AAPC algorithm.*

Keywords — *Renewable energy, Solar power generation, Active Power Control, Power limiting, Solar cell, Boost converter, Inverter, Grid synchronization, MATLAB.*

I. INTRODUCTION

The use Photovoltaic method for the generation of electrical energy is trending now a days due to scarcity of conventional energy resources and high cost of those resources. These kinds of resources are abundant, pollution free, distributed throughout the earth and recyclable type. The drawback is its high installation cost and low conversion efficiency. Therefore our aim is to increase the efficiency and power output of the system. Load needed constant voltage even if the input is variable. To generate power solar array is arranged in shunt-series circuit connections. So a voltage boost up is a necessary process to achieve required output. Our system can be used to supply constant stepped up voltage to dc loads. This system will pertain to domestic use and it will act as a AC source synchronized with the grid. The first stage consisting of step up DC converter circuit controlled by a Maximum Power Point Tracker (MPPT) algorithm along with Absolute Active Power Control (AAPC). The second stage will be a inverter. The third stage is grid synchronization.

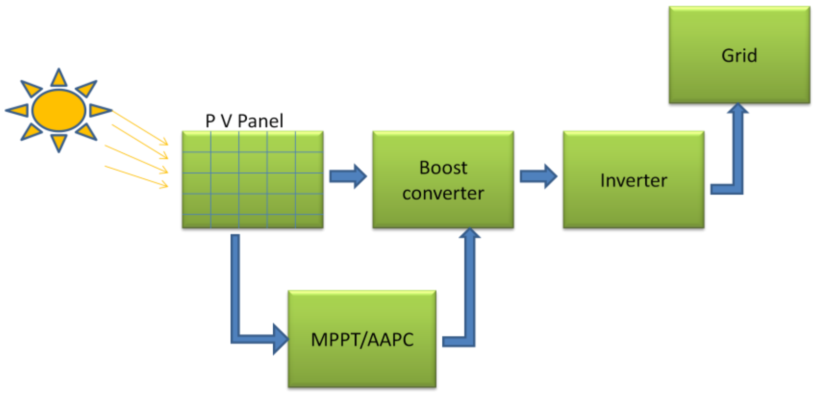

Figure 1. Block Diagram of the PV System [4]

II. PHOTO-VOLTAIC CELL

The PV cell is a device that converts the solar energy in to electrical energy. A PV cell is a one type of PN junction diode. It's a combination of P and N type materials. By a process called Doping, the P junction and N j unction is formed on the semiconductor wafer (Figure 2).

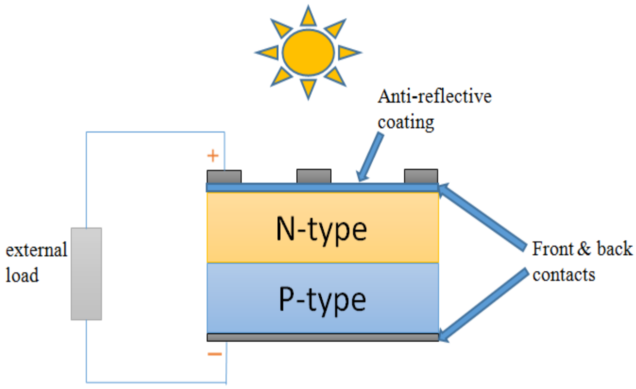

Figure 2. Structure of PV cell [1]

Output of solar cell is between 0.5V to 0.6V. A group of cell connected in series forms a solar module and a group of solar modules connected in series and parallel forms a solar array/panel. The output of PV array is changed according to the irradiation and weather condition.

A. Equivalent circuit of solar cell and PV model

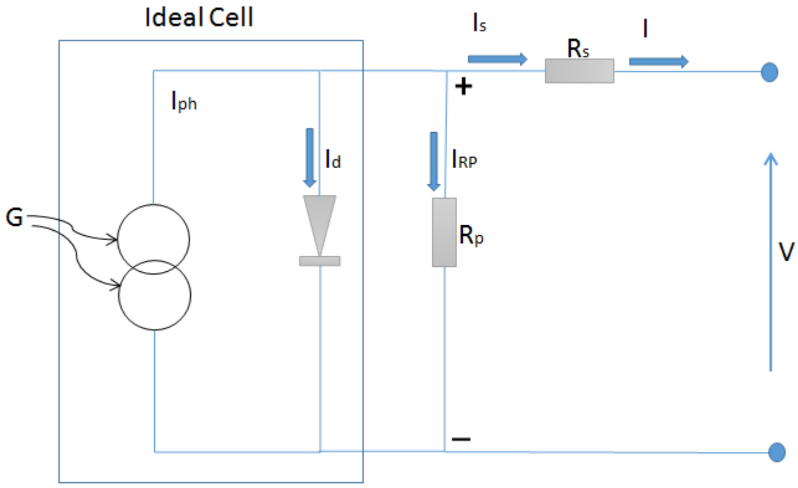

Figure 3. Equivalent circuit of a PV cell [3]

An ideal PV cell is modeled by a current source in parallel with a diode. However no solar cell is ideal and thereby shunt and series resistances are added to the model as shown in the PV cell diagram above. R_s is called the intrinsic series resistance whose value is very small. R_p is the equivalent parallel resistance which has a high value. Applying KCL to the node where Photo current, diode, R_p and R_s meet, we get,

$$I = I_{ph} - I_d - IR_p \tag{1}$$

$$I_{ph} = (G / G_{ref}) * (I_{phref} + \mu sc * \Delta T) \tag{2}$$

$$I_d = I_o * [\exp(v / N_s A V_T) - 1] \tag{3}$$

Where,

I	=	Cell current
I_{ph}	=	Photon current
G	=	Irradiation
G_{ref}	=	Reference irradiation
I_0	=	Reverse saturation current
V	=	Cell voltage
V_T	=	Thermal voltage
R_s	=	Series resistance
R_p	=	Parallel resistance
K	=	Boltzmann constant
T	=	Temperature in Kelvin
q	=	Chare of electron

B. Typical Characteristics of PV cell

The current to voltage characteristic of a solar array is not linear, which makes difficult to determine the MPP. The Figure 4 & 5 below gives the characteristic I-V and P-V curve for fixed level of solar exposure and atmospheric temperature.

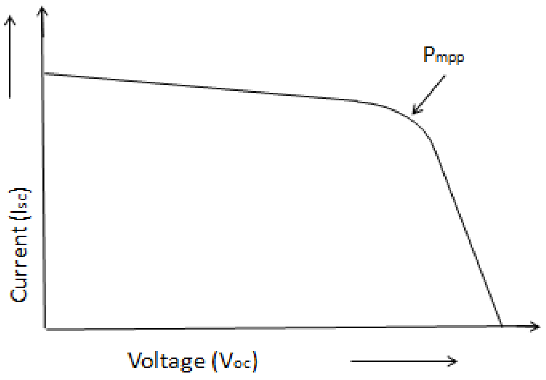

Figure 4 I-V characteristic of PV cell [4]

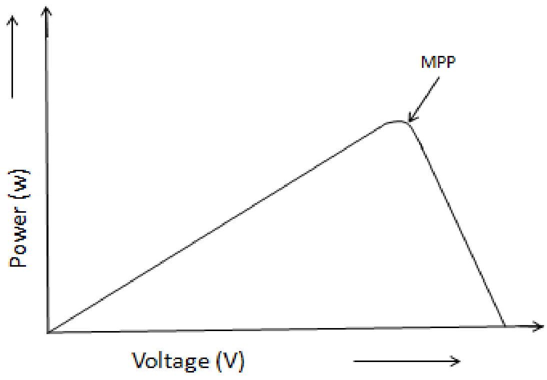

Figure 5 P-V characteristic of PV cell [4]

III. DC TO DC BOOST CONVERTER

The solar panel output varies according to the solar exposure and its temperature. Since the voltage produced is fluctuating, it becomes impossible to connect the further circuit of the system, as it can damage the connected circuit. Even the output voltages of panel are very low which cannot be used directly in to the system. Hence we designed and used the dc to dc converter which steps up the output voltage of panel to the required level with fixed output voltage. For AC electrical equipments, the system requires an inverter circuit which simply converts the DC output voltage of boost converter into the ac voltage. As seen from the figure the boost converter consists of four major components starting from inductor, electronic switch, diode and capacitor. The output of the boost converter is controlled by adjusting the on and off time off the electronic switch, which is done by controlling the duty cycle given to the switch. There are two different modes in which the boost can be operated namely Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM). Here in this paper we are the boost converter is working in Continuous Conduction Mode (CCM).

$$C = K/2Rf \tag{4}$$

$$L = K(1-K)R/2f \tag{5}$$

$$K = (V_a - V_s)/ V_a \tag{6}$$

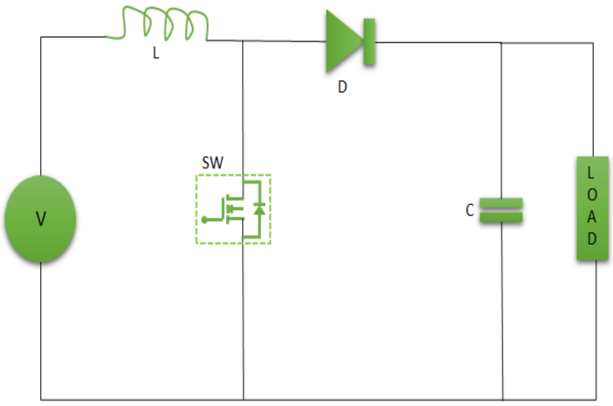

Figure 6. Boost converter circuit diagram [2]

A. Continuous Conduction Mode (CCM)

The continuous conduction mode is divided into two sub-modes called mode 1 & mode 2. In mode 1 at t = 0 to DT the switch (sw) is ON that is in closed condition (Figure xx). After the switch is closed, input current starts rising in the inductor L and then flows through switch. Energy is stored in the inductor while during this period the load is supplied by the output capacitor. Now, in mode 2, t = DT to T, switch is turned OFF or say it is in open condition. The current will now flow through inductor L and then through diode D to the output capacitor C and then through the load. The inductor in this mode will discharge till the switch SW is turned ON in the next cycle. During this mode the energy stored in the inductor along with the input voltage goes to the load. Hence in this way the boosted up voltage appears across the load due to summation of energy stored in the inductor and the supply voltage making its value greater than the input supply voltage. This is the reason the boost convertor is also called step-up DC to DC converter as it converts voltage level from one level to another.

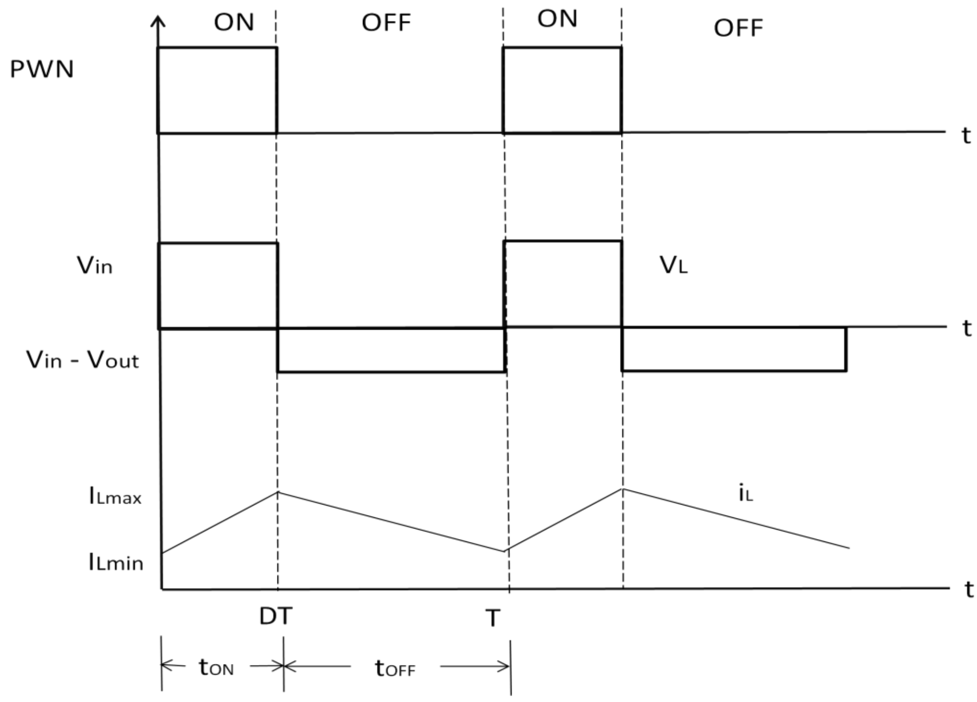

Figure 7. Waveform of boost converter [2]

IV. M.P.P.T. (MAXIMUM POWER POINT TRACKER)

The PV generation systems have few problems which are related to low conversion efficiency of about 10 to 13% so, development is done to increase the efficiency of PV panel by operating the system at maximum output power at any temperature and solar irradiation. There are several algorithms used to acquire maximum power output from the panel at any solar irradiation and temperature. The few such algorithms are,

1) Perturb and Observe (P & O)
2) Incremental conductance
3) Neural network based
4) Fuzzy logic control
5) Parasitic capacitance (PC)
6) Constant voltage (CV)
7) Open circuit voltage (OCV)
8) Short circuit current (SCC)

Out of these known algorithms we preferred the Perturb and Observe (P & O) method. It works by continuously measuring the output voltage and current of the PV panel, then constantly perturbing the voltage by adding a small disturbance, and then observing the changes of the output power to determine the next control signal. The P &O technique is very simple to implement and that is why this technique is most commonly used globally for maximum power extraction from the panel. The P&O method works well in slow changing environment but has some limitations under rapidly changing atmospheric condition. The P & O algorithm is explained in the flow diagram below (Figure 8). By comparing previous and current output power; new perturbation direction can be decided. If $\Delta P*\Delta V>0$, the operating voltage should increase; while $\Delta P*\Delta V<0$, the operating voltage should decrease. The operating voltage change is done by changing the duty cycle of DC- DC converter.

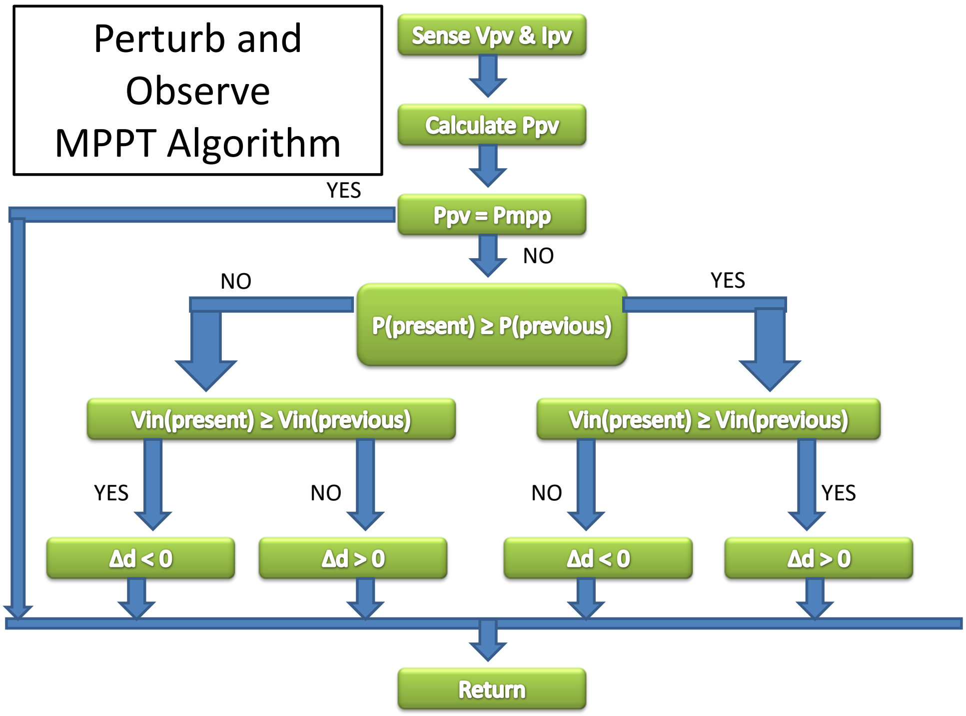

Figure 8. Perturb and observe (M.P.P.T.) algorithm [4]

V_{pv}	=	Panel output voltage
I_{pv}	=	Panel output current
P_{pv}	=	Panel output power
P_{mpp}	=	Power at maximum power point
d	=	Duty cycle of the DC-DC boost converter

V. A.A.P.C. (ABSOLUTE ACTIVE POWER CONTROL)

When power is generated using solar energy with the help of the photo voltaic cell/solar panel there are times when the whole solar power generation system is working on almost full-load. And when the system runs in such a condition for a long time it may get damaged due to overheating of the power electronic devices used in the system and it will degrade the inverter efficiency. So extracting maximum efficiency from system every time using MPPT technique is not correct. The solution for this problem is to limit the output power of the panel to a certain limit ($P_{limit)}$ so that system do not overload. While limiting the power output of the panel matter of concern is that it do not reduces the efficiency of the panel to very low level. The power limiting must be in an optimized manner. This power limiting or controlling method of called Absolute Active Power Control method. In this method the power output of the panel is limited to 80% of the rated power output capacity of the panel; so that the following system never gets overloaded as it will never let the power output reach the maximum power (P_{mpp}).

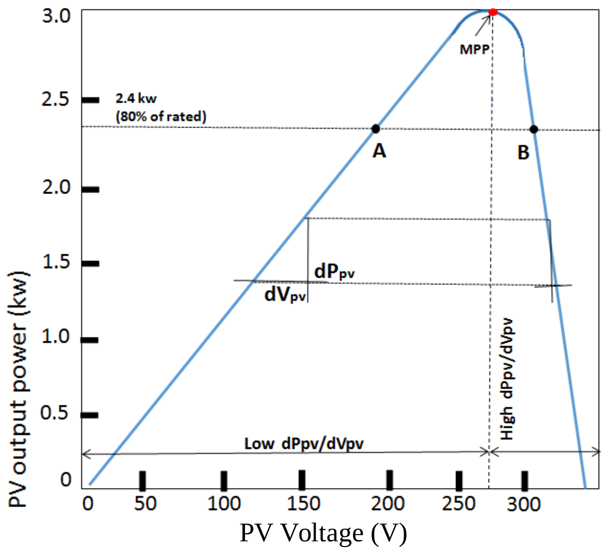

Figure 9. PV curve with AAPC algorithm [4]

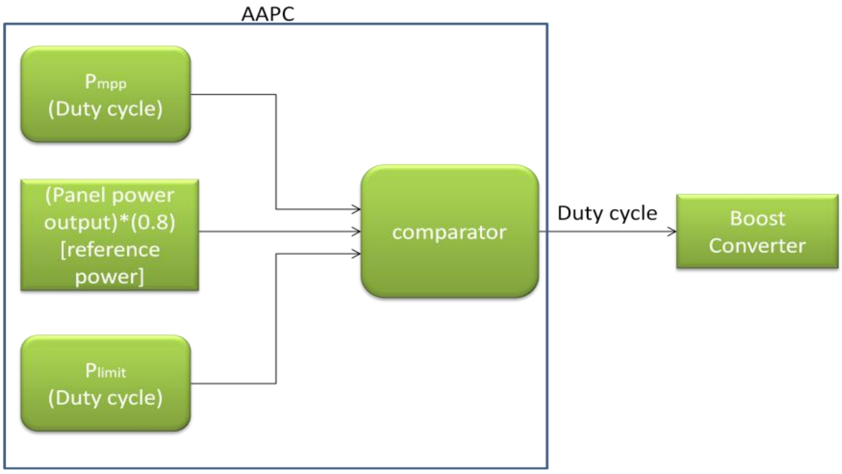

Figure 10. Proposed control system for AAPC [4]

The block diagram above (figure 10) shows the proposed system of AAPC strategy. As seen it controls the duty cycle of the boost converter for power control. It compares the power output of the panel with the P_{limit} value of power and if the panel output power is lower than P_{limit} then it will allow the system to work normally with MPPT but if the panel output power is higher than the P_{limit} value then the system will work in AAPC mode, the duty cycle for the P_{limit} will be supplied to the boost converter. In this way the panel power output is controlled using AAPC strategy.

VI. INVERTER AND GRID SYNCHRONIZATION

The inverter in the system is used to convert the DC voltage output of the DC to DC boost converter into AC voltage output. There are some inverter switching or controlling strategies i)Single Pulse Width Modulation, 2)Multiple Pulse Width Modulation, 3)Sinusoidal Pulse Width Modulation. Here in this system we are using Sinusoidal Pulse Modulation (S.P.W.M.). Here for switching the MOSFETs we are using the square wave along with SPWM waves to reduce the switching losses in the inverter (Figure 11).

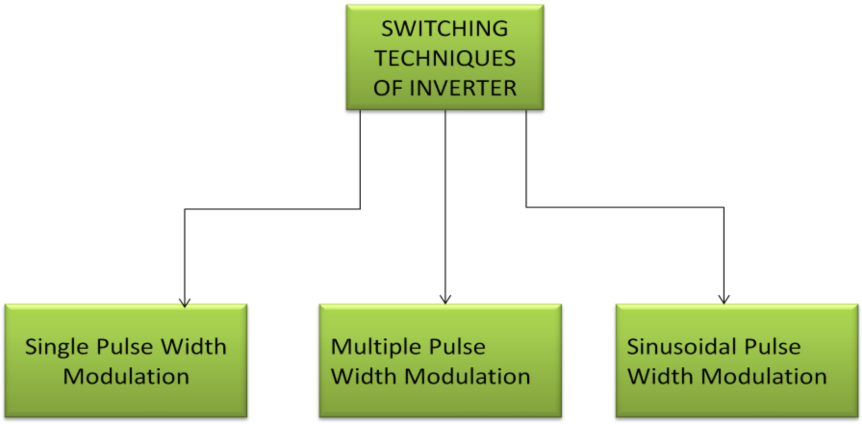

Figure 11. Switching Techniques for inverter [2]

The inverter switching is controlled by the sinusoidal PWM (SPWM) gating signals which drive the gate of the IGBTs. In order to generate the gating signal for the IGBTs by implementing the bipolar switching scheme, there are two inputs for the comparator which are a sinusoidal reference (Vr) signal and a triangular carrier signal (Vcr). When Vr has higher magnitude than Vcr, the comparator output is high (ON), otherwise it is low (OFF). The gating signal generation which is illustrated in term of waveform is depicted in Figure xx. The modulating signal frequency (f_m) is set to 50 Hz to match the frequency of the utility grid.

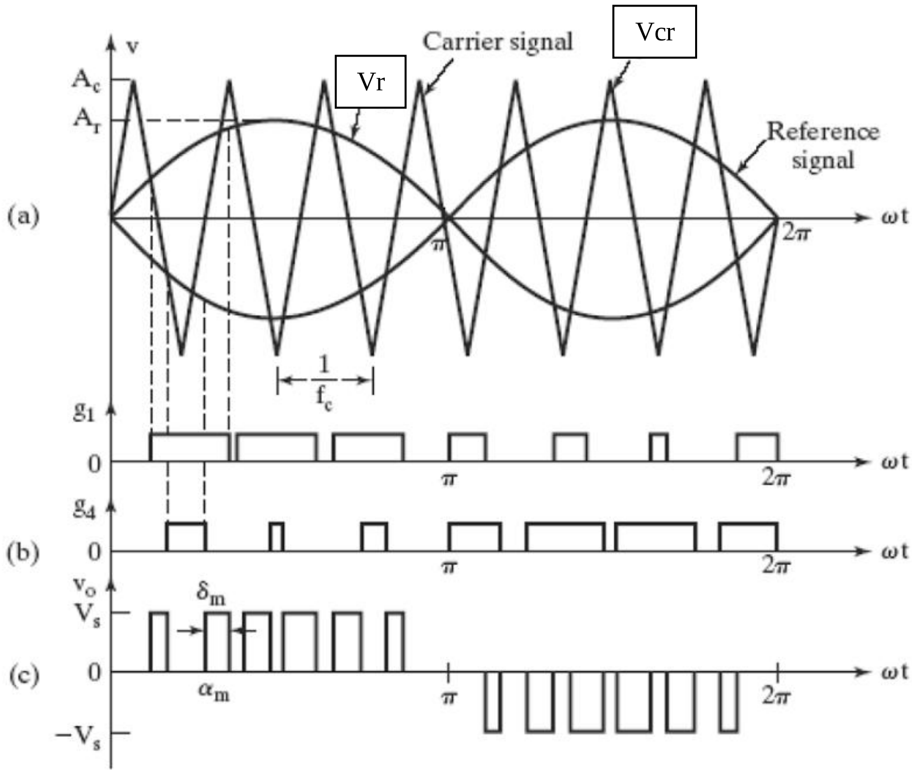

Figure 12. Gating signal generation [2]

Grid inverter needs a pure sinusoidal reference voltage to ensure that the sinusoidal output of the inverter is synchronized to the grid frequency. The voltage magnitude of the inverter output needs to exceed the grid voltage, to enable the inverter current to be supplied to the grid. The decoupling inductor, XL is needed to control the power flow from the inverter to the grid. The phase angle of reference signal (Vr) is varied with solar irradiance and temperature level in order to get the inverter current synchronized with the grid voltage. The appropriate phase angle for a certain range of temperature and irradiance level has to be set. In the developed model, the phase angle of Vr will automatically change to the appropriate value according to the range of cell temperature level.

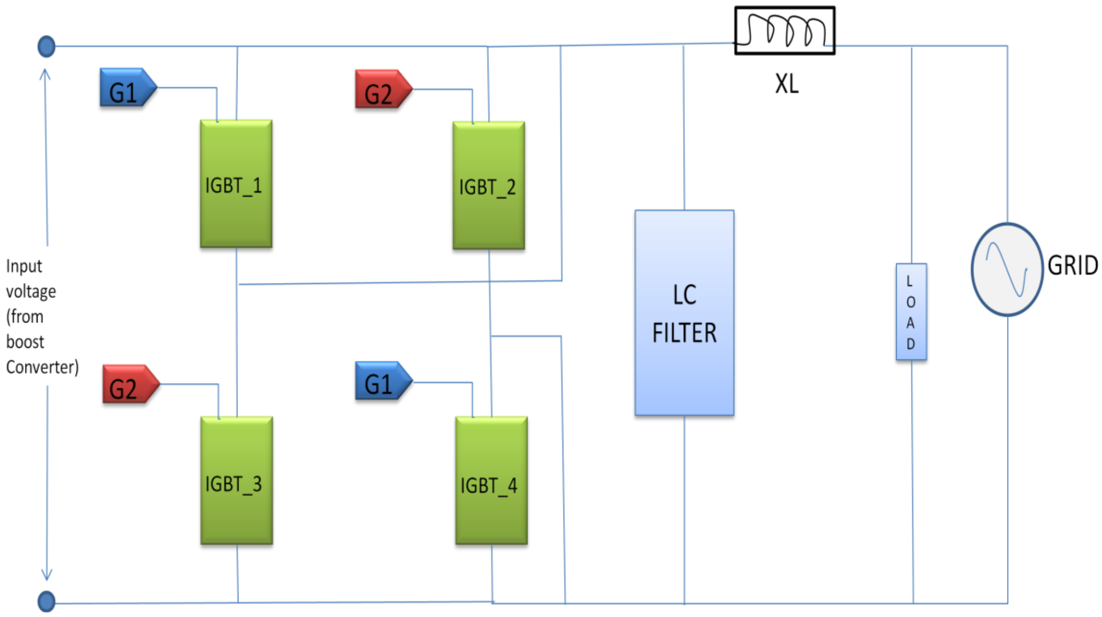

Figure 13. Inverter circuit diagram [3]

VII. SIMULATION & SIMULATION RESULTS

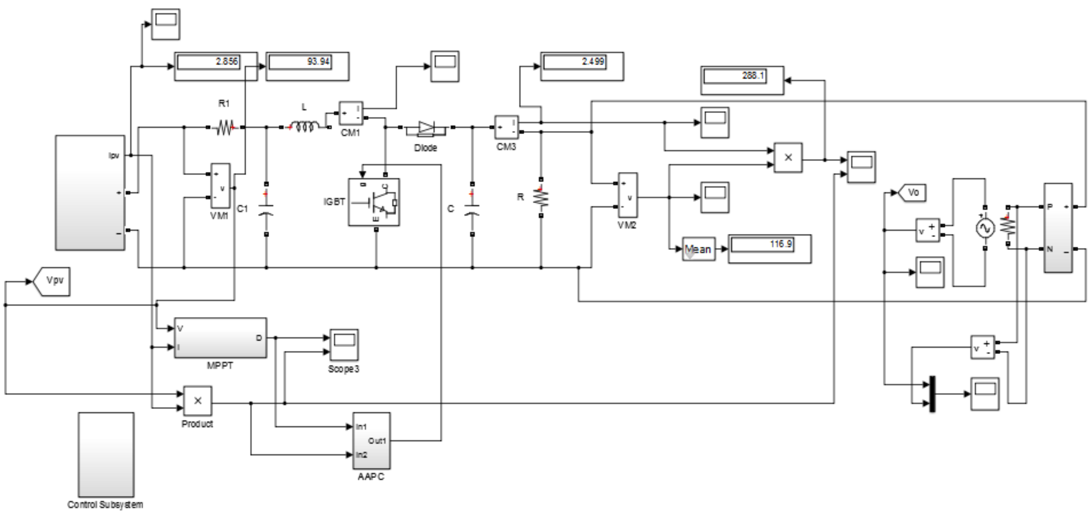

Figure 14. Complete system simulation

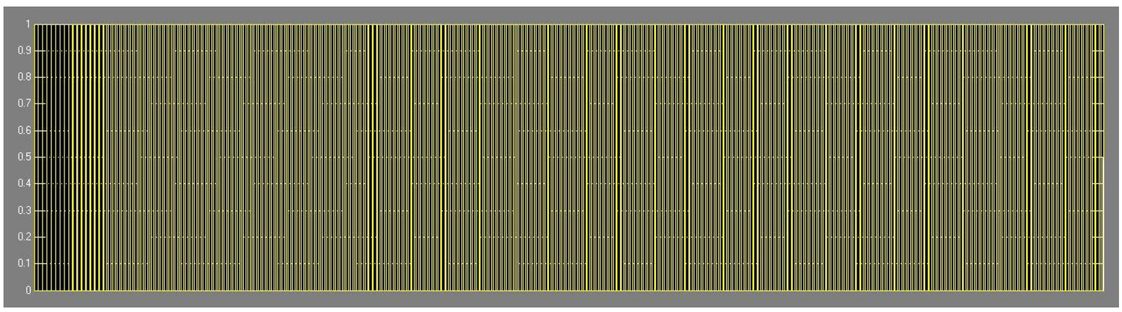

Figure 15.Duty cycle of the boost converter

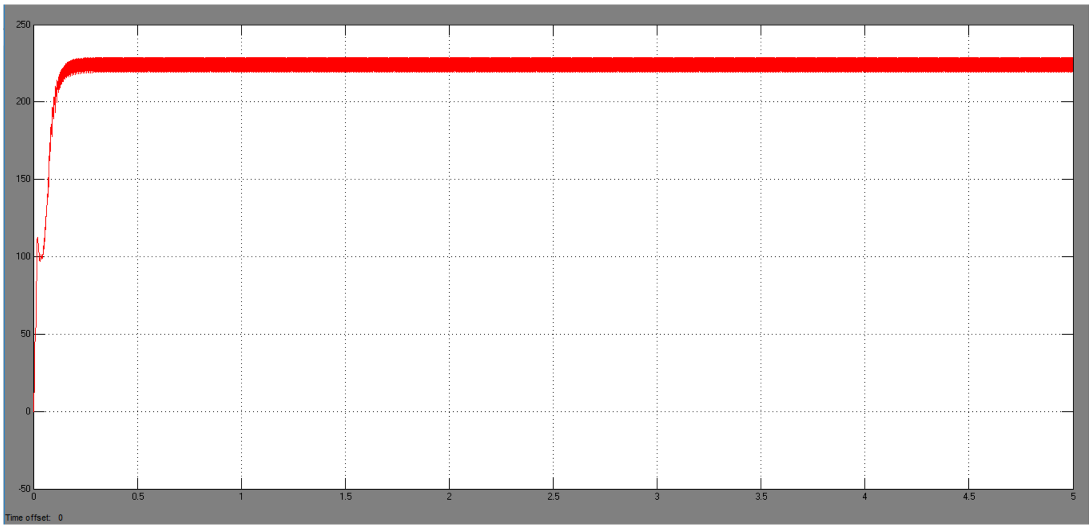

Figure 16. Boost output voltage (AAPC)

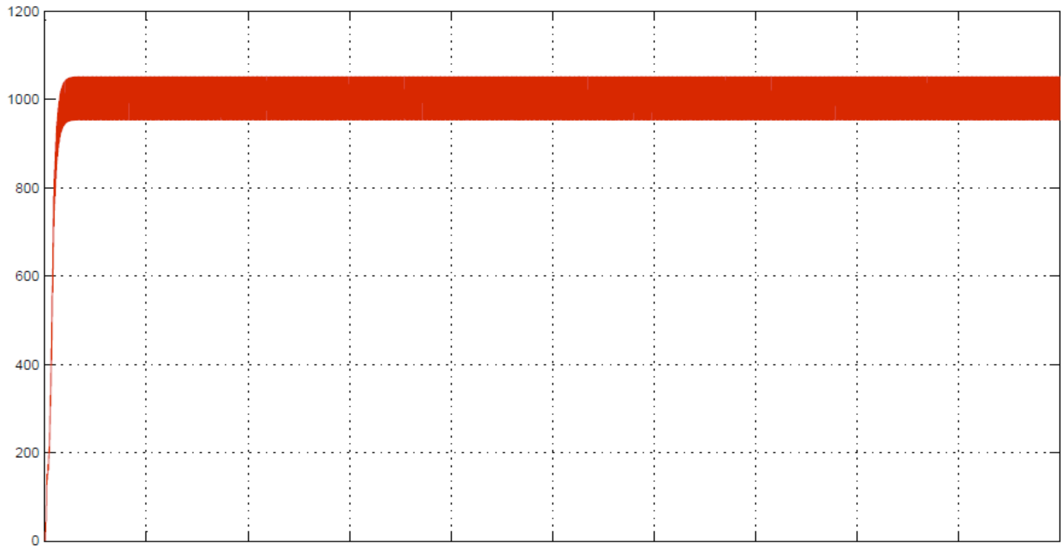

Figure 17. Power output with MPPT

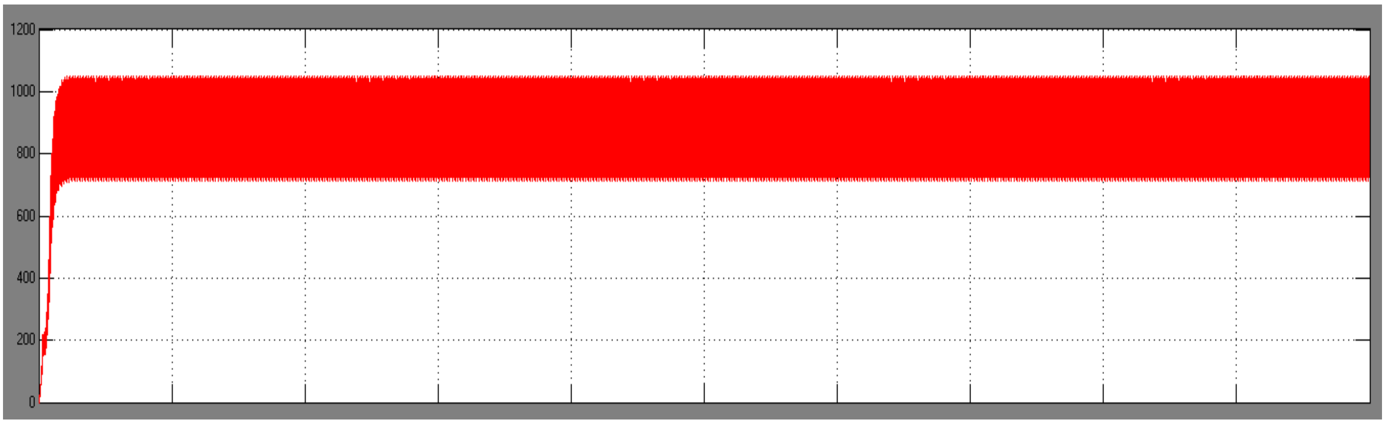

Figure 18. Power output with AAPC

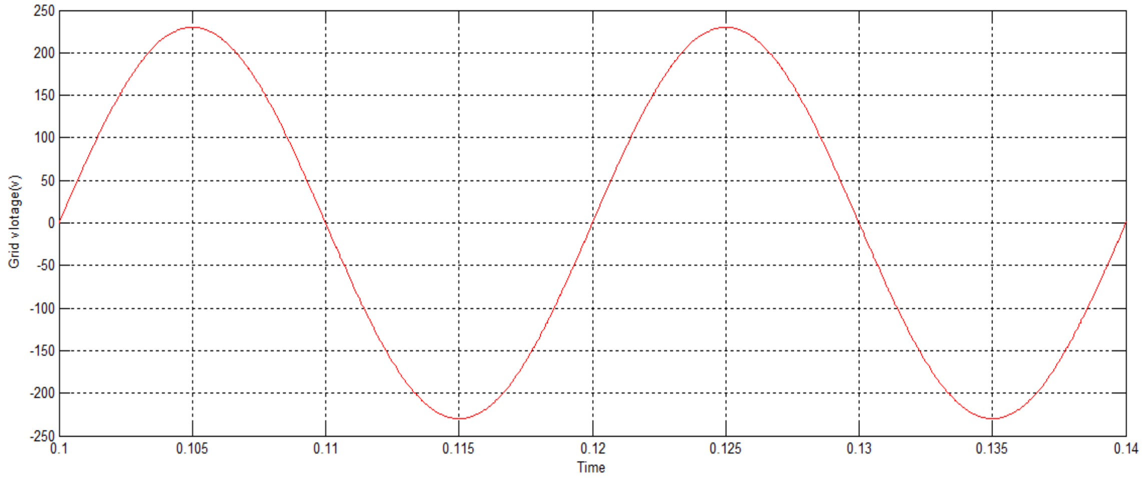

Figure 19. Reference waveform

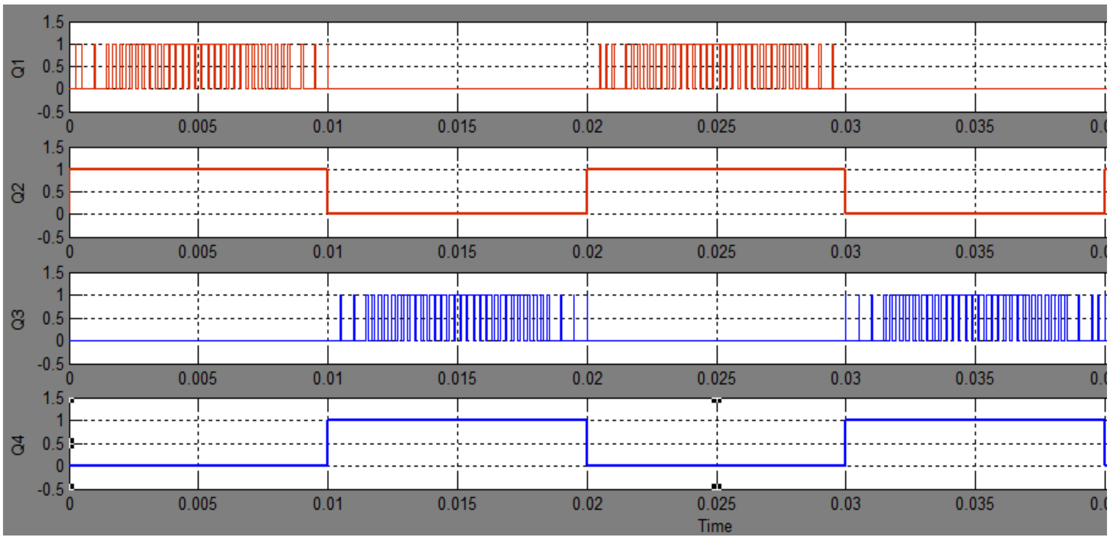

Figure 20. Gating signals for inverter

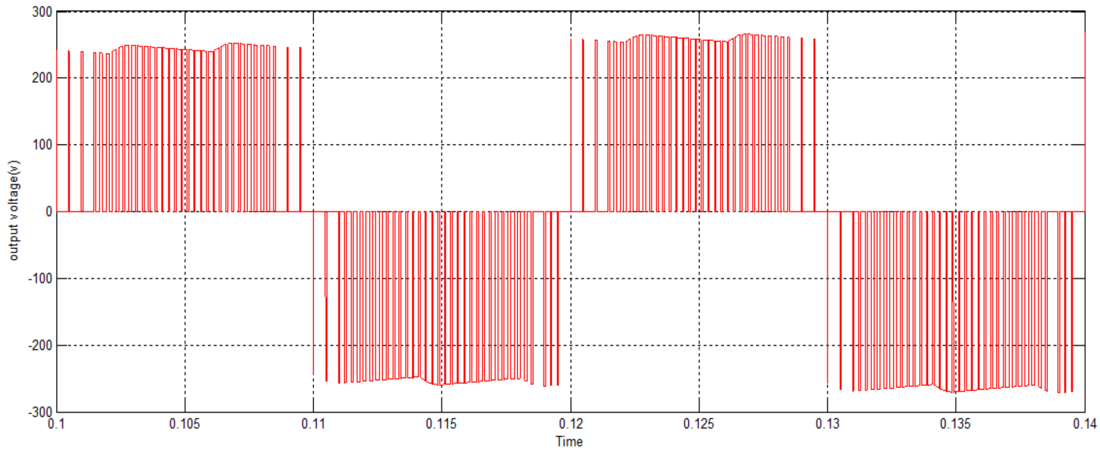

Figure 21. Inverter output

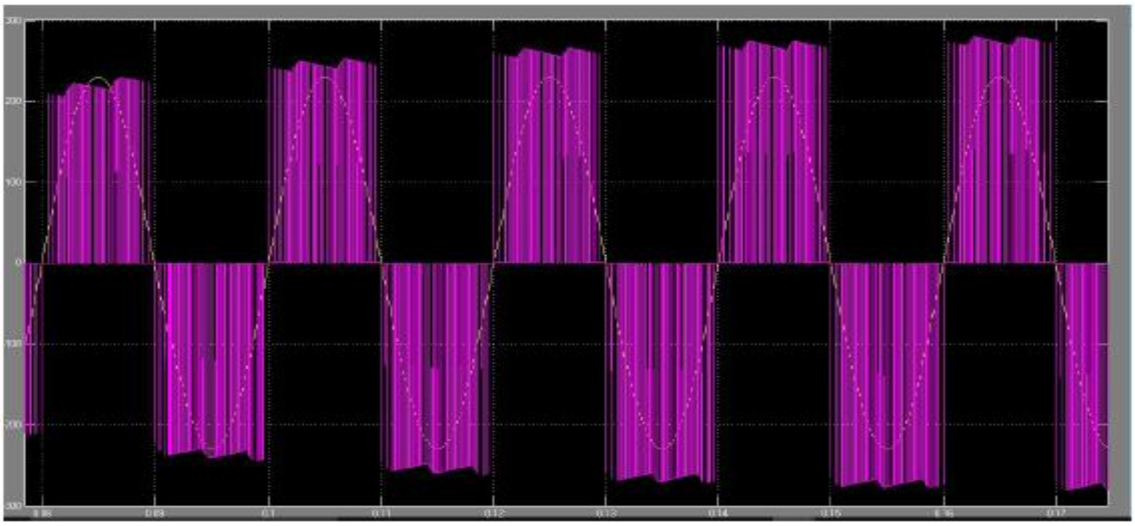

Figure 22. Grid synchronization

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