

Two Stage Grid Connected PV System Using Cuk Converter

Syam M.S, T.Sreejith Kailas

Abstract— In a grid connected photovoltaic system maximum power is to be drawn from the PV panel and has to be injected to the grid. For this various MPPT topologies and control methods are available. In a two stage system the loss factors such as fast irradiance variations, dc load variations, limited operating voltage range etc. cause zero loss but the use of additional converter causes extra loss in two stage system compared to the single stage grid connected system. As a result single stage grid connected systems are considered more efficient compared to the two stage systems in grid connected and stand alone applications. Thus in this paper, a Cuk converter is used instead of the boost converter that was used in the two stage conventional grid connected system. And as Cuk converter is having inductors at both input and output side it can reduce current ripples at both input and output sides, and it can also reduce the switching losses. Hence in this paper a Simulink model of two stage grid connected PV system using Cuk converter is presented. For tracking maximum power point the most common and accurate algorithm – incremental conductance algorithm is used. Inverter control is done using the DC bus voltage algorithm.

Index Terms— Cuk, DC/AC, DC bus voltage algorithm, DC/DC, Grid connected system, Photovoltaic system, Two stage system.

1 INTRODUCTION

Due to the depletion of conventional sources of energy and the very large time required for those to replenish renewable sources of energy like solar, wind etc. are getting more importance now a days. With the advancement in technology the efficiency of solar cells are getting increased which encourages the use of Photovoltaic system.

The main challenge of the generation side of the PV system is to generate as much power as it can, this is related to the payback and efficiency of the system. Thus in PV system efficient dc-dc converter is used to control the load power and to ensure that system operates in maximum power point. In this paper cuk converter is used in between the PV panel and inverter. In Cuk converter the source and load side are separated via a capacitor thus energy transfer from the source side to load side occurs through capacitor which leads to less current ripples at the source and load side. The most common algorithms for Maximum Power Point (MPP) are Perturb and Observe algorithm and Incremental conductance method [2-5]. MPP is oscillating in perturb and observe method and this will lead to power loss. This method cannot work efficiently under fast varying atmospheric conditions. These disadvantages are eliminated in incremental conductance method, which is used in this paper. Other methods of MPPT are parasitic conductance, Voltage controlled MPPT, Current controlled MPPT, Hill Climbing technique etc [6]. At the distribution side, whether standalone or grid connected, quality of power has to be ensured. And so in order to synchronize the generated PV power with the grid power, dc bus voltage algorithm is used. A lot of research has been done in GCPVS but only very few covers two stage GCPVS and the power loss caused due to the change in environmental conditions in two stage GCPVS is found to be zero [1], thus this paper presents simulation studies of a two stage grid connected PV system using cuk converter. Simulation studies were carried out using MATLAB Simulink 2012a.

2 SYSTEM MODELLING

The Modelling of GCPVS includes the modelling of PV module, modelling of DC/DC converter with suitable MPPT algorithm, modelling of inverter with suitable control and modelling of grid. These are separately discussed below.

2.1 PV Module

Using solar cell equations (1) and (2), model of PV module is built in Simulink. The model of a solar cell is shown in Fig.1 which is coded to obtain a PV module.

$$I_{ph} = I_L + I_d \quad (1)$$

$$I_d = I_o (e^{(v \cdot q / k \cdot T)} - 1) \quad (2)$$

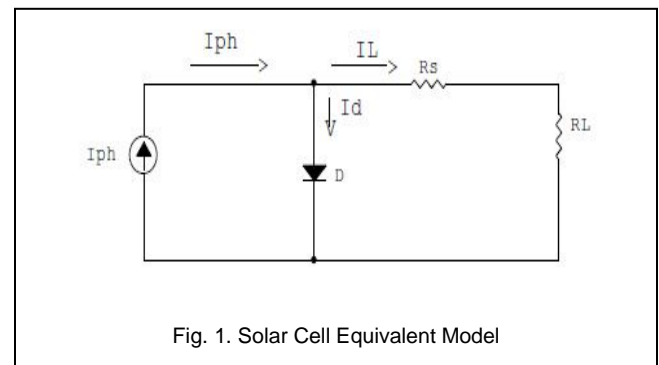


Fig. 1. Solar Cell Equivalent Model

Change in Irradiance affects the photon generated current, corresponding change on the open circuit voltage is less. Temperature variation affects the open circuit voltage, corresponding short circuit current change is less. The change in photon generated current, I_{ph} by the variation in irradiance is given by,

$$I_{ph} = I_r * I_{sc} \quad (3)$$

Where, I_{sc} is the short-circuit current of the module at 1000 W/m² and I_r is the Irradiance level.

2.2 Cuk Converter

Among the various DC/DC converter topologies available, buck-boost and cuk topologies can only produce output voltage higher or lower than the input voltage. Discontinuous input current, high peak currents in power components, and poor transient response of the buck boost converter leads to its less efficiency. Whereas Cuk converter has low switching losses and highest efficiency among the non-isolated dc-dc converters. Also due to the inductor at the input and output stages of cuk converter these currents are free from ripples and thus can provide better input/output current characteristics.

Operation of cuk converter shown in Fig.2 can be explained in two steps. In first step, when switch is closed capacitor releases energy to the output. Corresponding equations for this stage are as follows:

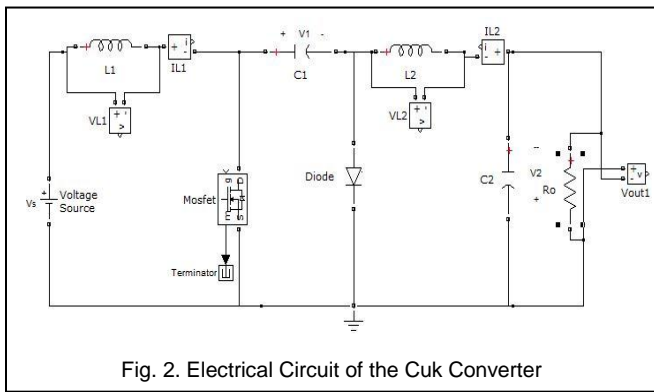


Fig. 2. Electrical Circuit of the Cuk Converter

On the second stage, when the switch is open, the diode is forward-biased and conducting energy to the output, as shown in Fig.3. Capacitor C1 is charging from the input. The equations for this mode of operation are as follows:

When Switch is ON,

$$v_{L1} = v_s \quad (4)$$

$$v_{L2} = -v_1 - v_2 \quad (5)$$

$$i_{c1} = i_2 \quad (6)$$

$$i_{c2} = i_2 - \frac{v_2}{R} \quad (7)$$

When Switch is OFF,

$$v_{L1} = v_s - v_1 \quad (8)$$

$$v_{L2} = -v_2 \quad (9)$$

$$i_{c1} = i_1 \quad (10)$$

$$i_{c2} = i_2 - v_2 * R \quad (11)$$

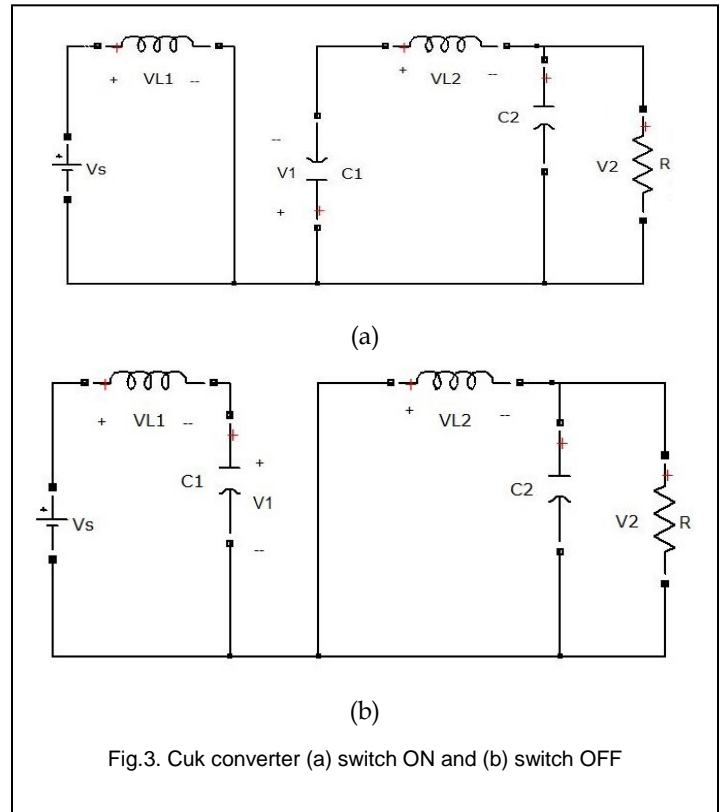


Fig.3. Cuk converter (a) switch ON and (b) switch OFF

From the operating conditions, at steady state the average values of inductor voltage and capacitor current waveforms are zero. Thus for a cuk converter, output and input currents and voltages are given as:

$$\frac{v_0}{v_{in}} = \frac{I_{in}}{I_0} = -\frac{D}{1-D} \quad (12)$$

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2.3 Inverter Control

The dc capacitor voltage at the output of cuk converter, V_{dc} provides the information regarding the real power flow between the solar module and the grid, thus by regulating this voltage a current component proportional to the real power flow, I_{Real} , can be derived which can be used for the reference generation for the control of inverter.

$$U_a = \sin(\theta) \tag{13}$$

$$U_b = \sin(\theta - \frac{2\pi}{3}) \tag{14}$$

$$U_c = \sin(\theta + \frac{2\pi}{3}) \tag{15}$$

Using PLL grid synchronizing angle is found out which is then used to find unity grid voltage samples, (U_a, U_b and U_c). These samples are then multiplied with the real power component for producing the reference grid currents, (I_a^*, I_b^* and I_c^*).

$$I_a^* = I_{Real} * U_a \tag{16}$$

$$I_b^* = I_{Real} * U_b \tag{17}$$

$$I_c^* = I_{Real} * U_c \tag{18}$$

The difference of reference grid currents and actual grid currents is then given to a hysteresis controller, which then produces the required six pulses for the three phase inverter.

3 SIMULATION

3.1 PV Module

A Simulink model of a PV cell is built as shown in Fig.4 which is then masked and is programmed to build a PV module model in Simulink.

For a PV array,

$$V_T = \frac{k * T}{q} * n_{cells} * Q_d \tag{19}$$

$$I_{ph_array} = I_{ph} * N_{par} \tag{20}$$

$$I_{sat_array} = I_{sat} * N_{par} \tag{21}$$

$$V_{T_array} = V_T * N_{ser} \tag{22}$$

$$R_{s_array} = R_s * \frac{N_{ser}}{N_{par}} \tag{23}$$

$$R_{p_array} = R_p * \frac{N_{ser}}{N_{par}} \tag{24}$$

Where, K is Boltzmann constant, q is electron charge, T is cell temperature, nCells is Number of cells in series per module, Rs is Series resistance of PV model, Rp is Parallel resistance of PV model, Isat is Diode saturation current of PV model, Iph is Light-generated photo-current of PV model, Qd is Diode quality factor of PV model, Npar is Number of parallel strings and Nser is Number of series-connected modules per string.

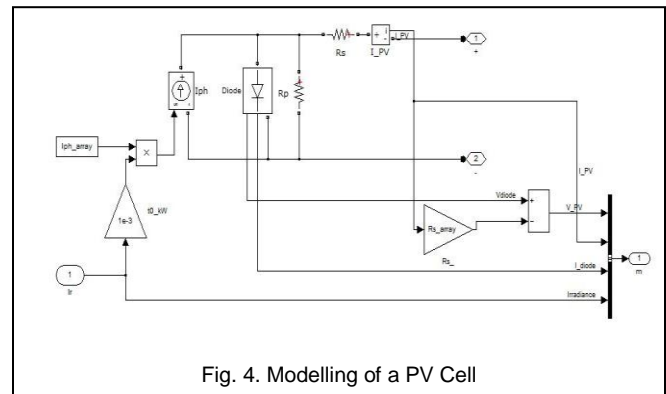


Fig. 4. Modelling of a PV Cell

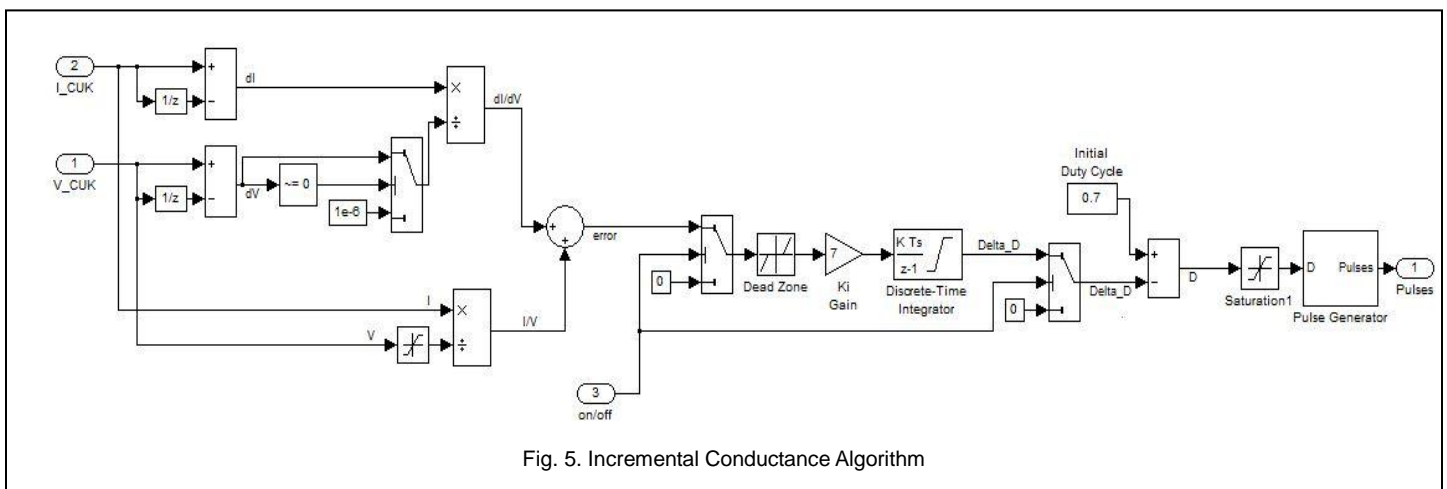
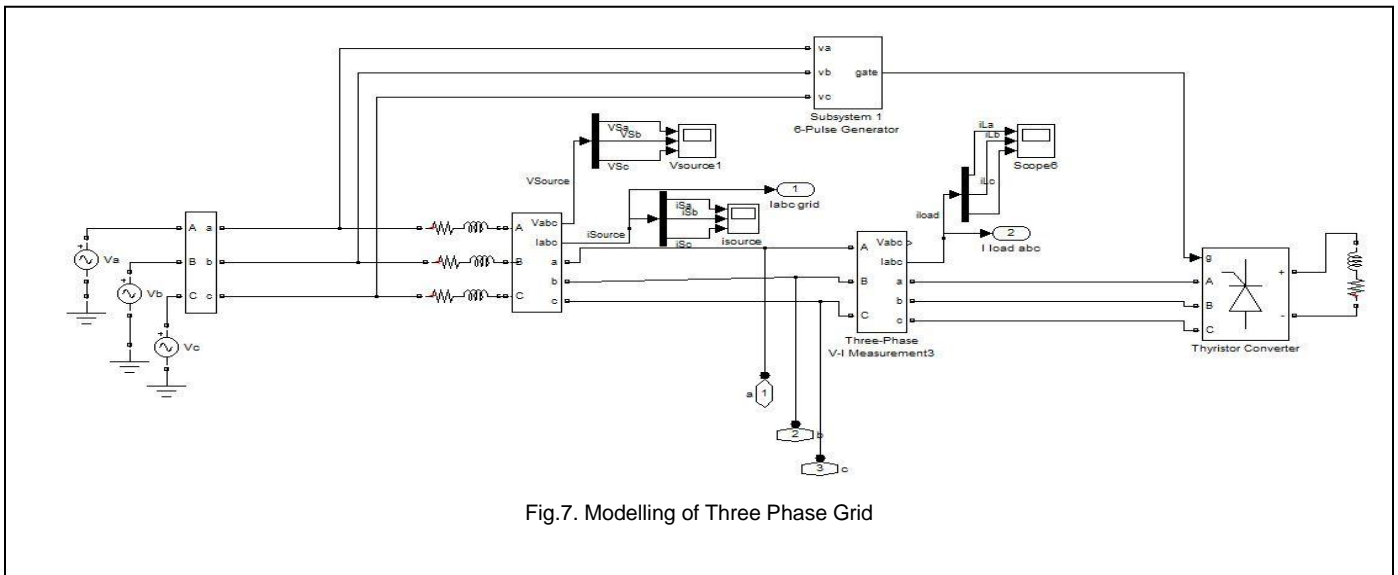
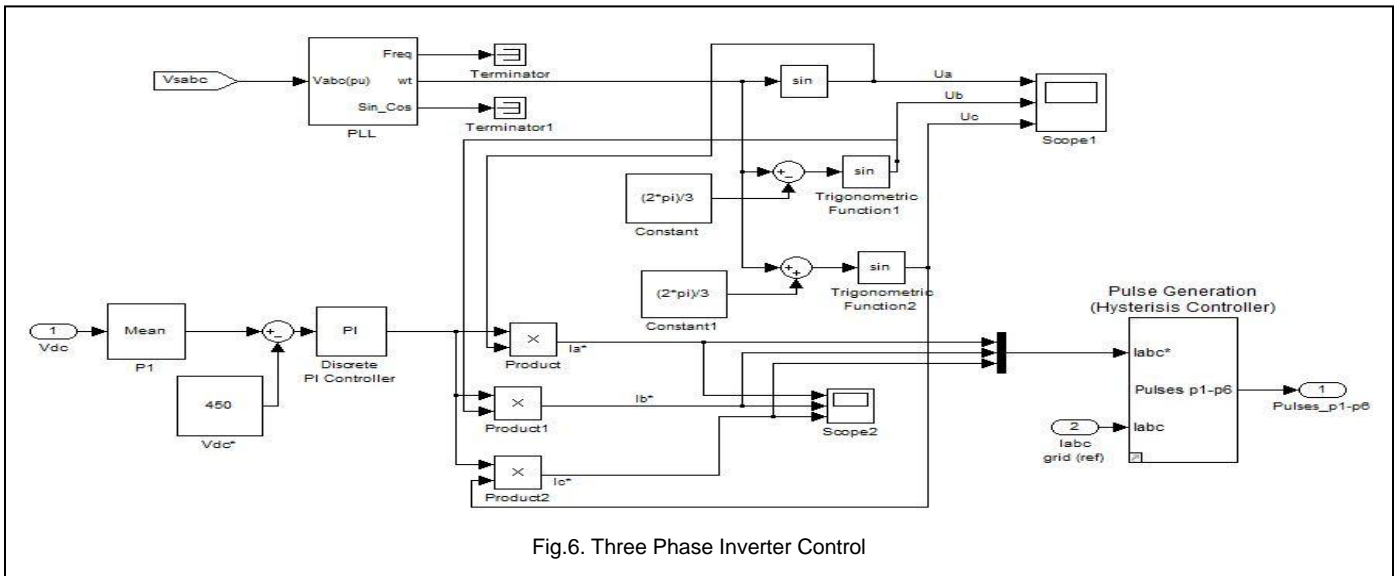


Fig. 5. Incremental Conductance Algorithm



3.2 MPPT

Incremental conductance algorithm as shown in Fig.5 is implemented for MPPT. In this method, incremental conductance and instantaneous conductance is added, to calculate the error. If the error exceeds 0.5 then a corresponding change is given for the duty cycle. The error is assumed to be in the range -0.2 to 0.2.

3.3 INVERTER CONTROL

Grid voltage is measured and it is used for generating unit reference signals. Difference of Reference dc voltage and output dc voltage gives the change in the dc voltage level and is given to a PI regulator to maintain constant output for the varying atmospheric conditions. Active current component, IReal when multiplied with unit reference signals produces the required reference current signal, Iabc*. Actual grid current and reference grid current are given to a hysteresis con-

troller, which generates the required six pulses for the three phase inverter. Fig.6 shows the inverter control implemented in Simulink.

3.4 Grid Modelling

A 3 ϕ Grid is modelled using three single phase sources as shown in fig.7, with a balanced load which is a thyristor converter fired by a six pulse generator. Generated 3 ϕ power is injected to 3 ϕ grid

4 SIMULATION RESULTS

Fig.8 and Fig.9 Shows the I-V and P-V curve of the P-V module. Output of PV module is connected to the cuk converter. Output of cuk converter is shown in Fig.10 and Fig.11 which is maintained constant by properly adjusting the duty ratio using incremental conductance algorithm.

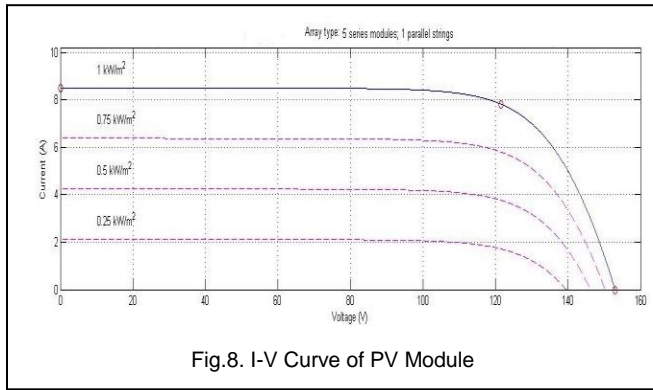


Fig.8. I-V Curve of PV Module

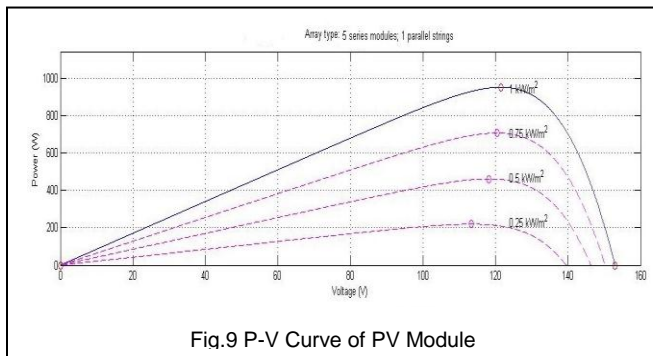


Fig.9 P-V Curve of PV Module

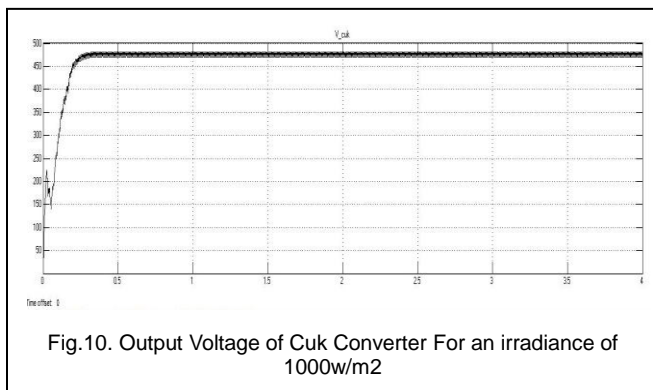


Fig.10. Output Voltage of Cuk Converter For an irradiance of 1000w/m2

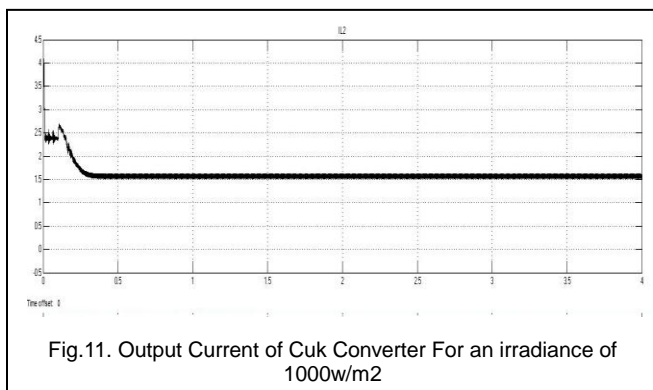


Fig.11. Output Current of Cuk Converter For an irradiance of 1000w/m2

ed as shown in Fig.12. By measuring the output Cuk voltage, an active current component proportional to the real power flow, I_{Real} , can be formed which when multiplied with the unit reference components of each phases, reference current is generated. . Hysterisis Controller takes the reference current and grid current for generating the control pulses for inverter, by properly adjusting the hysteresis band control pulses are generated as shown in Fig.13.

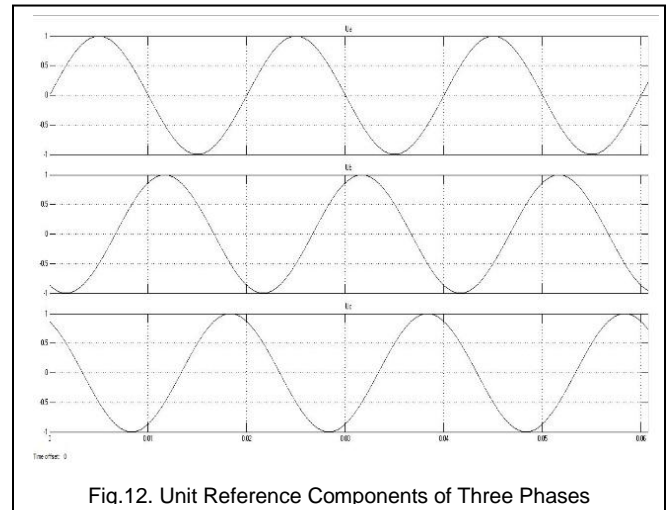


Fig.12. Unit Reference Components of Three Phases

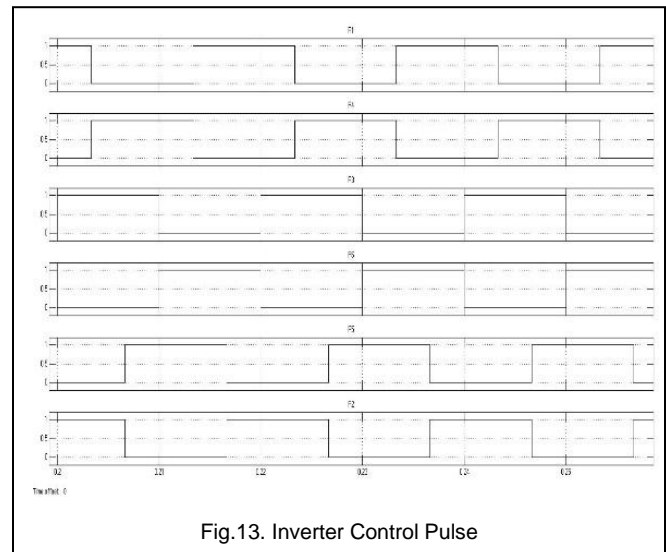


Fig.13. Inverter Control Pulse

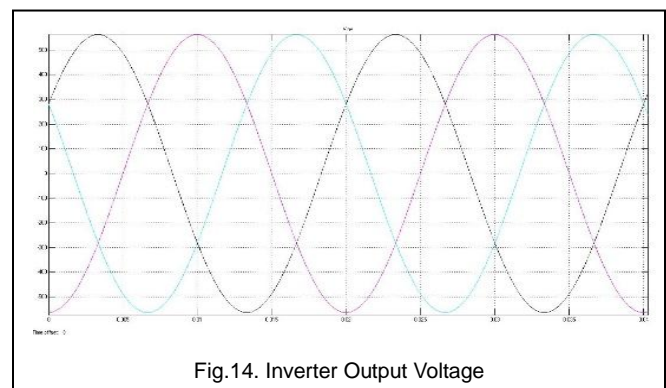


Fig.14. Inverter Output Voltage

Inverter control is done by measuring the cuk output voltage, Grid voltage and Grid Current. By measuring the grid voltage, PLL will generate a synchronizing angle, using that the unit reference components of three phases can be generat-

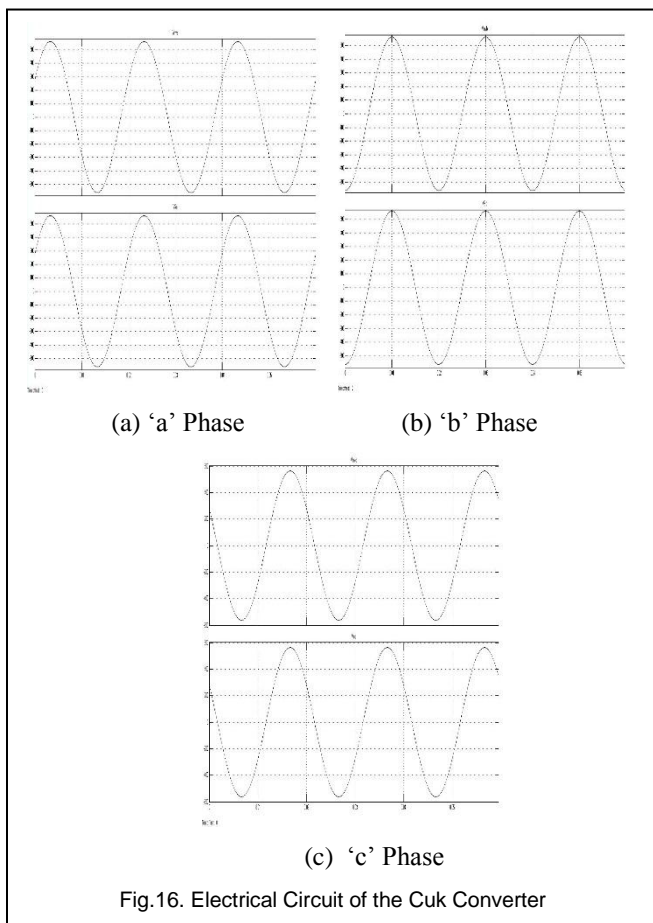
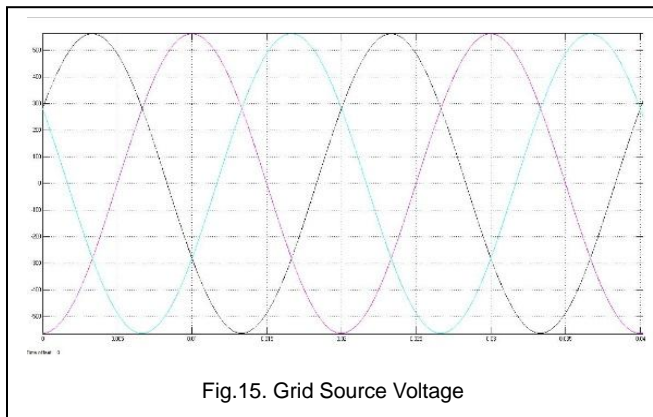


Fig.14 and 15 shows the phase to phase maximum voltage obtained at the output of inverter and grid respectively. Fig.16 shows the inverter output voltage and grid voltage waveforms for all the three phases.

4 CONCLUSION

Output voltage change due to environmental factors such as irradiance, temperature, shading effects etc. are zero in two stage GCPVS. Hence, a MATLAB simulation of 3 ϕ , two stage grid connected photovoltaic system is presented using Cuk converter and using incremental conductance algorithm which is the common and accurate method of mppt. Further, Cuk converter can step up or step down the input PV voltage de-

pending on the change in irradiance and thus can maintain the output voltage. Also, output current of cuk converter is found to have less current ripples, this helps in maintaining the power quality. Thus this paper presented an efficient means of grid connected photovoltaic system.

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