PV Fed Grid Power Control by Discrete CUK Converter and SPWM Inverter Control Techniques

Viji K¹, Chitra K² and Lakshmanan M³
¹ Assistant Professor, Department of EEE, CMR Institute of Technology, Bengaluru, India.
² Associate Professor & Head, Department of EEE, CMR Institute of Technology, Bengaluru, India.
³ Associate Professor, Department of EEE, CMR Institute of Technology, Bengaluru, India.

E-mail: kvijiperumal@gmail.com

Abstract. In this paper the power supplied to the grid is regulated with the help of Discrete Sliding Mode Controlled (DSMC) CUK converter and Sinusoidal Pulse Width Modulation (SPWM) topology controlled 3-phase Inverter. The CUK converter is used in the input side to Buck or Boost the PV (Photo Voltaic) array voltage to the required value of the 3-phase Inverter. Natural isolation of source and load is obtained in the CUK converter with the help of capacitor energy transfer so that the ripple content is less in both load and source side. These CUK converters are operating in continuous current mode so that regulation of power from the solar panel is easy and efficient compared to Buck-Boost converters. In this paper DSMC CUK converter topology is implemented so that converter is feasible to incorporate with any digital controller with less hardware requirements, it has flexibility in control characteristics and guaranteed stability of highly fluctuating solar power under different climate conditions. The simulation model has battery back-up which is charged during high irradiation time and provides power to load during less irradiation climate conditions. The 3-phase Inverter is controlled by SPWM technique to reduce the switching losses of the Inverter so that the harmonics in the load side is less and it is easy to implement. So that the overall system is efficient, ease of implementation, robust and economical.

1. Introduction
The power generation using renewable energy sources (RES) is in demand due to the growing need of electrical power and the exhaustion of conventional sources including the growing price of those. Solar energy is one of the RES which converts heat energy from the sun into electrical energy which is free of cost, will not pollute the environment and available enrich in nature. In the beginning days the price of the PV array is high with poor system efficiency; but due to energy demand and the research carried out in that related area leads to the development of new control techniques to overcome all the related issues in present days. So there is a need of efficient converter and robust control technique to stabilize the power produced by the PV array all the time irrespective of the climate conditions. Thus CUK converter is used in this application which is operating in continuous current mode so that it is easy to control the output power in all the climate conditions. DSMC technique is implemented to regulate the output power and the stability of the system is ensured by Lyapnov stability criteria [9]. The system is
robust due to the implementation of the Sliding Mode Control technique under unexpected uncertainties. The Perturb and Observe algorithm along with Incremental Conductance method is used to attain Maximum Power Point Tracking (MPPT) of the PV array but the power is fluctuating with increase in losses [1]. The voltage controlled MPPT and current controlled MPPT are implemented in paper [2] and the response was studied. The CUK DC-DC converters are used to transfer the energy produced by the PV module to the load side using MPPT algorithm with the increased energy transfer capability so that the switching losses are reduced and the efficiency increases [3]. So that CUK converter is selected in this paper for the PV fed grid application. Once the required DC power is received from the PV array using CUK converter it has to be efficiently connected to the grid to satisfy the load demand; for that there is a requirement of DC-AC converter called Inverter. The converted AC power from Inverter is stepped up by means of step-up transformer to send it to the transmission line and once again stepped down on the end before connecting it to the grid [4]. In this paper 3-phase Inverter is used to interface the CUK converter with grid and the Inverter is controlled with SPWM technique to reduce the switching losses and harmonics.

1.1. Block Diagram Description

![Block Diagram of PV Fed Grid](image)

The block Diagram of the PV fed Grid is shown in the figure.1. The heat energy of the sun is converted into electrical energy with the help of solar cells which is given as input to the CUK converter. The CUK converter is a type of DC-DC converter which can be step-up or step-down the input voltage according to the load requirement [5-6]. The inductor current and output voltage of the converter is sensed and the controlled with the help of DSMC. Since the controller is discrete it is easy to communicate with any digital devices; the generated gate pulse of the digital controller is given to the gate of the MOSFET. The controlled DC voltage is given as input to the 3-phase Inverter at the same time the DC voltage is charging the battery as well. During the night time and rainy season supply will be taken from the battery.
The 3-phase Inverter is controlled by measuring the real and reactive power of the grid. These values are compared with the reference and the error is obtained. With the help of PI controller, the error values are converted into proportional Modulation Index (M) and shift values. The reference signal generator generates 3-phase reference signal for Sinusoidal Pulse Width Modulation (SPWM) generator with respect to the new values of M and shift. The generated PWM signals are given the driver circuit of the 3-phase Inverter to control the AC voltage output of the Inverter connected to the grid. In such a way the active and reactive power of the grid is controlled.

2. Methodology of Work
2.1. Design of PV Array
The heat energy from sun which is a kind of renewable energy is converted into electrical energy with the help of PV array. It has series and parallel combination of PV module. The equivalent circuit of solar cell is shown in figure 2; it has one current source, one diode and two resistors in series and shunt to represent the losses in the cell. The voltage produced in the cell is given by V and the current flowing through the cell is given by I.

![Figure 2. Solar Cell Equivalent Circuit](image)

In this application the PV array of 1STH-215-P type is selected with 4 series modules and 3 parallel strings; the voltage, current and power response of the Array is shown in the figure 3 for 1KW/m². This response is obtained by selecting the irradiance of 1000W/m² with the temperature of about 25°C. The table.1 gives the selected PV Array Module data.

![Figure 3. The Voltage, Current and Power Response of PV array Module](image)
| Parameter                          | Value                  |
|-----------------------------------|------------------------|
| Module Type                       | 1Soltech 1STH-215-P    |
| Maximum Module Power              | 213W                   |
| Open Circuit Voltage Voc          | 36.3V                  |
| Voltage at MPP                    | 29V                    |
| Temperature coefficient of Voc    | -0.36(%/deg.C)         |
| No of Cells per Module            | 60                     |
| Short-Circuit Current Isc         | 7.84A                  |
| Current at MPP Imp               | 7.35                   |
| Temperature Coefficient of Isc    | 0.102(%/deg.C)         |

### 2.2. Mathematical Modeling of DSMC CUK Converter

In this paper CUK converter is used as DC-DC converter which converts input PV array DC voltage to the required output DC voltage for the Inverter. These converters can step-up or step-down the input voltage similar to Buck-Boost converter with inverted output voltage. The schematic diagram of Cuk converter is illustrated in figure 4. This converter uses an additional capacitor C2 and inductor L2 along with C1 and L1 to buck or boost the input voltage. The inductor L1 is connected in series with the source Vs resembles the Boost Converter and the switch S1 is connected in shut with the source. The load resistance (R) of 150Ω is used which is connected across the capacitor C2 so that the load voltage is the voltage across the capacitor C2. The parameters to be under control is the inductor L1 current iL1 and the output voltage Vo which is nothing but the voltage across the capacitor VC2. The freewheeling diode D is used to charge and discharge the inductor current and capacitor voltage [7-8].

![Circuit Diagram of CUK Converter](image)

From the equivalent circuit the switch ON and OFF conditions are considered to obtain the state space model of the system. To ensure the stability the system should track the sliding surface given in equation 1.

The sliding surface is given by

\[ S[k] = e_p[k] + \rho_1 e_i[k] + \rho_2 e_v[k] \]  \hspace{1cm} (1)

Where \( \rho_1, \rho_2 \) are the switching functions of the sliding surface. Current Error is expressed as \( e_i = (i_{L1} - i_{ref}) \), Voltage Error is expressed as \( e_v = (V_{C2} - V_{ref}) \) and the power Error is expressed as \( e_p = (V_{C2}i_{L1} - V_{ref}i_{ref}) \).

The control law is given by

\[ u = \frac{1}{2} (1 - \text{sgn}(S)) = \{(0 \text{ if } S>0 \text{ else } 1 \text{ if } S<0)\}. \]  \hspace{1cm} (2)
The stability is obtained by Lyapnov Stability method. Table 2 shows the parameters used for the CUK Converter for the simulation.

| Parameter              | Value    |
|------------------------|----------|
| Inductor L1            | 2.01 mH  |
| Inductor L2            | 1.09 mH  |
| Capacitor C1           | 830 µF   |
| Capacitor C2           | 49 µF    |
| Load Resistance R      | 150 Ω    |
| Switch Frequency       | 40 KHz   |
| Sampling Frequency     | 400 KHz  |

3. Results and Discussion

The 5KW Grid active and reactive power is to be regulated with the power factor of about 0.9. PV Array of Model: 1Soltech 1STH-215-P is used for this simulation with 4 series modules and 3 parallel strings are used to give the voltage of around 100V under the irradiance of 1000 W/m² at 25°C. MOSFET is used as a switch for CUK converter and the simulation is done with the help of MATLAB/SIMULINK simulation software. Figure 5 Shows the CUK converter response in which 5 (a) shows the PV array response of 100V and 20A current. Figure 5(b) shows the generated PWM signal for the CUK converter using DSMC technique. Figure 5(c) shows the CUK converter output voltage which is boosted of about 130V.

The output of the CUK converter is given to the 3-phase inverter. Grid voltage and current are sensed active power (P) and reactive power (Q) values are calculated; the calculated values are compared with the references and the error values are obtained. Proportional-Integral (PI) controller is used to control the error values and to generate the modulation Index (M) and the phase shift. These values are given to the 3-phase reference signal generator to produce the Sinusoidal Pulse Width Modulated (SPWM) gate pulse for the 3-phase Inverter [10]. The SPWM signals generated for the 3-phase Inverter switches is shown in Figure 6 (a-f).
Figure 6. SPWM Signals Generated for 3-Phase Inverter

Figure 7. Line Voltage of 3-Phase Inverter

Figure 8. Response of the Grid

The response of the 3-phase Inverter is shown in figure 7 in which 7(a) gives the line voltage $V_{ab}$, 7(b) gives the line voltage $V_{bc}$, and 7(c) shows the line voltage $V_{ca}$. The maximum voltage of about ±200V is obtained from the 3-phase Inverter. The voltage and current response of the grid is shown in the figure.
8 with the maximum voltage of 300V and maximum current of 100A. The total harmonic distortion of the grid current is less than 5% and it is the accepted range according to IEEE standards.

4. Conclusion
The PV fed Grid power using DSMC CUK converter and SPWM controlled Inverter is simulated using MATLAB/Simulink software and the responses are plotted. The stability and robustness of the system is achieved by DSMC algorithm and the performance of the system is good for the range of switch functions of the sliding surface \(\rho_1\) from 150 to 200, \(\rho_2\) is from 150 to 300. The Inverter is controlled with the help of SPWM technique which reduces the harmonics of the load current as less than 5% so the controller is more efficient.

References

[1] D. P. Hohm M. E. Ropp, Comparative 2000 Study of Maximum Power Point Tracking Algorithms Using an Experimental, Programmable, Maximum Power Point Tracking Test Bed IEEE pp 1699-1702

[2] Pefitis D et al 2008 A new MPPT method for Photovoltaic generation systems based on Hill Climbing Algorithm Proc. International Conference on Electrical Machin 1-5

[3] Azadeh Safari and Saad Mekhilef 2011 Simulation and Hardware implementation of Incremental Conductance MPPT with Direct Control Method Using Cuk Converter IEEE Transactions on Industrial Electronics 58

[4] Syam M S and T. Sreejith Kailas 2013 Grid Connected PV System using Cuk Converter International Conference on Microelectronics, Communication and Renewable Energy (ICMiCR-2013)

[5] Jayalaksmi N. S. Et al 2017 Design and Implementation of Single Phase Inverter Based on Cuk Converter for PV System International Journal Of Renewable Energy Research 7 585-591

[6] Piyush Choudhary and Som Nath Mahendra 2016 Feedback control and simulation of DC-DC Cuk converter for solar photovoltaic array 2016 IEEE Uttar Pradesh Section International Conference on Electrical, Computer and Electronics Engineering (UPCON) Indian Institute of Technology (Banaras Hindu University) Varanasi 591-596

[7] P. Nagalakshmi Kanna and B. Meenakshi 2015 Analysis and Design of DC- DC/AC NonIsolated Cuk Converter using Sliding Mode Controller IEEE 2015 International Conference on Circuit, Power and Computing Technologies [ICCPCT]

[8] Sidharth Samantara et al 2015 Modeling and Simulation of Integrated CUK Converter for Grid Connected PV System with EPP MPPT Hybridization 2015 IEEE Power, Communication and Information Technology Conference (PCITC)

[9] Viji.K et al 2017 Qualified Analysis of DSMC over SMC for Boost Converter International Journal of Control and Automation (IJACA) 10 2207-6387

[10] Chitra K et al 2019 Design And Implementation Of Simple Boost Pwm Controlled T-Source Inverter For Solar PV Application International Journal Of Scientific & Technology Research 8 717-720