DESIGN OF STANDALONE PV SYSTEM WITH CUK CONVERTER

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Abstract- With the growing population of the country, it is hard for the government to provide basic electricity to the people. However, it is the responsibility of the governement to provide electricity to every village. Renewable energy resources (RES) such as solar and wind energy will help to achieve this goal of rural electrification. Generally, solar energy installation costs are less than wind energy installation costs. In this concern, the RES Stand-alone photovoltaic (PV) system along with battery storage system has been considered to provide effective supply of electricity to remote areas around the world. Thus this research work aims to propose a standalone PV system with high voltage gain CUK converter and the excess energy produced by the panel is stored in the battery. The dc link voltage generated by the CUK converter is not given directly into the battery since it has low voltage capacity. As a result, there is a necessity of bidirectional battery converter which boost or lower the output voltage while also stabilising it with a PI control. The PWM generator delivers the appropriate pulses into the 1ϕ VSI (Voltage Source Inverter) which is connected to the load. The overall experiment is tested using a MATLAB simulation.

Keywords: RES, Standalone PV system, battery, CUK converter, VSI.

1 INTRODUCTION

Renewable energy sources (RES) are gaining a lot of attention around the world as a feasible alternative form of energy supply. They are also a big part of the global energy generation [1], [2]. Generally, solar PV systems have become very cost-effective solutions for both standalone and grid-connected operations in industrial, commercial and residential applications. However, the grid-connected PV sytem is more difficult to install because the grid and PV system parameters have to be perfectly synchronized. This is the key issue with the grid integrated PV system whereas the stand-alone PV has been implemented easily. Although the standalone configuration provide a well-regulated load voltage, the power supply's reliability has not be assured. Thus, with the aid of a battery backup device, the reliability of the standalone system has been improved and it also provides uninterruptible power supply to the standalone load [3], [4]. On the other hand, the PV system’s efficiency greatly depends on the voltage conversion capability of the converter [5]. In order to optimize the DC voltage produced by the solar panel, it is important to choose a best DC-DC converterwith high voltage transfer gain which replaces the use of transformer [6], [7].

The traditional boost converters are practically designed to attain optimum voltage gain by operating at the duty cycle close to 1, but this usually results in high conduction losses. The flaws of traditional boost converters are particularly noticeable in high-voltage applications, where the switch has to withstand high voltage stresses and suffer extreme reverse-recovery failure in the output diode [8], [9].

Generally, the isolated buck converters is used for voltage step-down conversion, and the performance decreases as the voltage conversion ratio decreases. On the other hand, the voltage step-up conversion is accomplished with independent boost converters, and performance declines as the voltage conversion ratio rises. As a result, isolated buck and boost converters are unable to achieve high voltage conversion efficiency with wide range of input or output voltage [10]. Thus, the above limitations are rectified by employing the buck-boost converter [11]. The traditional buck-boost converter is commonly utilized to feed loads that require both voltage bucking and boosting. It has the following distinguishing characteristics: simple structure, effective control of converter due to its single switch topology, and less number of energy storage components (i.e. inductors and capacitors) resulting in a second-order system [12]. However, in Continuous Conduction Mode (CCM), a traditional buckboost converter has a non-minimum phase issue because of the existence of a right-half-plane (RHP) zero in its control-to-output transfer operation which degrades the efficiency of the converter and it also suffers due to output ripple current[13]. In order to rectify the issues with above converters, the CUK converter topology is proposed in this work as it greatly reduces the current ripple that occurs at the output.

MPPT is a required component of a PV system from an operational standpoint. In the last few years, there has been a lot of study in the field of MPPT [14]. The trailing of MPP from the PV module is a big challenge with PV systems. MPPT is only feasible in stand-alone systems if there is a battery backup. The excess energy produced by the MPPT is stored in the battery for which the standalone load seems to be unable to utilize. The Perturb and Observe (P&O) algorithm is generally adopted in PV applications mainly because of its simplicity and ease of execution. The perturbation operation has been applied directly or indirectly in this technique. The direct P&O method is recommended because it does not necessitate the use of a PI controller and offers higher energy consumption performance as well as eliminates oscillations and noise. The major disadvantages of the P&O is its steady-state oscillation while trailing the MPP and its instability with the rapidly changing environmental conditions. Thus the peak power is obtained by assigning an INC (Incremental Conductance) algorithm based MPPT in this article [15]-[17].

Rechargeable batteries are needed for PV systems to provide a consistent power supply to the load without any interruptions even when the PV supply is absent. Multiple dc-dc converters are needed in such systems, not only for PV modules but also for energy storage batteries. To optimise the power production of PV panels, a dc-dc converter with MPPT is employed. Meanwhile, in PV systems, a bidirectional converter that serves as a regulator for a battery that paves way for versatile power flow [18]. Bidirectional DC-DC converters, such as buck/boost converters, are widely used when incorporating renewable energy sources with batteries [19]-[21]. In order to synthesize an efficient reference power from a DC reference volatge and to control the performance of the bidirectional battery converter, a PI controller [22], [23] is used which analogize the actual and reference dc link voltages and it supplies the PWM generator [24] which generates suitable pulses for the battery converter.

2 RELATED WORKS

Miloud Rezkallah et al [25] investigates a HIL integration of a solar PV array serving selfstanding load. On the basis of sliding mode, two control algorithms are created to ensure quick and finite-time convergence without requiring device parameter adjustments. To optimise the PV panel output and to stop the overcharging of BES device, and stabilize the frequency and voltage at PCC, the current controlled-voltage source converter (CC-VSC) and the boost converter are regulated. This paper presents and discusses an accurate certainity of the PV system.

I Anand et al [26] describes the PV system with active power control system that uses a inductor-based dual output/input converter to supply standalone dc loads with a battery backup. For active power control among PV and the dc load, the voltage-mode control technique is suggested in this work. It also provides a steady dc load voltage and ensures optimum power point monitoring and effective functioning of PV system.

Yun Yang et al [27] A LHC for the battery is suggested in this study to increase the performance of the energy storage device while maintaining the batterys SOC within tolerance. The real-time optimal references of the primary control are calculated by using the LHC's secondary control, enabling the voltage of dc bus to vary into a preset permissible tolerance, allowing the energy conversion of the entire PV-battery system to be optimised. Simulation studies demonstrate that the designed LHC improves the performance of the battery on a rainy day under nonuniform and uniform insolation conditions.

Jincy Philip et al [28] This paper implements an effective algorithm for controlling the hybrid energy generation system. The newly suggested hybrid energy system addresses the erratic nature of the PV energy generation while also improving power quality. To ensure the highest power during varying operating conditions, the PV module is connected via boost converter and operated using a MPPT algorithm. For organised power flow and active load control, the BESS is incorporated with the diesel generator.

Masatoshi Uno et al [29] presented the PV system along with storage battery which necessitate dc-dc converters for solar module management and battery control, making them complicated and expensive. This article suggested the switched capacitor converter (SCC)-based multiport converter (SC-MPC) for standalone PV system to reduce the system by lowering the amount of converters. By combining the PWM converter, an SCC and a series- converter (SRC resonant), the proposed SC-MPC can be developed. The SRC and PWM generators use PWM and PFM controllers to manage the PV output voltage, input power or battery voltage from a PV panel which depends upon the power balance between the source and load.

Dionisis Voglitsis et al [30] Standalone photovoltaic systems are an important technique for increasing the share of RES in global energy generation. Thus the systems power efficiency is critical in preventing power supply volatility. In order to attain the quality power standards, this necessitates a concrete design. In this context, subsequent work has established a methodology for setting the variable values that optimise the system's power quality indices. Here, a thorough sensitivity assessment of the effects of changing optimised parameters on power quality indices is carried out.

3 PROPOSED METHODOLOGY

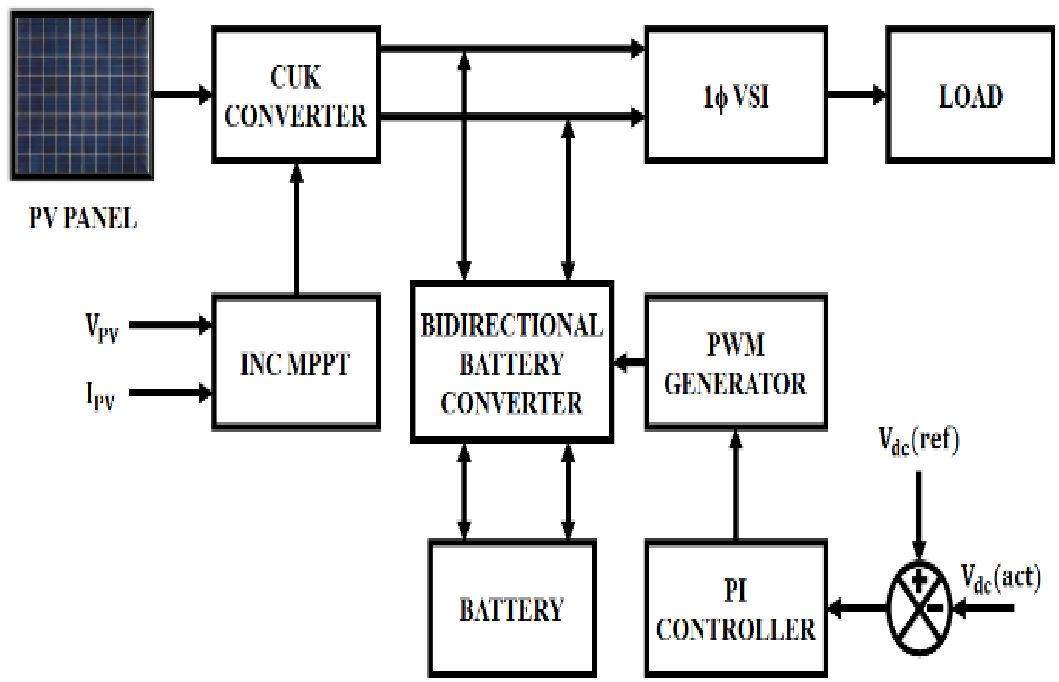


Figure 1 Block representation of standalone PV system

The proposed standalone PV system includes solar PV module, an energy storage battery to provide power to the load when solar PV is not available, an efficient DC-DC CUK converter, and a PI controller. The PI controller aids in regulating active power flow between the converter and the load. The proposed schematic block diagram of standalone PV system in given in Figure 1.

3.1 PV Panel Model

Photovoltaic cells are made up of semiconductor material which consumes energy from the sun and generates electricity. The solar cell is not active during the night time; thus it functions as a diode which means a p-n junction diode. During night time it doesn't produce any voltage or current. As it is connected to a high-voltage external supply, it produces a current known as diode current or dark current. PV current and voltage drawn by the load determine the total measure of power produced by the solar power panel at a specific temperature and degree of insolation. Figure 2 represents the electrical layout of one-diode solar cell model.

The net current is obtained by subtracting the source current I_{ph} from the standard diode current I_D. Thus the PV ouput current is given as,

$$I_{PV} = I_{ph} - I_D = I_{ph} - I_0 \left(exp\,\frac{e(V_{PV}+I_{PV}R_S)}{mkT} - 1 \right) \quad (1)$$

Where, I_{ph} is the photo current, R_s denotes the series resistance which reflects the resistance within one and all cell, m denotes the ideal factor, k represents the

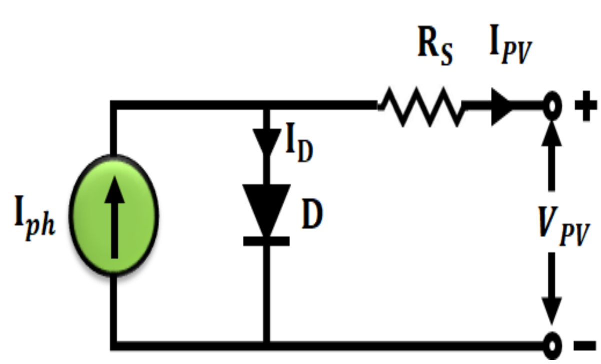


Figure 2 One-diode solar cell model

Boltzmann's constant, e is the charge of electronic particle, I_0 is the saturation current, T denotes the absolute cell temperature and the PV output voltage is V_{PV}.

3.2 CUK Converter Model

Based on the duty cycle, the CUK converter provide the voltage that is either less than or greater than the input potential. It is low in cost, high in performance, and it greatly mitigates the noise. CUK converters have various benefits and it is used in consumer electronics, automotive and others.

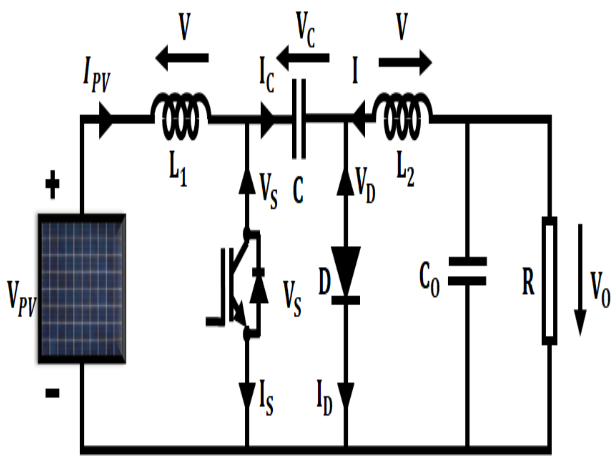


Figure 3 Circuit model of CUK Converter

An input voltage source V_s, an IGBT switch S, a diode D, a capacitor C_1 for energy transfer, a capacitor C_2 for energy storage, a load resistor R and two inductors L_1 and L_2 make up this circuit. Let V_1 and V_2 represent the voltages across C_1 and C_2 capacitors, respectively. Standard circuit model of CUK converter is depicted in Figure 3.

The circuit is said to be in charging state when the switch is turned ON. The circuit is said to be in discharging state when the switch S is OPEN. The CUK converter's equations are given as follows,

$$V_0 = -\frac{D}{1-D} * E \tag{2}$$

Where, V_0 is the average voltage output of CUK converter, D refers the duty cycle ratio and E denotes the source voltage.

The load current is given as,

$$I_0 = -\frac{V_0}{R} \tag{3}$$

Where, R is the load resistance. The inductor stores energy and it is given as,

$$E = \frac{1}{2}LI^2 \tag{4}$$

For CCM mode, the minimum value of inductor is given as,

$$L_{1min} = \frac{(1-D)^2 * R}{2Df} \tag{5}$$

$$L_{2min} = \frac{(1-D) * R}{2f} \tag{6}$$

For CCM mode, the capacitor's minimum value is given as,

$$C_{1min} = \frac{D}{2fR} \tag{7}$$

$$C_{1min} = \frac{1}{8fR} \tag{8}$$

Thus the peak to peak ripple current and volatges are given as,

$$\Delta I_1 = \frac{V}{L_1} * DTs \tag{9}$$

$$\Delta I_2 = \frac{V}{L_2} * DTs \tag{10}$$

$$\Delta V_1 = \frac{I_2}{C_1} * DTs \tag{11}$$

$$\Delta V_2 = \frac{Ts^2 D(V_1+V_2)}{8L_2C_2} \tag{12}$$

KVL has been applied to the loop containing the inductor and KCL has been applied to the node with the capacitor attached to it to analyse the dynamic response of this converter. The modes of working of CUK converter is. The following are the points that will be discussed:-

Mode 1: Switch OFF state

The inductor currents I_{L1} and I_{L2} pass through the diode when the switch S is open.Energy from both the input and L_1 is used to charge capacitor C_1 via the diode. Since V_{C1} is less than V_d, current I_{L1} decreases. The output is fed by the energy stored in L_2. As a result, the inductor current I_{L2} decreases. Figure 4 portrays the switch OFF state of CUK converter.

Mode 2: Switch ON state

V_{C1} reverse biases the diode when switch S is closed. The I_{L1} and I_{L2} inductor currents pass through the switch. C_1 discharges through the switch, passing energy to the output and L_2, since $V_{C1} > V_0$. As a result, I_{L2} levels rise. The input supplies energy to L_1, which causes I_{L1} to rise. The switch ON state of the CUK converter is portrayed in Figure 5.

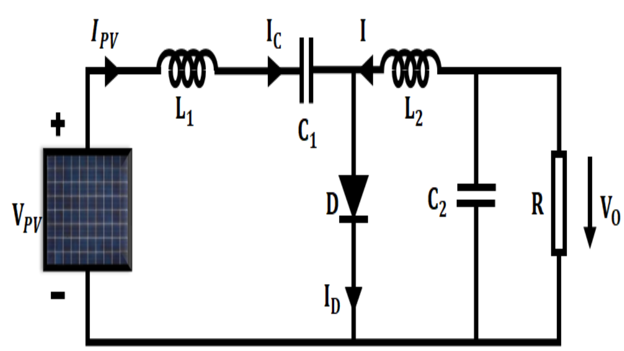


Figure 4 CUK converter in switch OFF state

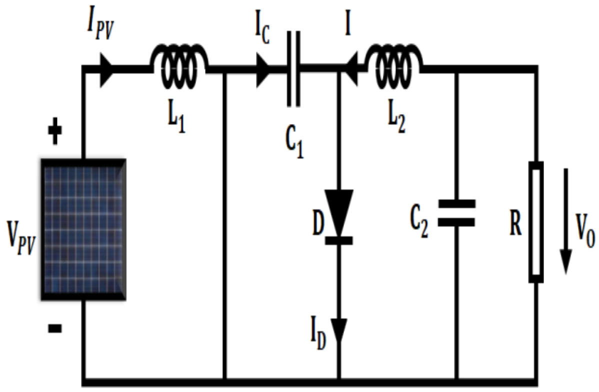


Figure 5 CUK converter in switch ON state

3.3 Incremental Conductance - MPPT

The incremental conductance method notices the current and voltage produced by the array using V and I sensors. Hence the slope of the PV curve is 0 at maximum power point (MPP). Thus the relation between incremental conductance of solar panel and its instantaneous conductance is given as,

$$\frac{dI}{dV} = -\frac{I}{V} \quad (13)$$

$$\frac{dP}{dV} = 0$$

From equation (13) it is clear that MPP is reached only if the ratio of output conductance change is equivalent to the inverse of output conductance.

$$\frac{dI}{dV} > -\frac{I}{V} \quad \left(\frac{dP}{dV} > 0\right) \quad (14)$$

$$\frac{dI}{dV} < -\frac{I}{V} \quad \left(\frac{dP}{dV} < 0\right) \quad (15)$$

The perturbation occurs to transfer the operating point towards the MPP is determined using equations (14) and (15), and the perturbation is continued until equation (13) is satisfied.

If the MPP is reached, the MPPT remains in this state until a change in current is detected. The values of dV and dI are estimated by the previous and present values of PV potential and current. By raising the value of MPP potential, amount of sunlight has increased only if dI>0 and dV>0.The flowchart of INC MPPT is illustrated in Figure 7.

The incremental conductance algorithm is depicted in Figure as a flowchart. Measure both current and voltage at the same time. As a result, the error caused by changes in insolation is mitigated. Since it does not generate steady state oscillations and provides accurate control under rapidly changing atmospheric conditions, the INC-MPPT technique is effective. Hence, it is used to track the maximum energy from the sun.

3.4 Battery

The battery backup is used in the PV standalone system to ensure that power is available at all times. Due to the advancement in technology, the efficiency of battery is improving day by day. The size and shape of the battery have been significantly reduced, but its performance has improved. The leadacid battery the most popular and oldest types of battery. The electrochemical process is the working principle of these batteries. Matlab/Simulink is used to model these batteries. The corresponding circuit model of the battery is shown in Figure 6.

The State-of-Charge (SOC) and Open Circuit Voltage (OCV) are the two parameters help evaluating the battery's characteristics. The SOC denotes the capacity of the battery. The storage capacity of the battery at the time of charging is determined by the SOC. The voltage of the battery when it is in its equilibrium state is known as open circuit voltage. The Open Circuit Voltage value is determined by the State of Charge. The SOC can be expressed as follows,

$$SOC = SOC_0 - \int((100 * I)/3600 * \alpha^u)dt \quad (16)$$

Where, I denotes the current, SOC_0 represents the battery at its initial state and α^u represents the usable capacity. A charge controller is a system that stops the battery from charging until it reaches the necessary power. The charge controllers bypass the excess current produced by the PV panels.

3.5 Bidirectional Battery Converter with PI Controller

The bi-directional buck-boost battery converter has been designed to deliver sufficient voltage to the battery depends upon its voltage capacity. The model circuit diagram of the Buck-Boost bidirectional converter is highlighted in Figure 8.

The peak to peak ripple current of inductor is,

$$\Delta I_L = \frac{(V_2 - V_1)}{2L_C}\left(\frac{V_1}{V_2}\right)T_s \quad (17)$$

$$I_a = \frac{P}{V_2} \quad (18)$$

$$I_{rms} = \sqrt{I_{Load}^2 + \frac{\Delta I^2}{3}} \quad (19)$$

Controlling the output voltage ensures the safe and efficient working condition of output load. A PI controller is employed to manage the output potential. The error signal is obtained in this control scheme by analogizing the actual V_{dc} with the reference V_{dc}. Then the signal is interpreted by using PI controller. By analogizing the attained signal with a high frequency saw tooth signal, PWM control signals are produced which is fed into the bidirectional converter and the output of the bidirectional converter is given to the 1ϕ VSI. The basic block representation of PI controller is portrayed in Figure 9.

Thus the PI controller is used to mitigate the steady state error. Thus the transfer gain of the PI controller is given as,

$$G_c(s) = K_p + \frac{K_i}{s} \quad (20)$$

K_p and K_i values are obtained by using Zeigler Nichols tuning approach.

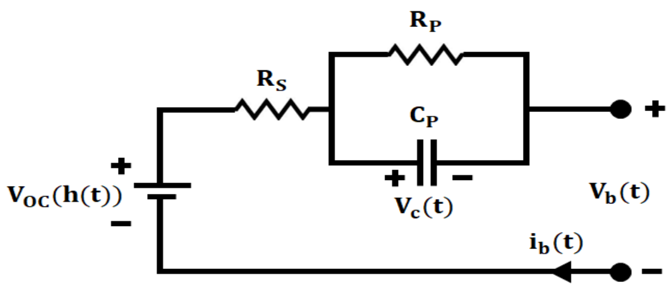


Figure 6 Cicuit layout of the battery

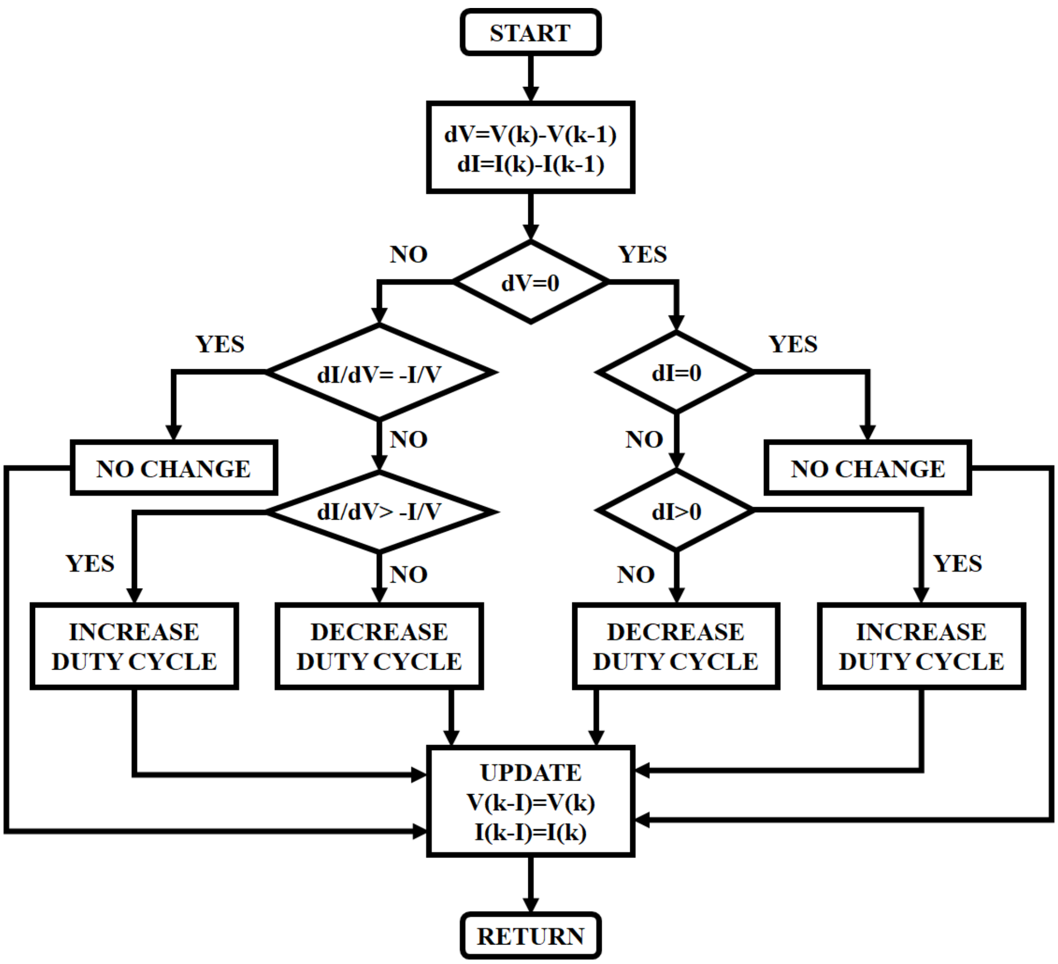


Figure 7 INC algorithm flowchart

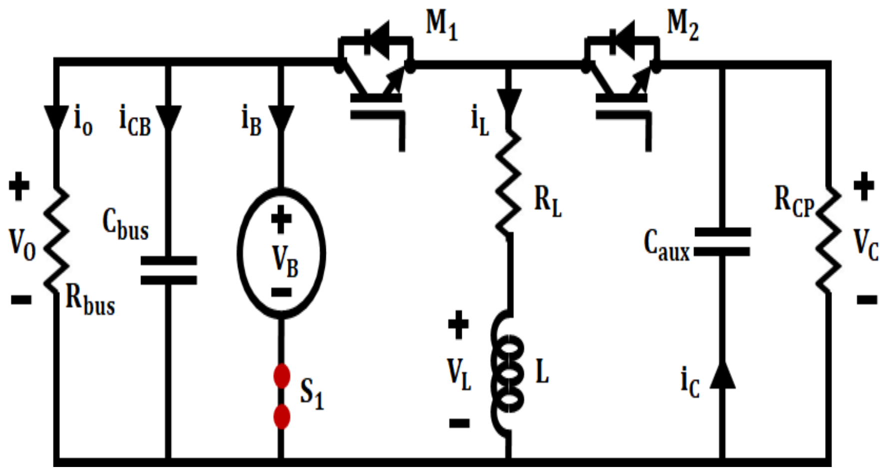


Figure 8 Bidirectional Buck-Boost battery converter model

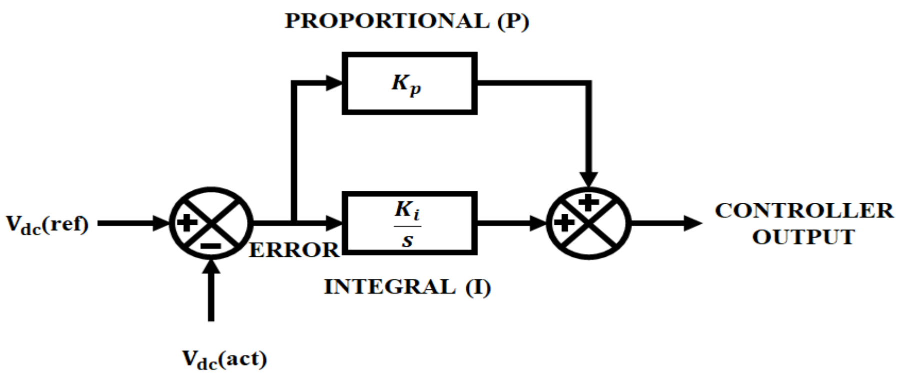


Figure 9 Block Representation of PI Controller

4 RESULTS & DISCUSSION

This research work aims to analyse a standalone PV system with a CUK converter, and the system's outcomes have been thoroughly examined. The CUK converter is employed to optimize the output PV output potential, thereby improving system's efficiency. Also, an incremental conductance algorithm based MPPT has been assigned to track the MPP and to extricate supreme power from the solar panel. However, MPPT is only feasible in stand-alone systems if there is a battery backup. The excess energy produced by the MPPT is stored in the battery since the standalone alone system is unable to save the excess energy. The battery receives its most suitable voltage with the aid of bidirectional battery converter which is controlled by a PI controller. Table 1 list out the PV panel specification and CUK converter ratings

Table 1 PV panel specification and CUK converter ratings

Components	Specifications
No. of series cells	36
Total No. of modules	10
Area of a single cell	$(125 \times 31.26) mm$
Operating Voltage	$16.8\ V$
Maximum Voltage	$1000\ V\ DC$
Operating Current	$5.8\ A$
Rating of Temperature	$-40\ to + 85°C$
Converter Ratings	
Input voltage, V_{PV}	$0\ to\ 12\ V\ DC$
Input current, I_i	$25\ A\ (Max)$
Load resistance	$20\ ohms$
Capacitances, C_1, C_2	$150\ \mu F$ & $50\ \mu F$
Inductances, L_1, L_2	$30\ mH$
Output current, I_o	$5\ A$
Operating frequency, f	$10\ KHz$
Duty cycle	0.6

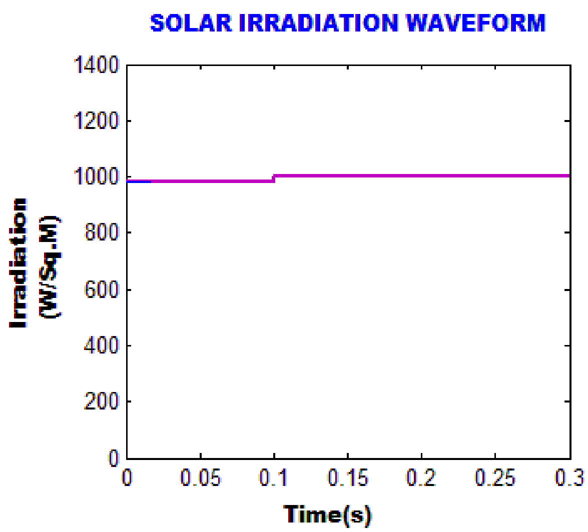


Figure 10 Solar insolation waveform

Figure 10 depicts the solar insolation waveform. Owing to changes in temperature, the solar insolation varies during the day. The irradiance level of solar varies from 980 W/m^2 to 1000 W/m^2 at a time period of 0.1 s, as shown in the above waveform.

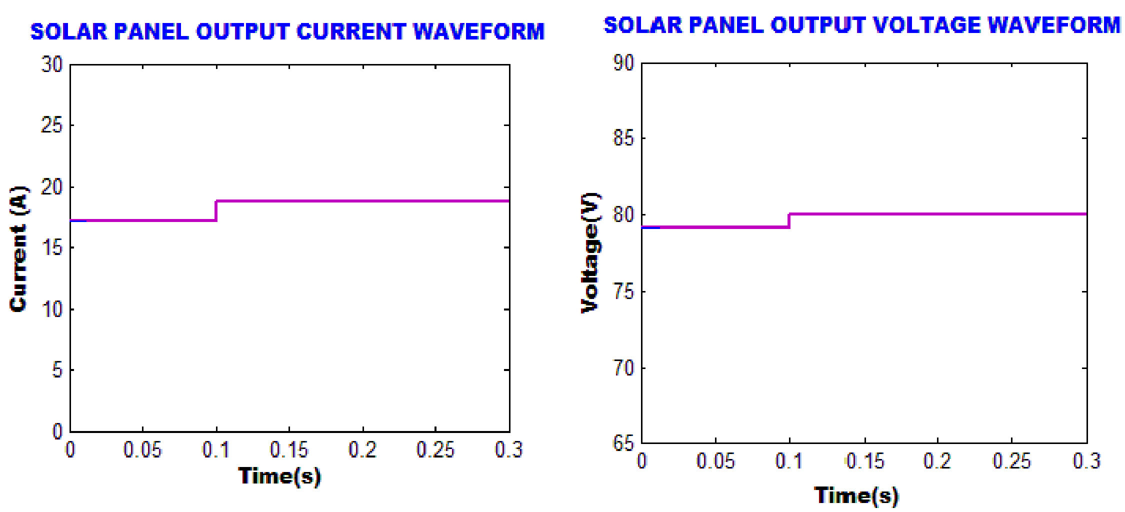
Figure 11 (a) and (b) highlights the PV current and voltage waveforms. The PV panel generates low DC potential due to solar irradiation. The derived current of the PV module ranges from 17.2 A to 18.8 A at the time period of 0.1 and PV output voltage ranges from 78 $V\ to$ 80 V at the time period of 0.1 s.

The potential outcome of PV panel is low, therefore it is optimized by using high voltage gain CUK converter which track its maximum suitable power from the panel with the aid of incremental conductance algorithm based MPPT. The generated voltage and current waveform of CUK converter has been illustrated in Figure 12 (a) and (b).

The output voltage generated by the CUK converter is given to the 1ϕ VSI whereas the excess energy is stored in the battery by means of bidirectional battery converter. Eventually, the output of the inverter is fed in to the load. Figure 13 depicts the current and voltage waveform of the load.

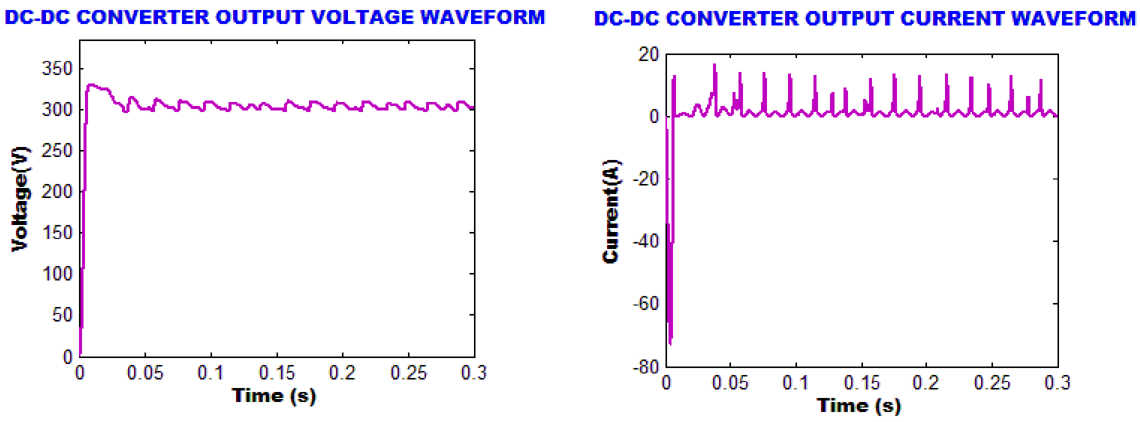
Figure 14 shows the waveform of real and reactive power and its observed that the real power rises at first, reaching 500W, but the reactive power falls to zero.

The voltage transfer gain of different converter have been compared which is highlighted in Figure 15 and is keenly noticed from the result that the voltage gain value of CUK converter is high compared to the boost and buck-boost converter. Eventually, the voltage gain ratio of the CUK converter is noted as 1:4 whereas the boost and buck-boost converter are given as 1:1.5 and 1:2 respectively.



(a) (b)

Figure 11 (a) PV output current waveform (b) PV output voltage waveform



(a) (b)

Figure 12 (a) CUK Converter's voltage waveform (b) CUK converter's current waveform

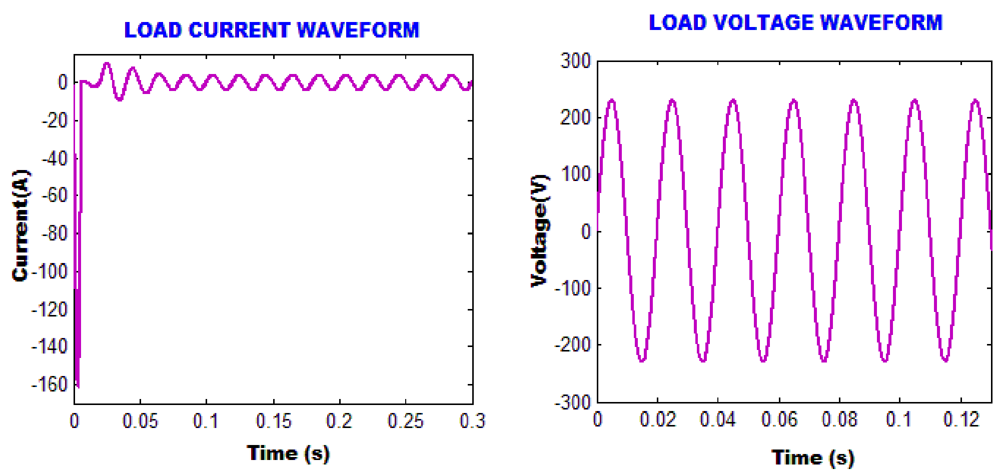


Figure 13 Generated current and volatge waveform of the load

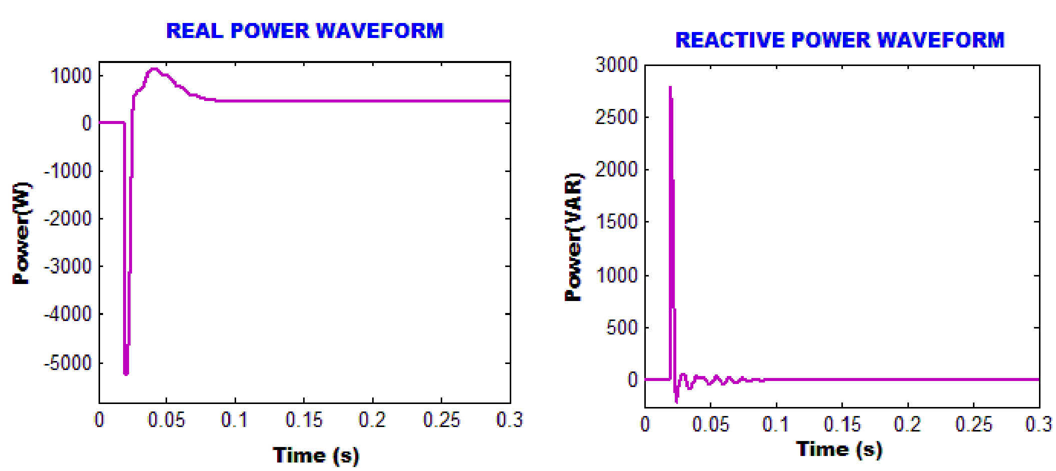


Figure 14 Waveform of real and reactive power

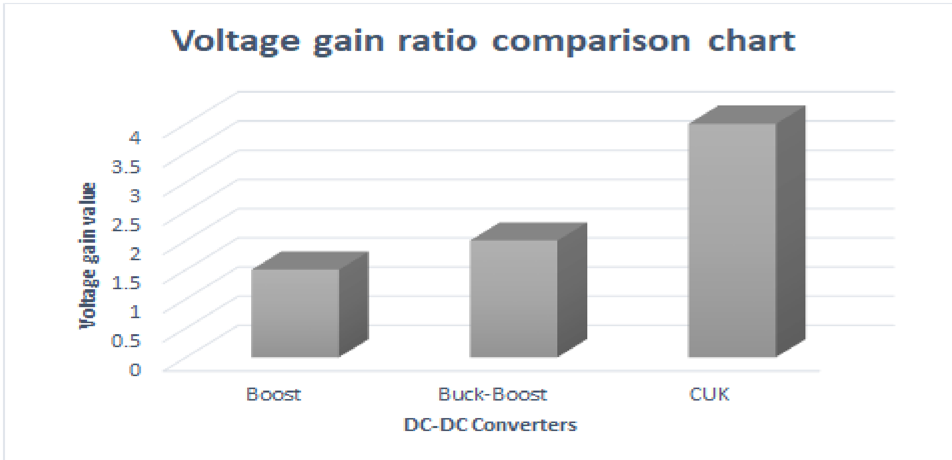


Figure 15 Voltage gain ratio comparison

5 CONCLUSION

The simulation result of the standalone PV with CUK converter and INC-MPPT shows that the proposed system is capable of producing fixed dc link voltage and extricating the optimum energy from the PV panel. Also, the bidirectional battery converter with PI control reveals that the device has the ability to stabilize the output voltage effectively while also reducing the time to attain steady state. When a device is interrupted, a battery converter with PI control easily restores output voltage stability, and the obtained output voltage will always equals the target set point, making it extremely secure to use for battery charging voltage.

References

[1] Mikaeel Ahmadi, Mohammed E. Lotfy, Ryuto Shigenobu, Abdul Motin Howlader, Tomonobu Senjyu, “Optimal Sizing of Multiple Renewable Energy Resources and PV Inverter Reactive Power Control Encompassing Environmental, Technical, and Economic Issues”, IEEE Systems Journal, Vol. 13, no. 3, pp. 3026 - 3037, 2019.

[2] Mariusz Malinowski, Jose I. Leon, Haitham Abu-Rub, “Solar Photovoltaic and Thermal Energy Systems: Current Technology and Future Trends”, Proceedings of the IEEE, Vol. 105, no. 11, pp. 2132 - 2146, 2017.

[3] Bhim Singh, Utkarsh Sharma, Shailendra Kumar, “Standalone Photovoltaic Water Pumping System U sing Induction Motor Drive With Reduced Sensors”, IEEE Transactions on Industry Applications, Vol. 54, no. 4, pp. 3645 - 3655, 2018.

[4] Gabriela Favaron, Ricardo da Silva Benedito, “Photovoltaic Systems for the Supply of Video Surveillance Equipment in Urban Environment”, IEEE Latin America Transactions, Vol. 17, no. 11, pp. 1865 - 1872, 2019.

[5] Moustafa Adly, Kai Strunz, “Irradiance-Adaptive PV Module Integrated Converter for High Efficiency and Power Quality in Standalone and DC Microgrid Applications”, IEEE Transactions on Industrial Electronics, Vol. 65, no. 1, pp. 436 - 446, 2018.

[6] Moumita Das, Vivek Agarwal, “Novel High-Performance Stand-Alone Solar PV System With High-Gain High-Efficiency DC–DC Converter Power Stages”, IEEE Transactions on Industry Applications, Vol. 51, no. 6, pp. 4718 - 4728, 2015.

[7] V. Karthikeyan, S. Kumaravel, G. Gurukumar, “High Step-Up Gain DC–DC Converter with Switched Capacitor and Regenerative Boost Configuration for Solar PV Applications”, IEEE Transactions on Circuits and Systems II: Express Briefs, Vol. 66, no. 12, pp. 2022 – 2026, 2019.

[8] Daiki Yamaguchi, Hideaki Fujita, “A New PV Converter for a High-Leg Delta Transformer Using Cooperative Control of Boost Converters and Inverters”, IEEE Transactions on Power Electronics, Vol. 33, no. 11, pp. 9542 – 9550, 2018.

[9] Mojtaba Forouzesh, Yanfeng Shen, Keyvan Yari, Yam P. Siwakoti, Frede Blaabjerg, “High-Efficiency High Step-Up DC–DC Converter With Dual Coupled Inductors for Grid-Connected Photovoltaic Systems”, IEEE Transactions on Power Electronics, Vol. 33, no. 7, pp. 5967 - 5982, 2018.

[10] Yangjun Lu, Hongfei Wu, Kai Sun, Yan Xing, "A Family of Isolated Buck-Boost Converters Based on Semiactive Rectifiers for High-Output Voltage Applications", IEEE Transactions on Power Electronics, Vol. 31, no. 9, pp. 6327 - 6340, 2015.

[11] Francisco Méndez-Díaz, Beatriz Pico, Enric Vidal-Idiarte, Javier Calvente, Roberto Giral, "HM/PWM Seamless Control of a Bidirectional Buck–Boost Converter for a Photovoltaic Application", IEEE Transactions on Power Electronics, Vol. 34, no. 3, pp. 2887 - 2899, 2019.

[12] Mummadi Veerachary, Vasudha Khubchandani, "Analysis, Design, and Control of Switching Capacitor Based Buck–Boost Converter", IEEE Transactions on Industry Applications, Vol. 55, no. 3, pp. 2845 - 2857, 2019.

[13] Niraj Rana, Arnab Ghosh, Subrata Banerjee, "Development of an Improved Tristate Buck–Boost Converter With Optimized Type-3 Controller", IEEE Journal of Emerging and Selected Topics in Power Electronics, Vol. 6, no 1, pp. 400 - 415, 2018.

[14] Enrico Dallago, Alessandro Liberale, Davide Miotti, Giuseppe Venchi, "Direct MPPT Algorithm for PV Sources With Only Voltage Measurements", IEEE Transactions on Power Electronics, Vol. 30, no. 12, pp. 6742 - 6750, 2015.

[15] Bhim Singh,Utkarsh Sharma, Shailendra Kumar, "Standalone Photovoltaic Water Pumping System U sing Induction Motor Drive With Reduced Sensors", IEEE Transactions on Industry Applications, Vol. 54, no. 4, pp. 3645 - 3655, 2018.

[16] Ahmed A. S. Mohamed, Alberto Berzoy, Osama A. Mohammed, "Design and Hardware Implementation of FL-MPPT Control of PV Systems Based on GA and Small-Signal Analysis", IEEE Transactions on Sustainable Energy, Vol. 8, no. 1, pp. 279 - 290, 2017.

[17] Mohammed A. Elgendy, Bashar Zahawi, David J. Atkinson, "Operating Characteristics of the P&O Algorithm at High Perturbation Frequencies for Standalone PV Systems", IEEE Transactions on Energy Conversion, Vol. 30, no. 1, pp. 189 - 198, 2015.

[18] Masatoshi Uno, Kazuki Sugiyama, "Switched Capacitor Converter Based Multiport Converter Integrating Bidirectional PWM and Series-Resonant Converters for Standalone Photovoltaic Systems", IEEE Transactions on Power Electronics, Vol. 34, no. 2, pp. 1394 - 1406, 2019.

[19] Xi Chen, Anirudh Ashok Pise, John Elmes, Issa Batarseh, "Ultra-Highly Efficient Low-Power Bidirectional Cascaded Buck-Boost Converter for Portable PV-Battery-Devices Applications", IEEE Transactions on Industry Applications, Vol. 55, no. 4, pp. 3989 - 4000, 2019.

[20] Fernando Sobrino-Manzanares, Ausias Garrigos, "Bidirectional, Interleaved, Multiphase, Multidevice, Soft-Switching, FPGA-Controlled, Buck–Boost Converter With PWM Real-Time Reconfiguration", IEEE Transactions on Power Electronics, Vol. 33, no. 11, pp. 9710 - 9721, 2018.

[21] Mehnaz Akhter Khan, Adeeb Ahmed, Iqbal Husain, Yilmaz Sozer, Mohamed Badawy, "Performance Analysis of Bidirectional DC–DC Converters for Electric Vehicles", IEEE Transactions on Industry Applications, Vol. 51, no. 4, pp. 3442 - 3452, 2015.

[22] Tingting He, Mingli Wu, Dylan Dah-Chuan Lu, Ricardo P. Aguilera, Jianwei Zhang, Jianguo Zhu, "Designed Dynamic Reference With Model Predictive Control for Bidirectional EV Chargers", IEEE Access , Vol. 7, pp. 129362 - 129375, 2019.

[23] Phatiphat Thounthong, Suwat Sikkabut, Pongsiri Mungporn, Luigi Piegari, Babak Nahid-Mobarakeh, Serge Pierfederici, Bernard Davat, "DC Bus Stabilization of Li-Ion Battery Based Energy Storage for a Hydrogen/Solar Power Plant for Autonomous Network Applications", IEEE Industry Application Society Annual Meeting, 2014.

[24] Jiefeng Hu, Jianguo Zhu, David G. Dorrell, "Predictive Direct Power Control of Doubly Fed Induction Generators Under Unbalanced Grid Voltage Conditions for Power Quality Improvement", IEEE Transactions on Sustainable Energy, Vol. 6, no. 3, pp. 943 - 950, 2015.

[25] Miloud Rezkallah, Abdelhamid Hamadi, Ambrish Chandra, Bhim Singh, "Real-Time HIL Implementation of Sliding Mode Control for Standalone System Based on PV Array Without Using Dumpload", IEEE Transactions on Sustainable Energy, Vol. 6, no. 4, pp. 1389 - 1398, 2015.

[26] I. Anand, Subramaniam Senthilkumar, Dipankar Biswas, M. Kaliamoorthy, "Dynamic Power Management System Employing a Single-Stage Power Converter for Standalone Solar PV Applications", IEEE Transactions on Power Electronics, Vol. 33, no.12, pp. 10352 - 10362, 2018.

[27] Yun Yang, Yaxiao Qin, Siew-Chong Tan, Shu Yuen Ron Hui, "Efficient Improvement of Photovoltaic-Battery Systems in Standalone DC Microgrids Using a Local Hierarchical Control for the Battery System", IEEE Transactions on Power Electronics, Vol. 34, no.11, pp. 10796 - 10807, 2019.

[28] Jincy Philip, Chinmay Jain, Krishan Kant, Bhim Singh, Sukumar Mishra, Ambrish Chandra, Kamal

Al-Haddad, "Control and Implementation of a Standalone Solar Photovoltaic Hybrid System", IEEE Transactions on Industry Applications, Vol. 52, no. 4, pp. 3472 - 3479, 2016.

[29] Masatoshi Uno, Kazuki Sugiyama, "Switched Capacitor Converter Based Multiport Converter Integrating Bidirectional PWM and Series-Resonant Converters for Standalone Photovoltaic Systems", IEEE Transactions on Power Electronics, Vol. 34, no.2, pp. 1394 - 1406, 2019.

[30] Dionisis Voglitsis, Nick P. Papanikolaou, Christos A. Christodoulou, Dimitris K. Baros, Ioannis F. Gonos, "Sensitivity Analysis for the Power Quality Indices of Standalone PV Systems", IEEE Access, Vol. 5, pp. 25913 - 25922, 2017.