International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-4, February 2020

High Efficient Solar Integrated an Isolated Dc-Dc Full-Bridge Converter for Electric Vehicle Battery Charging Application

G. Arun, R. Arunkumar, K. KrishnaKumar, P. Muthupattan, G. Kannayeram, K. Karthik Kumar

Abstract: In this paper, the power from a solar PV panel 20VDC, 12.5ADC is used for charging an electric vehicle battery (12V, 7Ah) with the help of an isolated dc-dc converter in an efficient manner. The power rating maintained in the system is around (200-250) W. The parasitic circuit analysis is carried out theoretically. The zero voltage transition (ZVT) technique is implemented at the inverter stage and an isolation transformer (1:1) is used for source-load isolation purposes. In order to achieve ZVT, a proper design procedure is followed and a pulse triggering technique is carried out at the switching element. The designed values of the parasitic elements are used in the Simulink tool. The open loop and closed loop system of the proposed converter are simulated in MATLAB Simulink package. In the open loop system, an irradiation analysis carried out similarly closed loop has reference voltage variation analysis in order to verify the system stability at the various operating condition. The problem of transients in open loop output is rectified in the closed loop operation. The MPP and PI control technique is initiated in the closed loop system for better performance. The MPP technique used is incremental conductance method for tracking maximum power from the PV array.

Keywords: Phase Shifted Full Bridge Converter (PSFBC), Zero Voltage Transition (ZVT), Maximum Power Point (MPP), Proportional and Integral controller (PI), Photovoltaic (PV), Incremental Conductance (IC).

Revised Manuscript Received on February 28, 2020.
* Correspondence Author

K. Karthik Kumar*, currently working as Assistant professor in the department of Electrical and Electronics Engineering, National Engineering College, Kovilpatti, India. Karthik134330@gmail.com

G. Kannayeram, currently working as Assistant professor (SG) in the department of Electrical and Electronics Engineering, National Engineering College, Kovilpatti, India.

G. Arun, R., Department of Electrical and Electronics Engineering, National Engineering College, Kovilpatti, India.

Arunkumar, Department of Electrical and Electronics Engineering, National Engineering College, Kovilpatti, India.

K. KrishnaKumar, Department of Electrical and Electronics Engineering, National Engineering College, Kovilpatti, India.

P. Muthupattan, Department of Electrical and Electronics Engineering, National Engineering College, Kovilpatti, India.

I. INTRODUCTION

Nowadays, Petroleum product suppliers are presently essentially drained and it is normal that accessibility of these assets will turn out to be considerably more scarer throughout the following 20-40 years.

Petroleum derivative is a significant reason for the environmental change and to keep away from the impacts of a worldwide temperature alteration elective assets are of intense need. In the conventional design of the Electric Vehicle battery charging application with Solar PV as a source, the boost converter is used at the front end so as to obtain high voltage gain [1]. But the operation of high frequency, voltage stress as well as proportional switching loss increases. The uniform and balanced charging of battery modules with the help of various charging facilities such as renewable source, plug-in charger, etc., in EVs. The energy loss during charging and discharging would be minimized by utilizing the same level of current. Charging can be done with a low value of SOC(State of Charge) while discharging the battery through high SOC hence, an equalized and balanced modes of charging with the same level of current are achieved[1]. The analysis of power flow and power level in on-board, as well as off-board charging system in either unidirectional or bidirectional mode, is discussed, various stages of conversions in EV application based on two different power flow methods through different topologies[2].

Interaction of EV with a grid made a difficult task of facing various harmonic factors so, it is necessary to model an accurate battery system. When a battery has been connected to the grid, not only the battery act as a load but also the other system in the vehicle acts as a load. Therefore, factors on the basis of the AC conversion stage must be considered. At every stage of conversion, the characteristic curve with a variable parameter related is to be analyzed. The constraints like charging time, environment, weight, size of all battery management system in various charging systems are well-reviewed, and the power flow at every conversion stages and its protection level between the stages in EV application are revised[3]-[2]. On realizing the inductive power transfer (IPT) for safe charging of a battery while on the other hand, it would cause the problem to the system efficiency and reliability[4].

It is important to look after the constant current(CC) and constant voltage(CV) mode to achieve uniform charging of a battery[3].In [4], an LCC tank topology based on these modes at ZPA condition at the resonant frequency is developed to achieve unity power factor and high efficiency for EV application. As in charging a battery in EVs, the important factor is SOC estimation. The SoC estimation can be varied through various methods of battery models and their equivalent. The problem behind the hybrid system shows the time-varying performances and non-linear as well as non-uniform plots. There would be various model-based methods to distinguish the SoC estimation in the EV battery management system[5]. The cost strategy of charging an EV in a PV assisted charging station is developed in [6] through some new optimization algorithm in order to reduce the EV user's cost and to get the optimal charging time. The concept of coupled inductor is for boosting the low magnitude of voltage to high value, in [7] a high step-up dc-dc converter is proposed for boosting the low output from the fuel cell. The efficiency at the conversion stage is high because low voltage stress and the performance is high compared with other converters. The application report of phase-shifted full-bridge converter describes, how the ZVT (zero voltage transition) is achieved. The switch parasites are used to commutate the switches in order to improve efficiency. The proper design of the switch capacitance and resonant inductor introduces a dead time between the switch pulses which leads to enable the switch to turn on at zero voltage in order to ensure lossless conversion[8]. A 600W phase-shifted full-bridge module with a current doubler circuit, an application note is given by Infineon technology. A verified heat sink model is designed for the MOSFET switch [9]. The design formulas for the components used in phase-shifted topology are available and that also gives the optimized design to achieve ZVS [10] [11]. There are various MPP techniques are available, this [12] shows a comparative analysis of all MPP techniques and also describes control variables and merits as well as demerits of each of them. The MPP is used to generate a PWM control signal for triggering the switch gate terminal.

The fig. 1 shows the overall system block diagram where the solar panel is connected to a battery through PSFBC. The PSFBC consists of three major power conversions that are inverter part for ZVT implementation, transformer part for isolation purpose and mid-point rectifier part for ac into dc power conversion. The ZVT is implemented both in the open loop as well as a closed loop system for the efficient performance of the system. The MPP and PI controller improves the closed loop system performance. The battery is considered as an impedance whose value is RC.

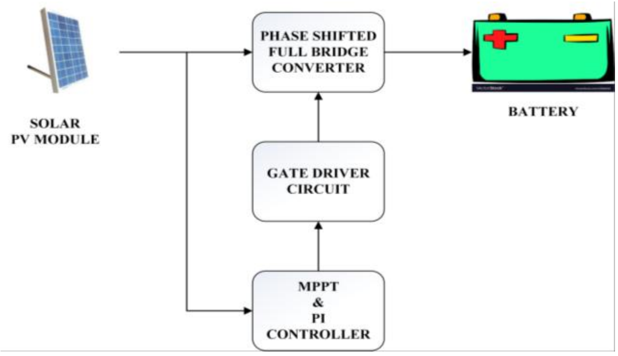

Fig. 1. Block Diagram

II. CIRCUIT ANALYSIS

The fig.2 describes the circuit diagram of the proposed converter design where the inverter with four semiconducting switches and its parasitic effect helps to achieve ZVT, the resonant filter describes the resonating condition and the 1:1 transformer provides isolation between source and load. The battery is taken as an RC load. The rectified voltage is filtered using the LC filter.

The capacitor at the initial stage acts as a capacitor link between solar PV and the converter. Its forms five different modes of operation and are discussed in the further contents.

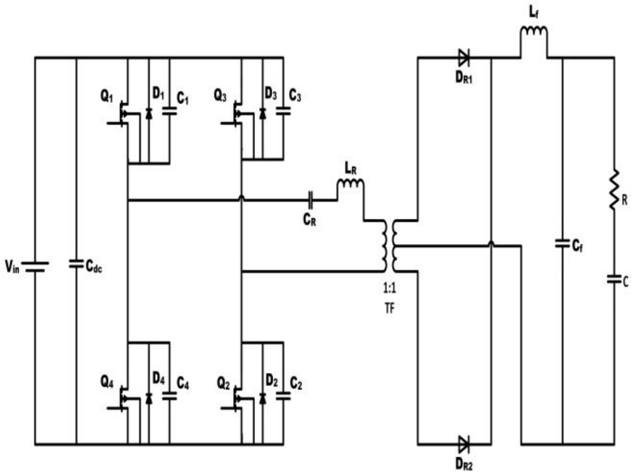

Fig. 2. Circuit Diagram

III. OPERATING PRINCIPLE

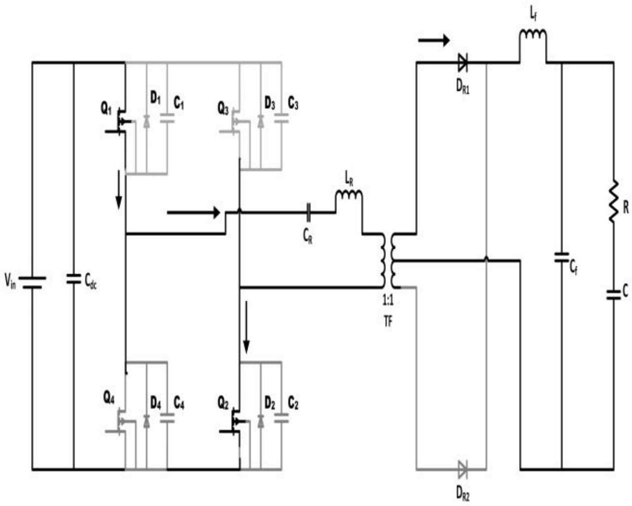

Fig. 3. Mode 1

Fig 3 shows the initial condition mode where the switch Q_3 and Q_4 are OFF and Q_1 and Q_2 are ON and the current flows through resonant element L_R and C_R to transformer and rectifier to charge the battery load through LC filters.

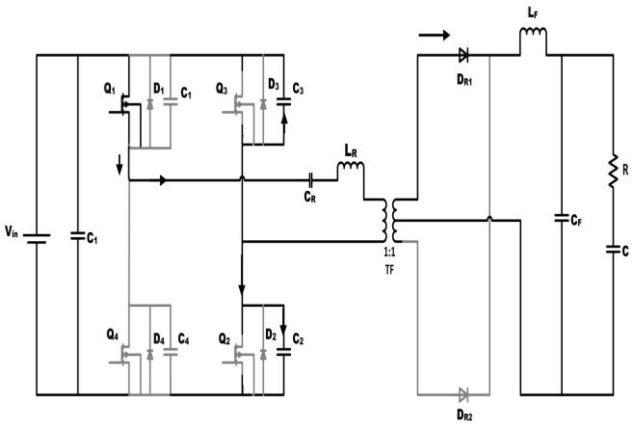

Fig. 4. Mode 2

Fig 4 explains the mode 2 operation which is called right leg transition. Here, the switch Q_3, Q_4, and Q_2 are OFF and the current flows from source to battery through a resonant element, ideal transformer, rectifier, and filters respectively.

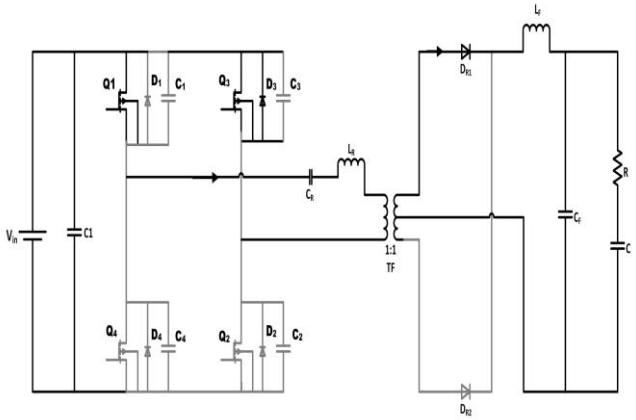

Fig. 5. Mode 3

Fig 5 shows the mode 3 operation which is called a clamped freewheeling mode where the switch Q_2 and Q_4 are OFF. Thus, the current path is shown in the figure. In each mode, the switches with its parasitic capacitance simultaneously work to achieve ZVT.

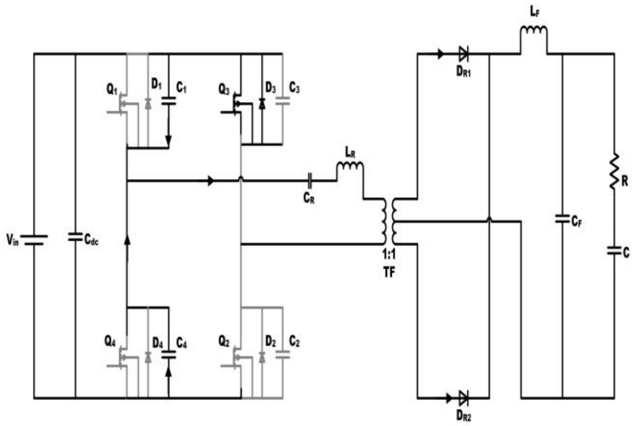

Fig. 6. Mode 4

The mode 4 leads to left leg transition mode where the essential current freewheels through switch Q_1 and the body diode of switch Q_3. The filter capacitor releases its charge to the RC load. Thus, the current path is shown in fig 6.

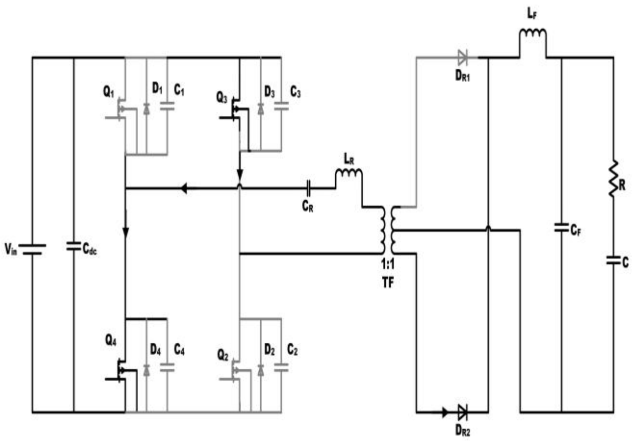

Fig. 7. Mode 5

The power transfer interval described in fig 7 in which the source to load power transferring happens and the battery gets charged simultaneously.

IV. ZERO VOLTAGE TRANSITION

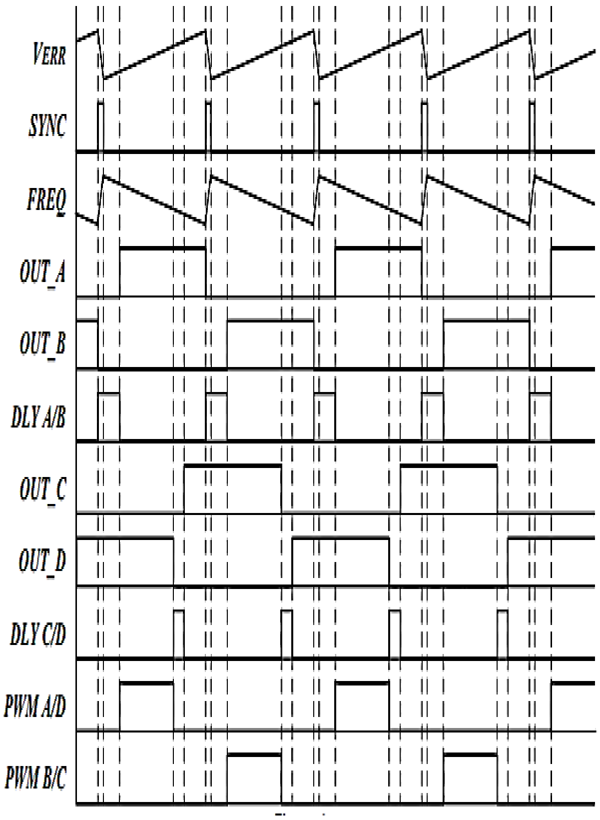

Fig. 8. Switching Waveform

Fig 8 shows the switching arrangements for the switches in the proposed converter. The triggering pulse for the two diagonal switches would generate a pulse for the switches in the same leg. This introduces a small delay which is known as the dead time that causes each switch to turn ON at zero potential thus reduces the switching losses and hence the efficiency will be more. Thereby, the ZVT is achieved in each mode of operation in the PSFBC.

V. SIMULATION SPECIFICATIONS

Table- I: Simulation Specifications

Power rating	**(200-250)W**
Module Data	Sunarray-S6B3612-250T
Ir(irradiation) W/m^2	1000 @ 25^{0}C
Output Voltage(Voc)	20V DC
Output Current(Isc)	12.5A DC
Series string	1
Parallel string	2
Inductor L_R, Capacitor C_{dc},C_R	1.8μH, 470μF, 150μF
PSFBC Output Voltage	20V DC
PSFBC Output Current	12.5A DC
Isolation Transformer	1:1
MOSFET in PSFBC	C_{oss}=2.93nF, V_{GS} = 10 V, I_D=5.6A, V_{DS}=80V
Switching Frequency	f_{SW}=100kHz
K_P, K_i	3.251, 0.255
L&C filter	L=13mH, C=800μF
Battery Nominal Voltage	12V DC
Capacity	7Ah

The above table I consists of the simulation specifications. The open-circuit voltage and short circuit current from the solar PV is considered as input for the PSFBC and the output from PSFBC is expected to be 20VDC and 12.5ADC and these above values are used in the MATLAB Simulink tool. The 20VDC is used to charge the battery of 12V, 7Ah. The C_{oss} value is nothing but the value of parasitic capacitance of each MOSFET switch.

VI. SIMULATION RESULTS AND DISCUSSIONS

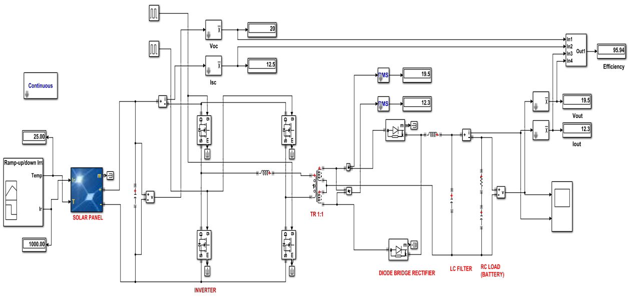

Fig. 9. Open loop Simulink model

Fig 9 shows the open loop Simulink model of the proposed converter where the 20VDC and 12.5ADC converted into 19.5VDC and 12.3ADC with the implementation of ZVT at the inverter side and the smooth response can be obtained by the filter design made.

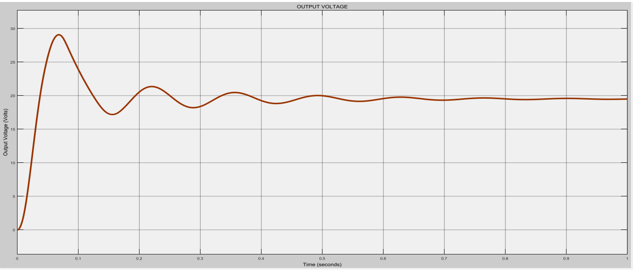

Fig. 10. PSFBC Output Voltage (19.5VDC)

Fig 10 shows the output voltage wave with a 0.07 second rise time and 0.8 second settling time. This leads to transient and steady-state response characteristics which would also system performance. This is applicable to output current response that is shown in fig 11.

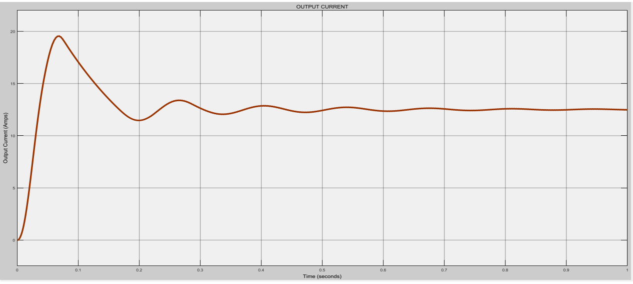

Fig. 11. PSFBC Output Current (12.3ADC)

The below table II shows the irradiation variation effects in the system. The maximum efficiency is obtained at Ir=1000(W/m^2) @ 25^{0}C which is taken as the rated value result. Here, the increase in irradiation causes an increase in efficiency to a particular point.

Table- II: Variation in irradiance

S.No	**Ir (W/m^2)**	**v_{in} (V)**	**i_{in} (A)**	**v_{out} (V)**	**i_{out} (A)**	**η (%)**
1	800	20	12	19	11.5	91.0
2	900	20	12.3	19.3	12	94.1
3	1000	20	12.5	19.5	12.3	95.9

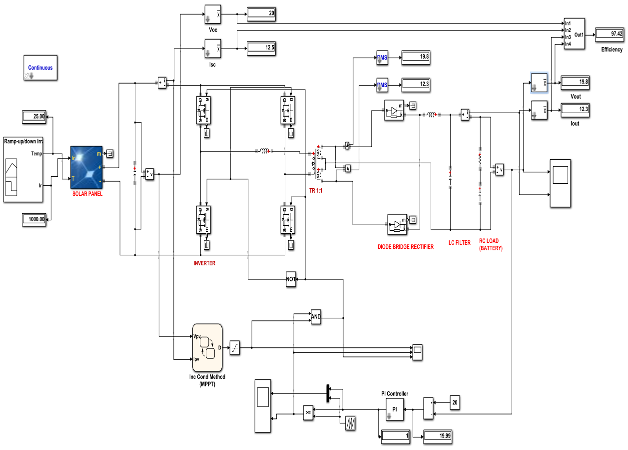

Fig. 12. Closed loop Simulink model

Fig 12 shows the closed loop Simulink model. Here, the MPP and PI technique is taken to provide a system with better efficiency. The PI controller has K_p and K_i values that are tuned in the MATLAB controller designer toolbox. The AND logic of the signal from the MPP and PI controller used to trigger the switching devices. The efficiency gets improved to 97.4% which is high compared to open loop system efficiency.

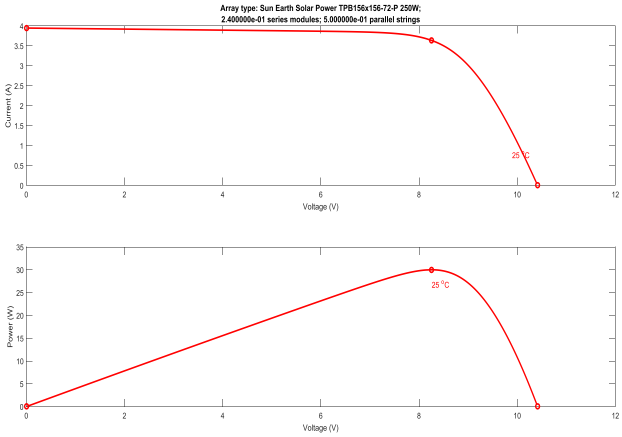

Fig. 13. IV and PV curve (Pmax=250W)

The curve shown in fig 13 is known as the current-voltage (IV) and power-voltage (PV) curve. This characteristic would be obtained from solar PV.

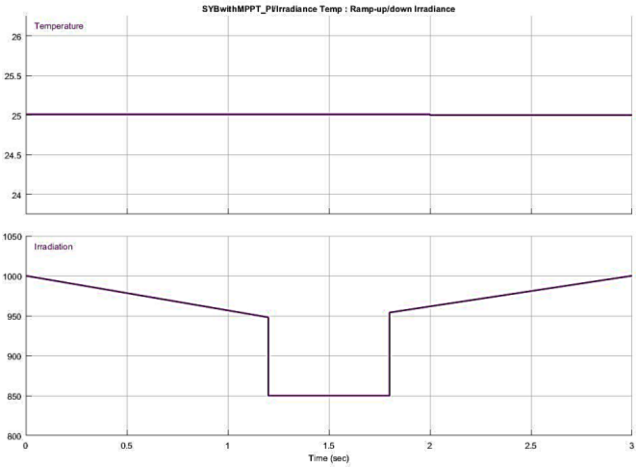

Fig. 14. Temperature and Irradiation Variation

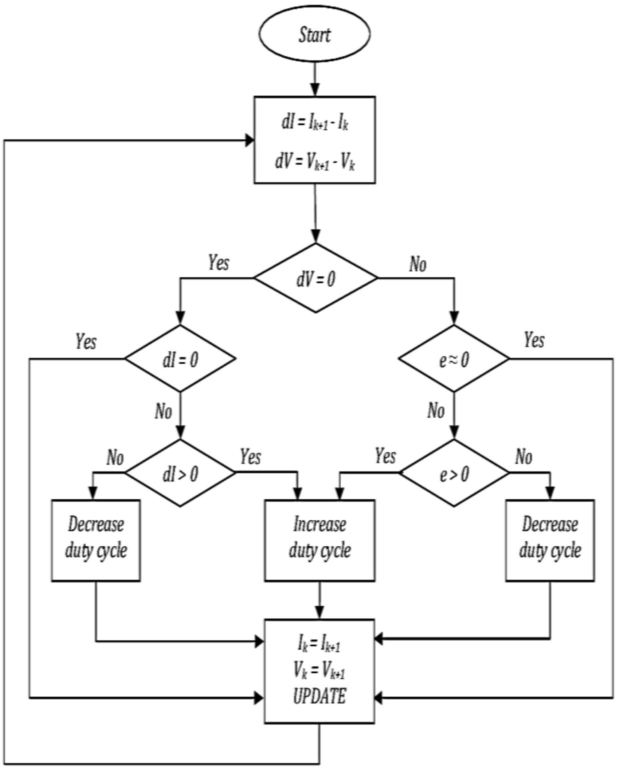

Fig. 15. IC Method

Fig 14 shows the variation in the irradiation at a constant temperature. Even though, the irradiation changes, the output remains the same. Fig is due to the MPPT algorithm mentioned in fig 15.

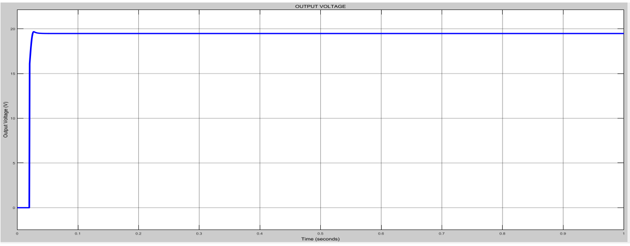

Fig. 16. PSFBC Output Voltage (19.8VDC)

Fig 16 clarifies the output voltage response with less rise time and settling time compared to the open-loop system. The steady-state error is almost zero thus causing high efficiency. The response is similar to the output current response as shown in fig 17.

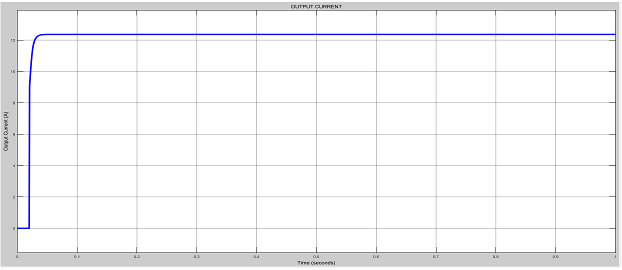

Fig. 17. PSFBC Output Current (12.3ADC)

Table III shows the reference voltage variation in which the increase in reference voltage results in an increase in power output thus the efficiency gets improved to a better level.

Table- III: Variation in Reference Voltage

S.NO	V_{ref} (V)	v_{in} (V)	i_{in} (A)	v_{out} (V)	i_{out} (A)	η (%)
1	15	20	12.5	19.4	12	93.1
2	18	20	12.5	19.6	12.2	95.6
3	20	20	12.5	19.8	12.3	97.4

The battery model is assumed to be RC load and its value is designed as per the power rating mentioned.

VII. CONCLUSION

In this paper, it is aimed to transfer power from solar PV to battery in an efficient manner. At first, the solar PV with variation in irradiation analysis made with an open loop system and the power and efficiency are analyzed. Then, the variation in reference voltage in the PI controller with closed loop configuration leads to the change in the efficiency of the system and it is analyzed for various voltages. The designed values of parasitic elements are used in simulation which provides better results than existing converters for battery application. The ultimate objective of source and load isolation using a transformer is provided which would provide isolation to the source. The ZVT technique to reduce switch loss is operated well than the previously existing model. The better efficiency of around 97% is achieved from the system.

REFERENCES

1. Duan, Chen, Caisheng Wang, Zongzheng Li, Jianfei Chen, Shidao Wang, Adrian Snyder, and Chenguang Jiang. "A Solar Power Assisted Battery Balancing System For Electric Vehicles." IEEE Transactions on Transportation Electrification (2018).
2. Yilmaz, Murat, and Philip T. Krein. "Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles." IEEE Transactions on Power Electronics 28, no. 5 (2013): 2151-2169.
3. Haidar, Ahmed MA, and Kashem M. Muttaqi. "Behavioral characterization of electric vehicle charging loads in a distribution power grid through modeling of battery chargers." IEEE Transactions on Industry Applications 52, no. 1 (2016): 483-492.
4. Vu, Van-Binh, Duc-Hung Tran, and Woojin Choi. "Implementation of the constant current and constant voltage charge of inductive power transfer systems with the double-sidedlcccompensation topology for electric vehicle battery charge applications." IEEE Transactions on Power Electronics 33, no. 9 (2018): 7398-7410.
5. Xiong, Rui, Jiayi Cao, Quanqing Yu, Hongwen He, and Fengchun Sun. "Critical review on the battery state of charge estimation methods for electric vehicles." IEEE Access 6 (2018): 1832-1843.
6. Tao, Jisheng, Debao Huang, Deling Li, Xian Yang, and Chanhui Ling. "Pricing strategy and charging management for PV-assisted electric vehicle charging station." In 2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA), pp. 577-581. IEEE, 2018.
7. Tseng, Kuo-Ching, Jang-Ting Lin, and Chi-Chih Huang. "High step-up converter with three-winding coupled inductor for fuel cell energy source applications." IEEE Transactions on Power Electronics 30, no. 2 (2015): 574-581.
8. Instruments, Texas. "Phase-shifted full-bridge, zero-voltage transition design considerations." Application Report, SLUA 107A (2011).
9. Di Domenico, F., and R. Mente. "ZVS Phase Shift Full Bridge: CFD2 Optimized Design." Infineon Application Note (2013).
10. Instruments, Texas. "Phase-Shifted Full Bridge DC/DC Power Converter Design Guide." TIDU248, May (2014).
11. Abdel-Rahman, Sam. "Design of phase-shifted full-bridge converter with current doubler rectifier." Infineon Technologies AG, DE (2013): 9.
12. Subudhi, Bidyadhar, and Raseswari Pradhan. "A comparative study on maximum power point tracking techniques for photovoltaic power systems." IEEE Transactions on sustainable energy 4, no. 1 (2013): 89-98.

AUTHORS PROFILE

G. Arun, is Currently Pursuing BE (Electrical and Electronics Engineering) in National Engineering College, Kovilpatti.

R. Arunkumar, is Currently Pursuing BE (Electrical and Electronics Engineering) in National Engineering College, Kovilpatti.

K. Krishnakumar, is Currently Pursuing BE (Electrical and Electronics Engineering) in National Engineering College, Kovilpatti.

P. Muthupattan, is Currently Pursuing BE (Electrical and Electronics Engineering) in National Engineering College, Kovilpatti.

Dr. G. Kannayeram, is working as Assistant Professor (Senior Grade) in Electrical and Electronics Engineering of National Engineering College K.R.Nagar, Kovilpatti. He pursued his B.E degree at National Engineering College, in the year 1998 and M.E.E., (Power Systems) at Jadavpur University, Kolkata, India in the year 2007. He received his Ph.D. degree (Electrical Engineering) at Anna University, Chennai in the year 2018. He is an active member of the Institute of Engineers (I) and Indian Society for Technical Education. He has published more than 30 papers in national and international conferences/ Journals.

K. Karthik Kumar has completed his UG-Electrical and Electronics Engineering course (2017) and PG- Power Electronics course (2019) at Mepco Schlenk Engineering College, Sivakasi; and currently working as Assistant professor in the department of Electrical and Electronics Engineering, National Engineering College, Kovilpatti. His research interest includes power electronics converters for electric vehicle application. He has published 5 research articles in international conference/ Journals.