Journal of Green Engineering (JGE)

Volume-10, Issue-2, February 2020

A Novel Single Stage AC/DC PFC Converter for Renewable Energy Sources

[1]A.Santhi MaryAntony and [2]D.Godwin Immanuel

[1] Research Scholar, Department of EEE, Sathyabama Institute of Science and Technology, Chennai,Tamilnadu,India.
[2] Associate Professor, Department of EEE, Sathyabama Institute of Science and Technology, Chennai, Tamilnadu,India.

Abstract

A new Single Stage Three Level (SSTL) isolated AC/DC PFC converter with higher input power factor for continuous input current has been designed. The converter has to be operated in the discontinuous mode to obtain its high power factor through flexible dc link voltage. The power factor correction in the solar panel is achieved by using two stages of conversion where all the switching operation is shared through a control scheme. A flexible dc link voltage helps to shape the current and voltage waveform, resulting in power factor correction. The switches are subjected to soft switching techniques in the Discontinuous Mode of Operation [DCM]. Variable dc link increases the power factor [PF] through which Power Factor Correction [PFC] can be attained.

Keywords: Single-stage three level, Isolated AC/DC PFC converter, Discontinuous Mode, Total Harmonic Distortion, Flexible DC link voltage.

Journal of Green Engineering, Vol. 10_2, 480–493. Alpha Publishers

Alpha Publishers

1 Introduction

The AC/DC power converters should operate in a manner such that quality of power parameters should be high and its harmonic distortion should be less [1,2]. Fundamental frequency is defined as the smallest frequency of a periodic waveform. It tells us the distortion of a voltage or current due to harmonics in the signal [12]. It is an important aspect in audio, communication systems and power systems. By predicting the n^{th} level harmonic component, Total harmonic distortion [TDH] can be calculated.

Power Factor Correction aims at improving the power quality. Conventional methods use single stage, but modern trends have suggested the use of a three stage such that the size of the circuit can be reduced and the circuit can operate at the high frequency range. Power Factor improves the power quality of the electrical network . It is useful in situations when there is a motor failure, failure in electrical or electronic equipment, unwanted tripping of circuit breakers and unstable operation of the equipment and where the usage of energy is high and the cost is also high [10]. Power factor correction is a unique requirement for the power quality improvement. Poor power factor leads to the instability of power quality analysis [3,7]. By means of various optimisation techniques, power quality can be improved.

The PFC equipment uses a bank of capacitors which is used to offset an inductive load or a bank of reactors in case of capacitive load [13]. The following parameters are checked for the optimum condition of working of the power system levels of voltage, harmonic content in the waveform, condition of the equipment and the operation of the equipment.

Renewable sources are making a great impact in the power factor correction techniques. Modern world is facing the threat of the depletion of non-renewable sources such as coal, petroleum etc. Therefore, the shift has been made to renewable sources such as PV (Photo-voltaic) systems, Wind System, Fuel Cell etc [4,8]. A PV system is a system which supplies solar power by means of photovoltaic [5]. The advantages of PV system are the energy produced by solar cells is clean because no fuel is used other than sun rays [11].

2 Existing System

The existing converter uses a diode full bridge. The 230V AC supply is rectified through full bridge diode. The rectified DC fed to an inverter where the switches are operated with pulse width modulation techniques. The duty cycle denotes the time period during which a signal is active. It is commonly denoted as a percentage [14] . Single Stage PFC converters are less costly and are used for dc load applications as shown in figure 1. The disadvantages of the existing system, shown in figure 2 includes low power factor as compared to proposed system, low voltage gain, the losses will be more, less reliable and the efficiency is less.

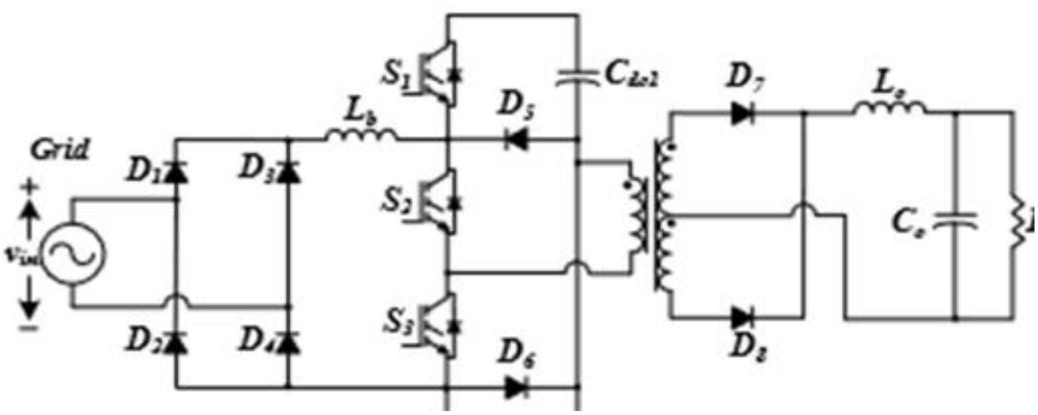

Figure 1 Circuit Diagram for existing topology

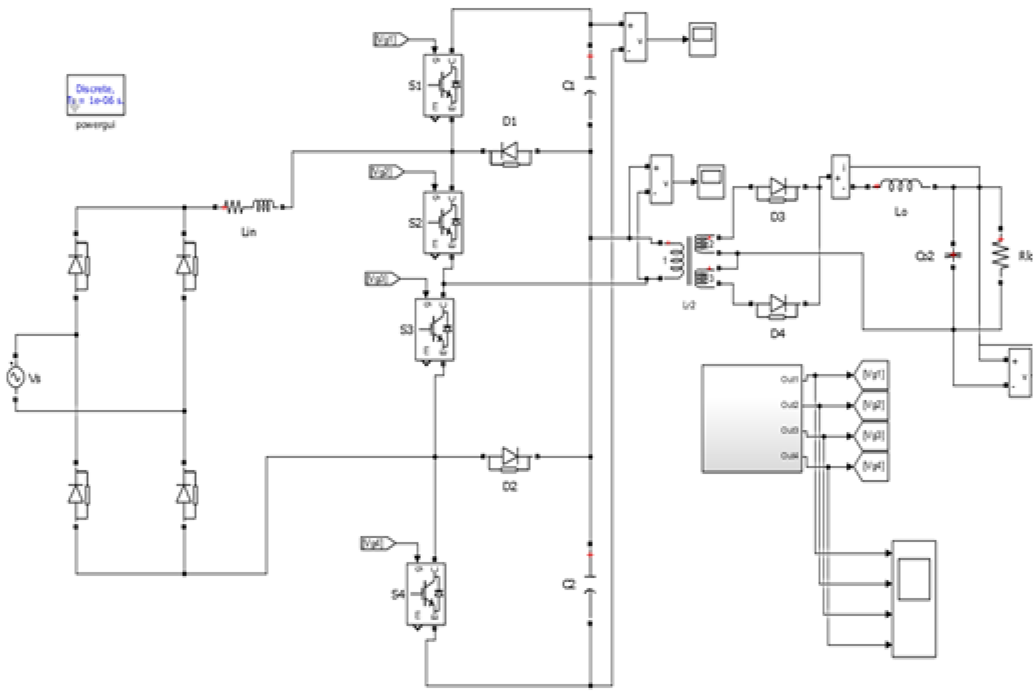

Figure 2 Simulation Diagram

3 Proposed Single Stage Pfc Converter for Pv System

The source of input is a Photo-voltaic system which includes a Solar Grid array. The solar cells are very important in generation of electrical power as environmental concerns are increasing over the use of fossil fuels. The inter-connection of solar cells sources and power electronics converters aim at improving power quality, thereby providing a renewable source of energy.

Renewable sources of power including photo-voltaic cells have low output voltage and require series connection or a booster circuit, preferably voltage booster to provide sufficient output voltage [6]. The Single Stage PFC converter for PV systems is shown in figure 3, the power factor is improved, the efficiency is maintained during both light load and full load condition.

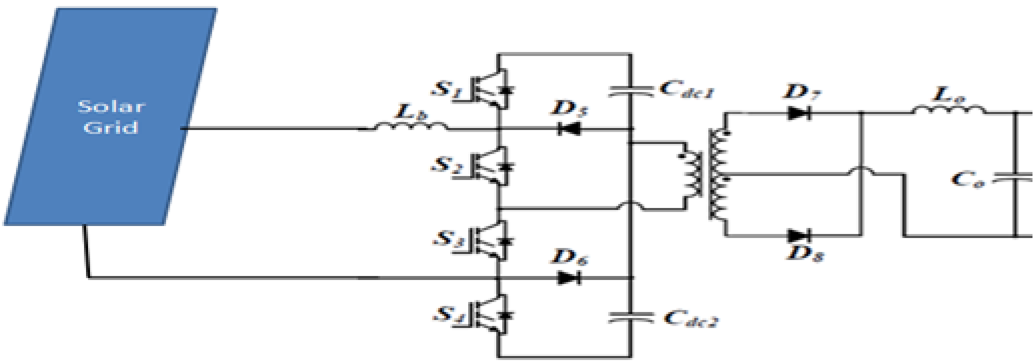

Figure 3 Proposed single stage PFC converter for PV system

4 Principle of Operation

The modes of operation are explained in the following paragraphs.

Mode 1 : At time t = t_1; The upper capacitor is discharged by means of applying half the dc voltage. The Diode starts its conducting as shown in figure 4. The Boost inductor, L_b, has negligible effect on the circuit operation.

Mode 2 : At time t=t_2, the switch S2 is kept in the ON state, shown in figure 5. The diode D_5 conducts.

Mode 3: At time t=t_3, At time t=t_2, the switch S3 is turned ON as shown in figure 6. A voltage V_{in} is applied across the Boost inductor.

Mode 4 : At time t=t_4, The switch S4 is turned ON and switch S3 is in ON condition, shown in figure 7. The output current commutes from diode D_8 to diode D_7. The diodes are commutated by transferring the energy from the input inductor to the R load.

Mode 5 : At time t=$t_{5,}$ As shown in figure 8, the discharging of capacitors take place through the load and a voltage of $V_{dc}/2$ is applied to the primary side. The nullified current is obtained.

Mode 6 : At time t=$t_{6,}$ The leakage current freewheels through diode D6 and zero voltage is to the primary of the transformer. There is a linear variation in the output current as shown in figure 9.

Mode 7 : At time t=t_7, the switch S7 is turned ON shown in figure 10. This mode is similar to Mode 3 of operation, but with a change of primary current.

Mode 8 : At time t=t_8, The switch S3 is turned OFF. The operation of this mode is same as that of mode 4 and inductor stored energy is transferred to dc capacitor bus, as shown in figure 11.

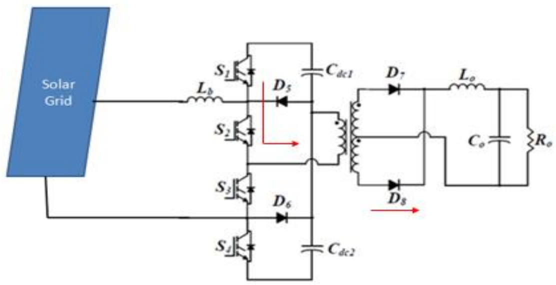

Figure 2 Mode 1

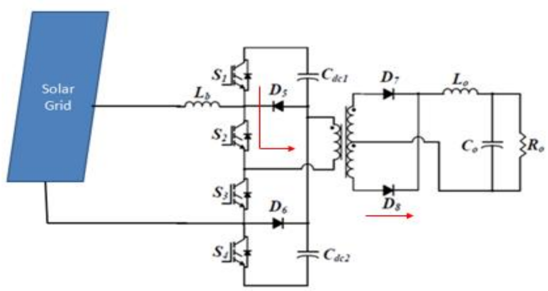

Figure 5 Mode 2

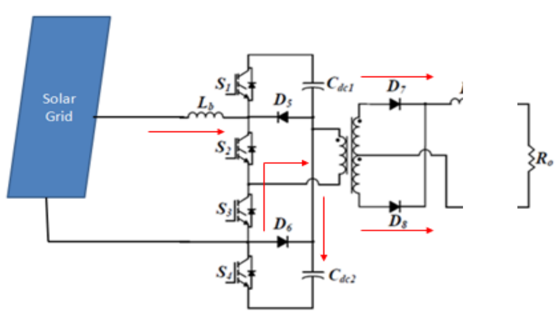

Figure 6 Mode 3

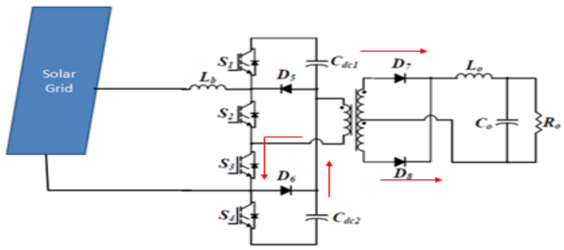

Figure 7 Mode 4

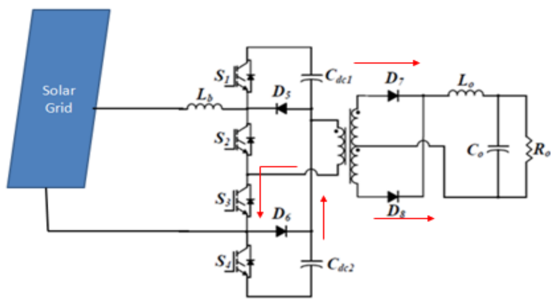

Figure 8 Mode 5

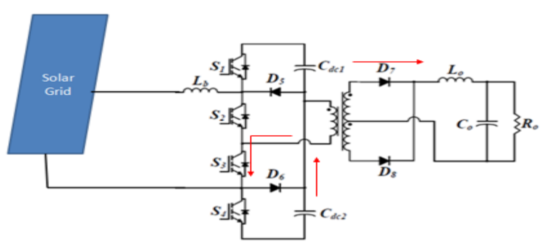

Figure 9 Mode 6

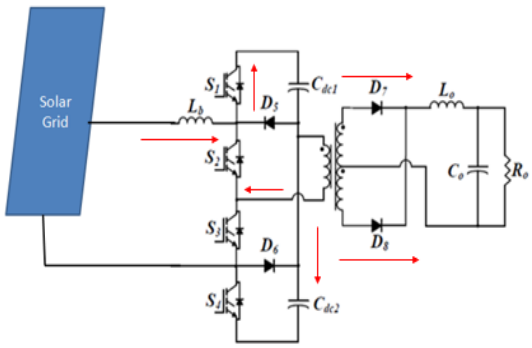

Figure 10 Mode 7

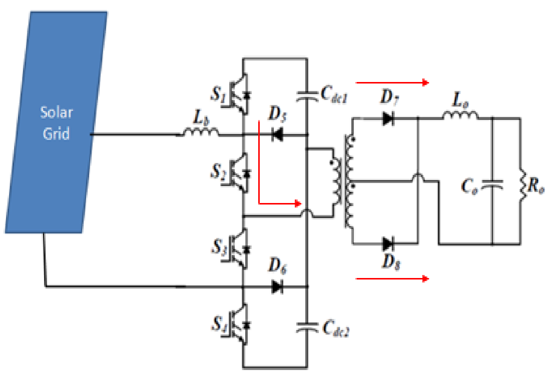

Figure 11 Mode 8

5 Simulation Results

The proposed single stage PFC converter is simulated by means of Simulink in MATLAB based on the design considerations as shown in figure 12 .The simulation results of input voltage and input current are shown in figure 13 and figure 14. A closed loop operation is followed by using a PID controller with a phase locked loop [9]. Power factor corrected waveform is obtained in figure 15.

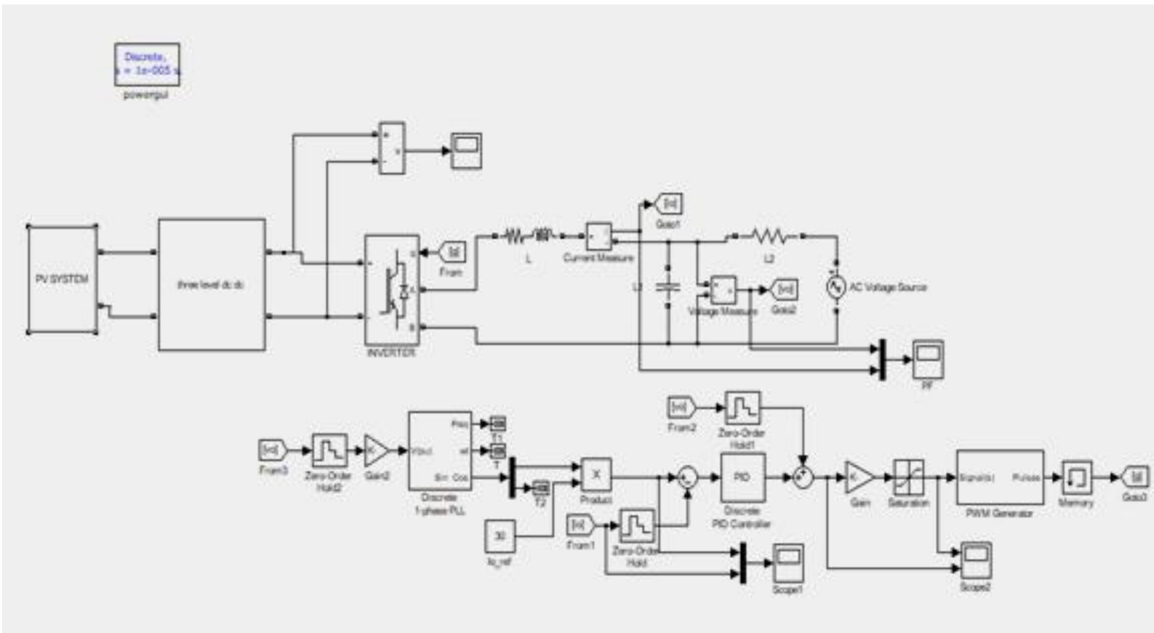

Figure 12 Simulation Circuit Diagram

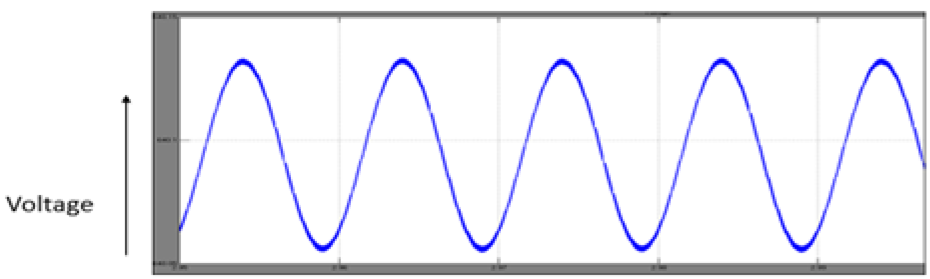

Figure 13 Input voltage

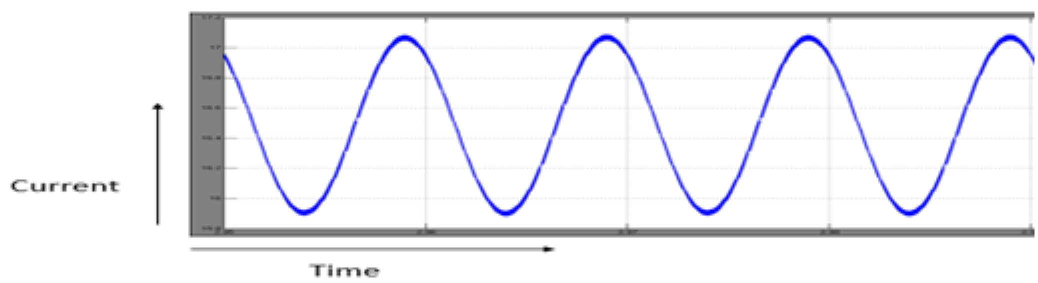

Figure 14 Input current

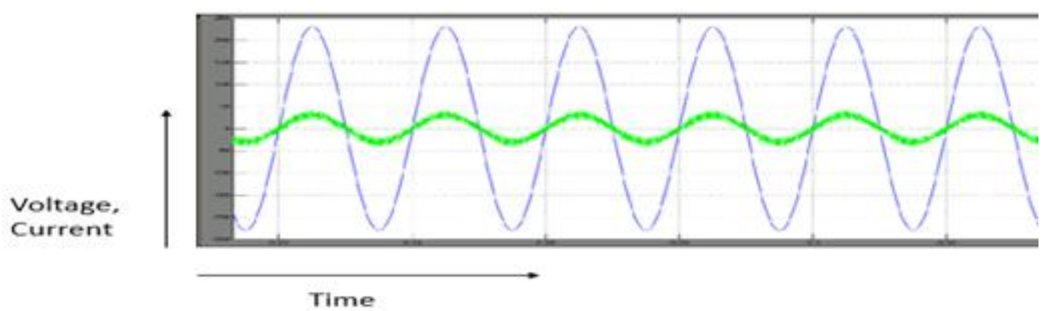

Figure 15 Output voltage and output current waveforms

6 Experimental Results

The input supply is provided with a solar panel, which provides D.C. source of energy. This D.C. current is then passed to the Boost converter and resulting output is fed to an inverter as power factor correction cannot be carried out on D.C. The PWM pulse is provided to the inverter circuit which is used to tune the inverter frequency. The driver switching circuits uses power MOSFET as switches.

The supply voltage of 12V, is stepped up to 40 V by means of the DC-DC converter and followed by inverter shown in figure 16. The PWM pulse, then is used to glow the lamp which acts as an R-Load. Linear and non-linear loads lower the power factor which is corrected by means of the following circuit. The circuit consists of, [1] DC-DC converter, [2] Inverter,[3] Control circuit, [4]Driver circuit, which consists of MOSFET switches. The simulation results and hardware result are compared and tabulated in Table 1.

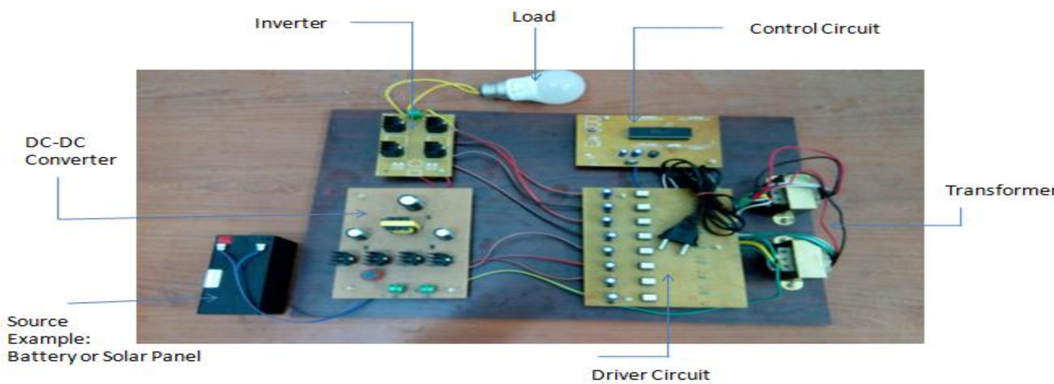

Figure 16 Experimental Prototype for Three Level Single Stage PFC Converter

Table 1 Comparison of PF and THD

Parameters	Existing System	Proposed System
Input Voltage, Input Current	265V, 2.21 A	640.12 V,17.1 A
Output Voltage, Output Current	82V, 6.5 A	245V V,48A
Power Factor	0.91	0.93
Total Harmonic Distortion (THD)	0.4556	0.3952

7 Conclusion

The converter is aimed at achieving high power factor with less number of switches and the cost is reduced. The use of two independent controllers helps in simplifying the controller and design configuration of the circuit. Efficiency is, as high as 91% can be achieved which is a valuable asset in reducing the power loss and thereby increasing the power quality. Since the non-renewable sources of energy are getting depleted, the use of the solar grid provides a sustainable method of power factor correction [PFC] by utilizing the sunlight which is in huge abundance in our country like India, thereby setting the foundation of the use of renewable sources of energy in enhancing the power quality.

References

[1] Banu Priya.R and Ruban Raja.R, "Power Quality Improvement using UPFC with solar cells by MPPT", International Journal of Advanced Research in Computer Engineering & Technology (IJARCET) ,Vol. 7, no. 7,pp. 2516-2521, 2014.

[2] Bhim Singh, Sanjeev Singh, Ambrish Chandra, and Kamal Al-Haddad, "Comprehensive Study of Single-Phase AC-DC Power Factor Corrected Converters With High-Frequency Isolation", IEEE Transactions on Industrial Informatics, Vol. 7, no. 4, pp. 540 – 556, 2011.

[3] Chang.Y.C and Liaw.C.M, "A flyback rectifier with spread harmonic spectrum", IEEE Trans. Ind. Electron., Vol. 58, no. 8, pp. 3485–3499, 2011.

[4] Chen.S.M, Liang.T.J, Yang.L.S and Chen.J.F, "A Safety Enhanced, High Step-Up DC–DC Converter for AC Photovoltaic Module Application," IEEE Trans. Power Electron., vol. 27, no. 4, pp. 1809-1817, 2012.

[5] Dusmez.S, Li.X, and Akin.B, "A fully integrated three-level isolated single-stage PFC converter," IEEE Transactions on Power Electronics, Vol. 30, no. 4, pp. 2050–2062, 2014.

[6] Forouzesh.M, Siwakoti .Y.P, Gorji.S.A, Blaabjerg.F and Lehman.B, "Step-Up DC–DC Converters: A Comprehensive Review of Voltage Boosting Techniques, Topologies, and Applications," IEEE Trans. Power Electron., Vol. 32, no. 12, pp. 9143-9178, 2017.

[7] Mojtaba Forouzesh, Yanfeng Shen, KeyvanYari, Yam P. Siwakoti, FredeBlaabjerg, Fellow,"High- Efficiency High Step-Up DC–DC Converter With Dual Coupled Inductors for Grid-Connected Photovoltaic Systems", IEEE Transactions on Power Electronics, Vol .33,Issue 7, pp. 5967 – 5982, 2018.

[8] Nie.Z, Ferdowsi.M, and Emadi.A, "Boost integrated push-pull rectifier with power factor correction and output voltage regulation using a new digital control technique", Proceeding of 26th Annual International Telecommunications Energy Conference, pp. 59–64, 2004.

[9] K Babul Reddy, Santhi Mary Antony .A,"A single sensor based PFC Sepic converter fed BLDC motor drive for fan application", International Journal of Applied Engineering research", Vol 10, no.5, pp. 12187-12196, 2015.

[10] Singh.S and Singh.B, "An adjustable speed PMBLDCM drive for air conditioner using PFC Zeta converter", International Journal of Power Electronics, Vol. 3, No. 2, A pp. 171–188, 2011.

[11] Ychen.S, Liang.T.J, Yang.L.S and Chen.J.F, "A Safety Enhanced, High Step-Up DC–DC Converter for AC Photovoltaic Module

Application", IEEE Trans. Power Electronics, Vol. 27, no. 4, pp. 1809-1817, 2012.

[12] J. Sebastian, J. A. Cobos, J. M. Lopera and J. Uceda, "The determination of the boundaries between continuous and discontinuous conduction modes in PWM DC-to-DC converters used as power factor preregulators," IEEE Trans. Power Electron., Vol. 10, no. 5, pp. 574–582, 1995.

[13]A.Santhi Mary Antony , Godwin Immanuel, "A Novel Single Phase bridgeless AC/DC PFC converter for Low Total Harmonics Distortion and High Power Factor", International Journal of Power Electronics and Drive System (IJPEDS) , Vol. 9, no. 1, pp. 17-24, 2018.

[14]A.Santhi Mary Antony ,Godwin Immanuel, "Bridgeless Isolated Cuk-Converter with Bumpless Control for Reduced THD and Power Factor Correction", Journal of Advanced Research in Dynamical & Control Systems, Vol. 10, 09-Special Issue, pp. 1357 – 1363, 2018.

Biographies

A.Santhi Mary Antony has completed her B.E degree in Electrical and Electronics Engineering from Madras University, Chennai, in 2005 and M.E degree in Power Electronics and Industrial drives from Sathyabama University, Tamilnadu, in 2005. She is stalking her Ph.D under the School of Electrical and Electronics Engineering at Sathyabama Institute of Science and Technology from 2016. Her research is extended in the field of PFC Converters for Renewable Energy sources, Wireless Power Transmission and Application of Power Systems in Power Electronics.

D.Godwin Immanuel completed his B.E degree in Electrical and Electronics Engineering in Manonmaniam sundarnar university, Tirunelveli.

He had completed his Masters in Power system Engineering in Annamalai University and done his Ph.d in Sathyabama University,Chennai. He is currently working as an Associate professor in Sathyabama Institute of Science and Technology Chennai. His research is extended in the fields of Smart grid, FACTS and Power System Optimization problems.