Design and Simulation of two stage power converter for PV fed grid system with PLL

Dr. BOOMA NAGARAJAN, DHANALAKSHMI N, JAYA PRIYA J, MANIKANDAN V

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING, JERUSALEM COLLEGE OF ENGINEERING, CHENNAI

booma_nagarajan@yahoo.com dhanalakshmi0395@gmail.com jayapriya10795@gmail.com

Abstract- The need for a pollution free environment and the continuous increase in energy demands makes renewable energy production more important. Photovoltaic generate electric power when illuminated by sunlight. It directly converts the sun's energy into electricity which can be easily transported and converted to other forms to benefit the society. The role of power electronics converter is very important in the PV systems. The electricity generated by a PV module is in the form of direct current (DC). Transformation of direct current to alternating current (AC) required by many common appliances and for grid-connection is achieved with inverter system. Boost converter is used to boost the photovoltaic voltage at the required high level and that is supplied to inverter (DC/AC) injects the AC voltage to load or grid. The frequency and magnitude of voltage is taken and controlled using controller topology called phase locked loop (PLL). PLL takes the grid voltage and produces angular waveform to be compared with reference to generate pulse for inverter. Thus the phase, frequency and magnitude of voltages are locked using PLL. Both simulation and experimental results are presented to show the effectiveness as well as its efficiency improvement.

1. INTRODUCTION:

Large number of small scale Photovoltaic systems are connected to the Distribution grid in order to support power demand. Photovoltaic systems are interconnected to grid via power electronic converters. The common problem in interconnecting the PV with grid arises in synchronization of frequency. Kakimoto et all (2009) proposed the responses to step and periodic changes of the frequency are examined. The voltage control is modified so as not to affect the frequency control. The PV generators cooperate well with the conventional generators to maintain the system frequency. The generator output is modulated in proportion to the frequency deviation. Jaume miret et all (2012) proposed a controller for a PV three-phase inverter that ensures minimum peak values in the grid-injected currents, as compared with conventional controllers. The peak problems values are considerably reduced using the proposed scheme. Molina-Garcia et all (2012) proposed solution gives high performances, in terms of rms-voltage regulation, by estimating the reactive power. An alternate power solution suitable for radial topologies is described and implemented, avoiding convergence problems and minimizing computational time costs. Xiangdong et all (2013) proposed design of a low complexity grid synchronization method, which decouples the active and reactive power component so that each component can be controlled independently. It lowers the implementation complexity and the computational burden on digital processor comparing to methods using synchronous frame PLLs. Andrea Bonfiglio et all (2014) proposed an optimized control strategy to manage the reactive power reference generated by PV plants. It improves the quality of the low/medium voltage distribution network. It highlights the variation of solar irradiation. Yang et all (2014) proposed advanced features that can be provided by next generation PV systems, and to enhance reliable utilization of PV systems. The proposed reactive power injection strategies include constant active current control, constant average active powercontrol.

Hamidreza et all (2015) proposed a strategy for limiting the TOV caused by single-stage grid-connected photovoltaic energy system. It is less expensive, less effective, solution is acceptable. The effectiveness was demonstrated by time-domain simulation.

Faa-Jenglin et all (2015) proposed a inverter of the three-phase grid-connected PV system should provide a proper ratio of reactive power to meet the low voltage ride through regulations and control the output current without exceeding the maximum current limit simultaneously during grid faults. The control performance of the intelligent control using TSKPFNN-AMF controller proved to be better than other.

Monirul Islam et all (2016) proposed a family of new transformer less PV inverter topology for single-phase grid-tied operation is proposed using super-junction MOSFETs and SiC diodes as no recovery issues required for unity power operation. The common mode kept constant during the whole grid period reduces the leakage current significantly. These papers discusses the interconnection with grid.

2. SYSTEM DESCRIPTION:

The block diagram of the single-phase grid connected PV system is shown in Fig. 1. It consists of a solar panel, boost converter and inverter. The source is the PV panel and the solar source voltage is given to boost converter. The boost converter steps up the voltage and supplies to single phase inverter. The inverter converts direct current to alternating current. Phase locked loop (PLL) based control loop is used to synchronize the operation of PV system with the grid.

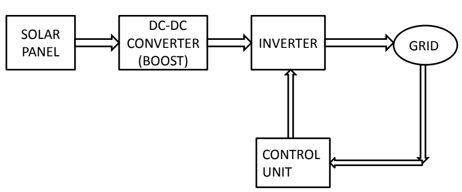

Fig.1. Block diagram of a single-phase grid-connected PV system

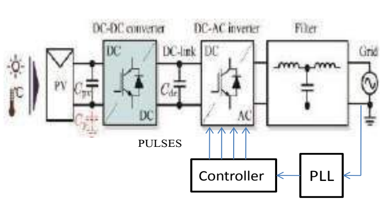

Fig.2. Block diagram of a single-phase grid-connected PV system

The PV panel is connected to DC-DC converter. The converter used here is boost converter. The boosted voltage is fed to DC-AC inverter 180 degree mode of conduction. The harmonics present in the output voltage is filtered using a LCL filter. The magnitude and frequency of grid is controlled using PLL and controller unit generates pulse,which is given to inverter. The inverter produces controlled voltage where the frequency and magnitude is locked or matched using phase locked loop.

3. TABLE: CICUIT PARAMETERS FOR SIMULATIONS:

DESCRIPTION	SYMBOL	VALUE
Grid voltage	Vg	230√2V
Line frequency	Fg	50Hz
Output voltage	VL	250V
Inductance	L	7.5mH
ESR of inductor	*RLin / RLdc*	0.2Ω
Capacitance	CL/CH	47µF

4. OPEN LOOP SIMULATION RESULTS:

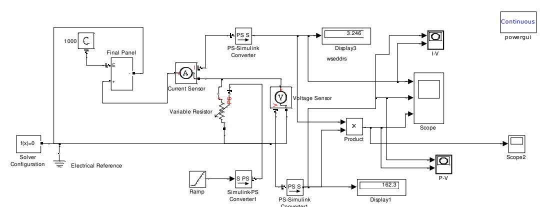

Fig.3. Simulink model of PV array

This block models a solar cell as a parallel combination of a current source, two exponential diodes and a parallel resistor, R_p, that are connected in series with a resistance Rs. The output current I is given by

$$I=I_{ph}-I_s*(e^{((V+I*R_s)/(N*V_t))}-1)-I_{s2}*(e^{((V+I*R_s)/(N_2*Vt))}-1) - (V+I*R_s)/R_p \quad \ldots(1)$$

where I_s and I_{s2} are the diode saturation currents, V_t is the thermal voltage, N and N_2 are the quality factors (diode emission coefficients) and I_{ph} is the solar-generated current.

Models of reduced complexity can be specified in the mask. The quality factor varies for amorphous cells, and typically has a value in the range of 1 to 2. The physical signal input I_r is the irradiance (light intensity) in W/m^2 falling on the cell. The solar-generated current I_{ph} is given by $I_r*(I_{ph0}/I_{r0})$ where I_{ph0} is the measured solar-generated current for irradiance

I_{r0}.

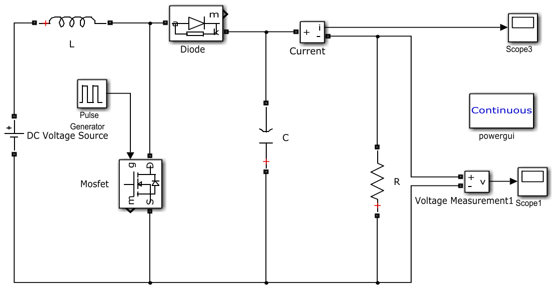

Fig.4. Simulink model of boost converter.

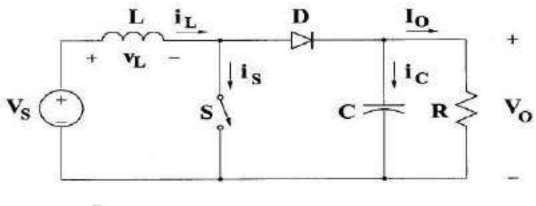

Fig.5 Configuration of Boost converter.

A boost converter is a switch mode DC to DC converter in which the output voltage is greater than the input voltage. Since the output voltage is greater than the input voltage the output current is less than the input voltage. The main working principle of the boost converter is that the inductor in the input circuit resists sudden variation in the input current. When the switch is off, the inductor stores energy in the form of magnetic energy and discharges it when switch is closed. The capacitor in the output circuit is assumed large that the time constant of RC circuit in the output stage is high. The boost converter can be operated in two modes viz,

1) Continuous conduction mode in which the current in the inductor never goes to zero. The switch is on at t = 0. The input current which rises, flows through the inductor L. During this stage the inductor charges and the inductor current rises. When the switch is off the diode will be short circuited and now the inductor discharges through the diode and RC combination.

2) Discontinuous conduction mode is the one in which the inductor drains its stored energy before the completion of switching cycle. The inductor in the discontinuous mode drains all the current which it piled up in charging interval of same switching cycle.

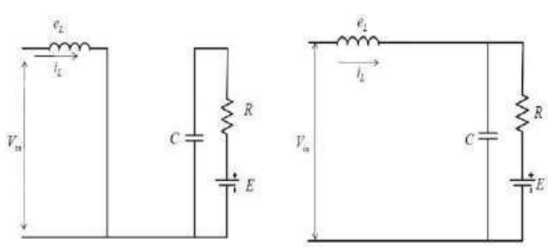

Fig.6. Modes of operation of boost converter.

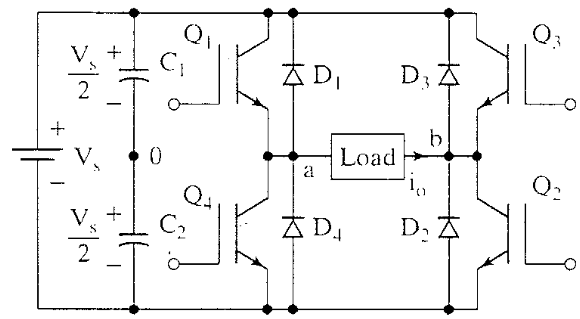

Fig.7 Configuration of Inverter.

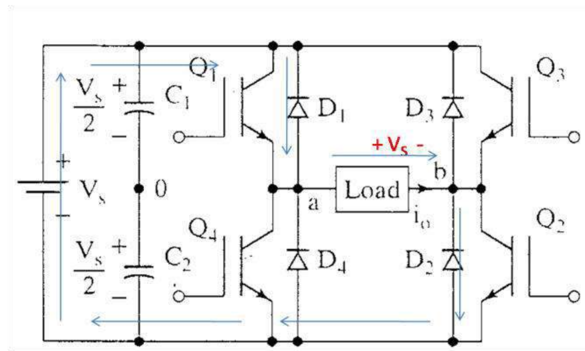

Fig.8. Modes of operation of inverter.

Q1-Q2 on, Q3-Q4 off, $v_o = V_s$

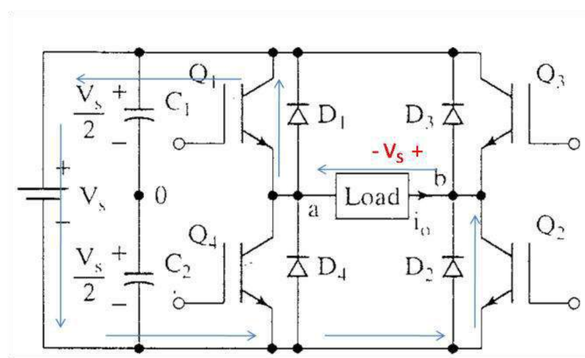

Fig.9. Modes of operation of inverter.

Q3-Q4 on, Q1-Q2 off, $v_o = -V_s$

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC).

The input voltage, output voltage and frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power; the power is provided by the DC source.

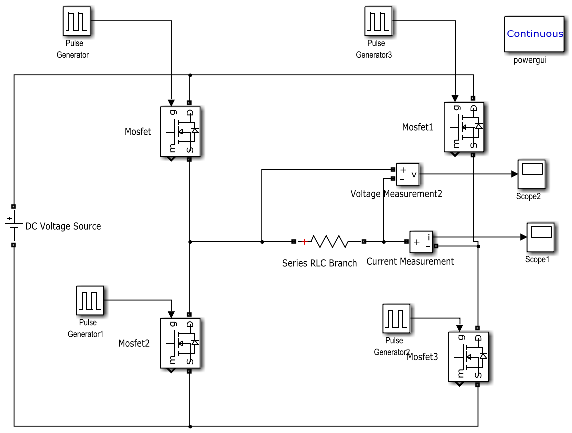

Fig.10. Simulink model of inverter.

6. DESCRIPTION OF CONTROL LOOP

A phase-locked loop or phase lock loop (PLL) is a control system that gives output signal whose phase is related to the phase of an input signal. While there are several differing types, it is easy to initially visualize as an electronic circuit consisting of a variable frequency oscillator and a phase detector. The oscillator generates a periodic signal, and the phase detector compares the phase of that signal with the phase of the input periodic signal, adjusting the oscillator to keep the phases matched. Bringing the output signal back toward the input signal for comparison is called a feedback loop since the output is "fed back" toward the input forming a loop. This Phase Locked Loop (PLL) system can be used to synchronize on a variable frequency sinusoidal signal. When the Automatic Gain Control is enabled, the input (phase error) of the PLL regulator is scaled according to the input signal magnitude.

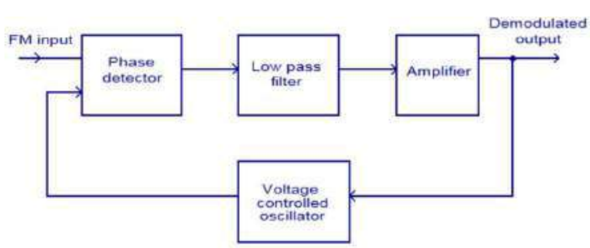

Fig.11 Block diagram of PLL.

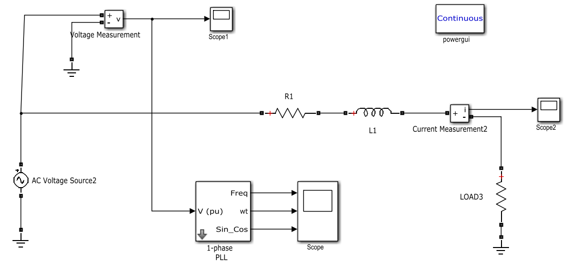

Fig.12. Simulink model of PLL

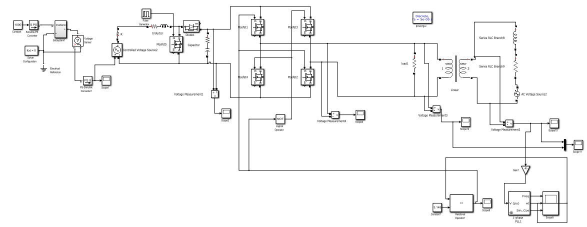

Fig.13. Simulink model of closed loop without filter.

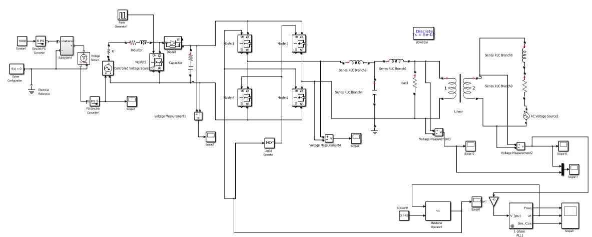

Fig.14. Simulink model of closed loop with filter.

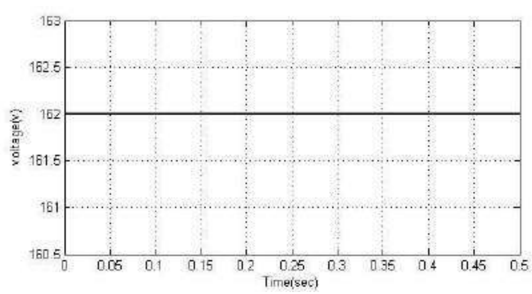

Fig.15. Solar output voltage waveform.

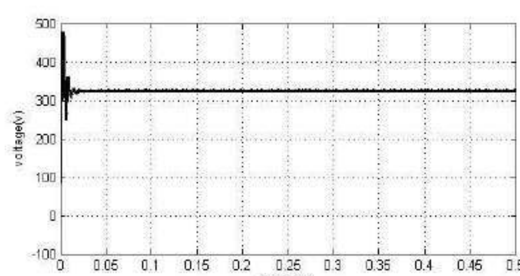

Fig.16. Boosted output voltage waveform.

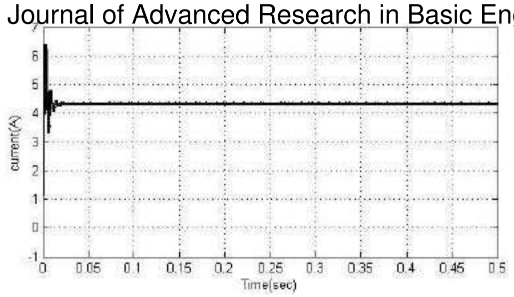

Fig.17. Boosted output current waveform.

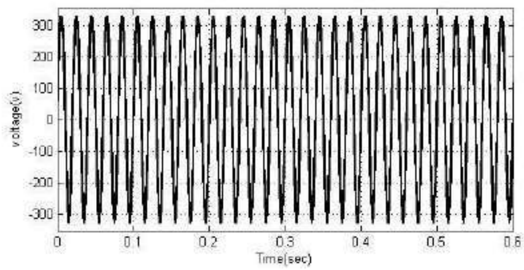

Fig.18. Output voltage waveform of inverter.

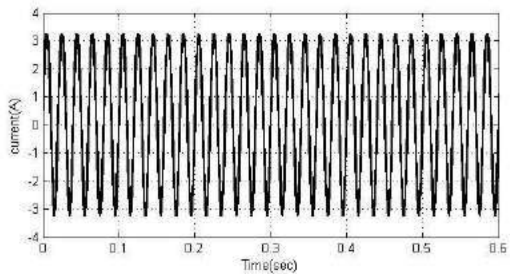

Fig.19. Output current waveform of inverter.

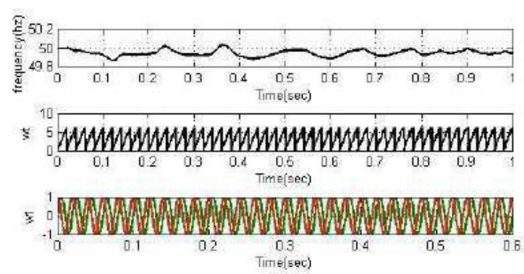

Fig.20. Output of PLL angular waveform.

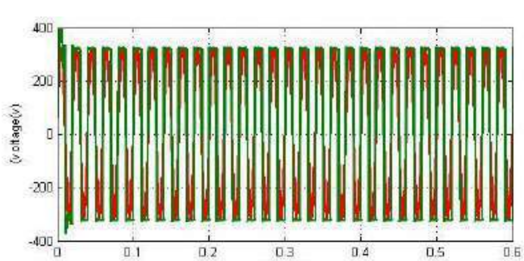

Fig.21. Output voltage of closed loop.

7. CONCLUSION:

The proposed PLL achieves robust synchronization of frequency and magnitude of voltage of grid with PV. The robust and accurate response of PLL enhances the performance by improving the power quality of injected voltage.

8. REFERENCES:

1. Dragon Jorcic , ‘’Phase Locked Loop for FACTS’’, *IEEE Trans. Power Electronics*, vol.18,no.3,pp.1-18, Aug.2003.
2. Naoto Kakimoto, Satoshi Takayama, Hiroyuki Satoh, and Kouichi Nakamura "Power Modulation of Photovoltaic Generator for Frequency Control of Power System," IEEE *Trans. Energy Conversion*, vol. 24, no. 4, pp.943-949, Dec. 2009.
3. Amirnaser Yazdani, Anna Rita Di Fazio, Hamidreza Ghoddami, Mario Russo, Mehrdad Kazerani, Juri Jatskevich,Kai Strunz, Sonia Leva, and Juan A. Martinez "Modeling Guidelines and a Benchmark for Power System Simulation Studies of Three-Phase Single-Stage Photovoltaic Systems", IEEE *Trans. Power Delivery*, vol. 26, no. 2,pp.1247-1263, Apr.2011.
4. Reinaldo Tonkoski*, Student Member, IEEE, Luiz A. C.Lopes, Senior Member, IEEE, and* Tarek H. M. El-Fouly*,"* Coordinated Active Power Curtailment of Grid Connected PV Inverters for Overvoltage Prevention," *IEEE Trans. Sustainable Energy, vol. 2, no. 2*,pp.139-147, Apr. 2011.
5. Jaume Miret*, Member, IEEE*, Miguel Castilla, Antonio Camacho, Lu´ıs Garc´ıa de Vicu˜na, and Jos´e " MatasControl Scheme for Photovoltaic Three-Phase Inverters to Minimize Peak Currents During Unbalanced Grid-Voltage Sags," *IEEE Trans. Power Electronics*, vol. 27, no. 10, pp.4262-4271, Oct. 2012.
6. A. Molina-García, *Senior Member, IEEE, R. A. Mastromauro, Member, IEEE, T. García-Sánchez, S. Pugliese, M. Liserre, Fellow, IEEE, S. Stasi, IEEE, Member "*Reactive Power Flow Control for PV InvertersVoltage Support in LV Distribution Networks,"*IEEE Trans. Smart Grid,* pp.1-10, 2012.
7. Xiangdong Zong, Peter W. Lehn" Reactive Power Control of Single Phase Grid Tied Voltage Sourced Inverters for Residential Pv Application" *IEEE* Trans.vol.18,no.3 ,pp.696-701, Aug.2012.
8. Antonia Camacho, Miguel Castilla , Jaume Miret , Ramon Guzman and Angel Bowell"Reactive Power control for Distributed generation power plants to

Comply With Voltage Limits During Grid Faults" *IEEE Trans. Power electronics* , pp.1-10, oct.2013.

9. Andrea Bonfiglio, Massimo Brignone, Federico Delfino, "Optimal Control and Operation of Grid-Connected Photovoltaic Production Units for Voltage Support in Medium-Voltage Networks," *IEEE Trans. Sustainable energy,* vol.5,no.1,pp.254-263 , Jan. 2014.
10. Yongheng yang , Huai Wang ,Frede Blaabjerg,"Reactive Power Injection Strategies for Single phase Phovoltaic System Considering Grid requirements " *IEEE Trans. Power Delivery* ,pp.1-12,Apr. 2014.
11. Afsim Samadi ,Robert Eriksson , Lennart Soder ,Barry ,G.Rawn and Jens C.Boemer ,"Co-ordinated Active Power Dependent Voltage Regulation in Distribution Grids with PV System" IEEE Trans. Smart Grid vol.29, no.3, pp.1454-1464,Jun. 2014.
12. Hamidriza Ghoddami, Aminaser Yazdani ,"A Mitigation Strategy for Temporary Over Voltage Caused By Grid-Connected PV System" *IEEE Trans. Energy Conversion ,* pp.1-8 , 2015.
13. Fao-Jenglin,Kuangchin Lin ,Ting-Han Ke ,Bo-Hui Yang and Yang-Ruei Chang,"Reactive Power Control of Three Phase Grid Conneted PV System During Grid Faults Using Takagi Sugeno Kang Probabilistic Fuzzy Network Control" *IEEE Trans.Industrial Application ,* pp.1-12, Aug.2015.
14. Shibani Ghosh , Suifur Rahman ,Manisa Pipattanosomporn,"Distribution Voltage Regulation Through Active Power Curtailment with PV Inverters and Solar Generation *Forecasts" IEEE Trans. Sustainable Energy* vol.8,no.1,pp.13-22,Jan.2016.
15. Monirul Islam ,Saad Mekhilef , "Efficient Transformerless MOSFET Inverter for Grid –Tied PV System" *IEEE Trans. Power Electronics*, pp.1-11,May. 2016.

Dr.N.Booma is a Professor in the Dept. of Electrical and Electronics , Jerusalem college of Engineering, Chennai. She has completed her graduate programme in Electrical Electronics Engineering from Madras University, Chennai, India, in 2000, Master of Engineering in Power Systems Engineering from the College of Engineering, Guindy, Anna University and her Ph.D degree in the area of Resonant inverters for induction heating from Anna University. She has 17 years of teaching experience. She has received Best Women Professor Award ,Best Teacher Award, Best Academic achiever Award from her Institution. She has published 17 research papers in International journals .She has also published over 50 technical papers in national and international conferences proceedings. She is the Life member of professional bodies like IEI, ISTE. Her current research interest includes resonant inverters for induction heating, intelligent controllers, power electronics for Renewable Energy, FACTS and power quality.

Ms. DHANALAKSHMI N is currently pursuing her B.E (Electrical and Electronics Engineering) in Jerusalem college of engineering, Anna university, Chennai.

Ms. JAYAPRIYA J is currently pursuing her B.E (Electrical and Electronics Engineering) in Jerusalem college of engineering, Anna University, Chennai.

Mr. MANIKANDAN V received his D.E.E.E. from Sri Balaji Polytechnic college, Chennai ,Tamil Nadu, India, in 2014. He is is currently pursuing her B.E (Electrical and Electronics Engineering) in Jerusalem college of engineering, Anna University, Chennai.