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Series connected Forward Flyback converter for Photovoltaic applications

Anju.C.P[1], Vidhya.S.Menon[2]

[1] M.Tech student, Electrical and Electronics, ASIET, Kerala, India
[2] Assistant professor, Electrical and Electronics, ASIET, Kerala, India

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Abstract - *Solar radiant energy accounts for most of the usable renewable energy on the earth. However power conditioning systems for the sources needs high step up voltage gain due to the low output of the generating sources. This paper presents a high step up converter topology called Series-connected Forward Flyback (SFFB) converter. SFFB is a hybrid type of forward and flyback converter, sharing the transformer for increasing the utilization factor. By stacking the outputs of them, extremely high voltage gain can be obtained with small volume and high efficiency with a galvanic isolation. This paper discusses Perturb and Observe (P&O) as MPPT algorithm to provide switching pulses to the converter. The concept of Maximum Power Point Tracking (MPPT) is to increase the efficiency of photovoltaic system. The proposed system has been modeled and simulated using MATLAB/Simulink software package.*

Key Words: Photovoltaic systems, DC to DC Converters, Maximum Power Point Tracking etc…

1. INTRODUCTION

Energy is required for large number of purposes. Traditional energy is used from coal, natural gas, oil and nuclear energy. But they are exhaustible and polluting. So we need to find an alternate source which is renewable energy source. Solar energy is a good option and the electricity produced is clean, long lasting, no moving parts, less maintenance and silent. The rapid growth of the solar industry over the past several years has expanded the importance of PV system design and application for more reliable and efficient operation.[1] PV Module represents the fundamental power conversion unit of a PV generator system. The output characteristics of PV module depends on the solar insolation, temperature and output voltage of PV module. Since PV module has non linear characteristics, it is necessary to model it for the design and application of the PV system applications. Maximum power point tracking is an electronic algorithm to harvest maximum power from the PV panel. DC to DC converters are used to regulate voltage output from the PV panel. The basic block diagram of photovoltaic system is given below.

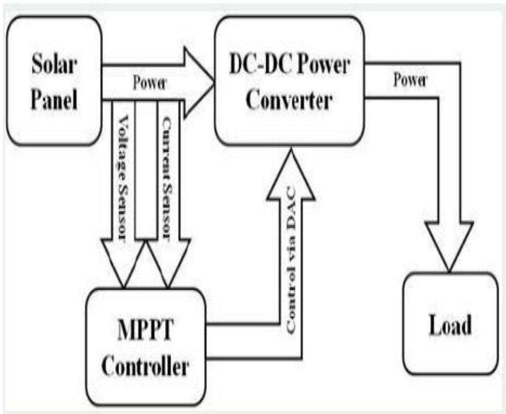

Fig -1: Basic configuration of PV system

1.1 Photovoltaic model

Solar cell is basically a pn junction fabricated in a thin wafer or layer of semiconductor. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. PV system naturally exhibits non linear I-V and P-V characteristics which vary with the radiant intensity and cell temperature.[6] Figure 2 shows the equivalent circuit of PV cell.

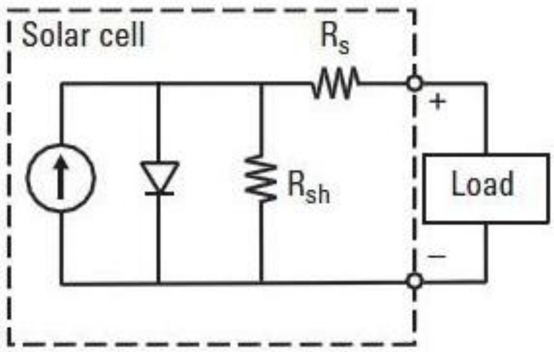

Fig -2: Equivalent circuit of PV cell

The photovoltaic cell output voltage is basically a function of the photon current which is mainly determined by load current depending on solar irradiation level during the operation.

$$Vc = (A*k*Tc/e)\ln((Iph+Io-Ic)/Io) - Rs*Ic \quad (1)$$

The symbols used are

Vc : Cell output voltage
Tc : Reference cell operating temperature
Rs : Series cell resistance
Iph : Light generated photon current
Io : Reverse saturation current of diode
Ic : Cell output current
k : Boltzmann constant
A : Ideality factor
e : Charge of an electron

Typical I-V and P-V characteristics of solar panel are given below.

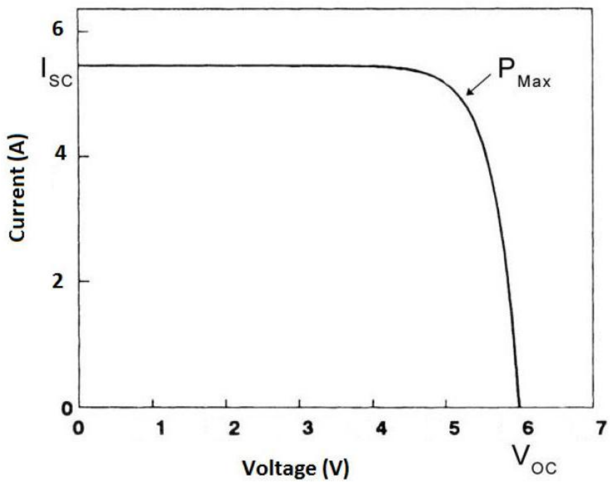

Fig -3: I-V Characteristics

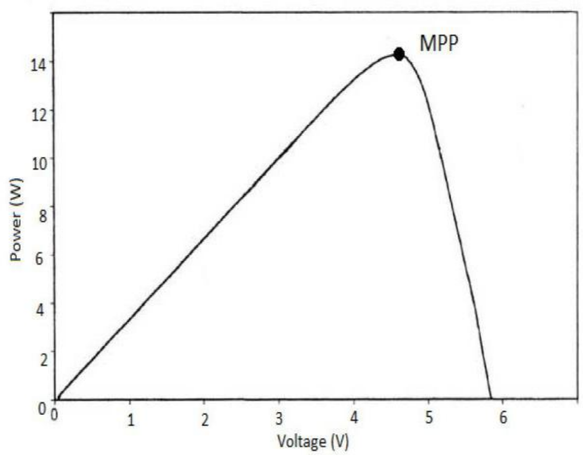

Fig -4: P-V Characteristics

2. MAXIMUM POWER POINT TRACKING

Tracking the maximum power point (MPP) of a PV array is an essential part of PV system. The power output of PV module changes with the amount of solar irradiance and with the variation of temperature. From figure 4 it is understood that there exists a single maxima point of the power that corresponds to a specific voltage and current. Since the efficiency of solar cell is around 8-15%, it is desirable to operate the module at peak power point so that the maximum power can be delivered to the load under varying temperature and irradiance levels. Therefore MPPT is nothing but an electronic algorithm which enables the PV panel to harvest maximum power in any conditions[3]. The various MPPT algorithms are Perturb & Observe method (P & O), Incremental conductance, Fractional short circuit current, Fractional open circuit voltage, Fuzzy logic control, neural network etc. Among these Perturb & Observe method is discussed below.

2.1 Perturb & Observe Method (P&O)

Perturb & Observe Method is one of the most popular algorithms. As the name implies the method will perturb the system by either increasing or decreasing the array's operating voltage point and comparing the result to the one obtained in the previous perturbation cycle.[4] If the perturbation leads to an increase or decrease in the array power, the subsequent perturbation is made in the same or opposite direction. In this manner the peak power tracker continuously seeks the peak power condition. The flowchart for Perturb & Observe is given below.

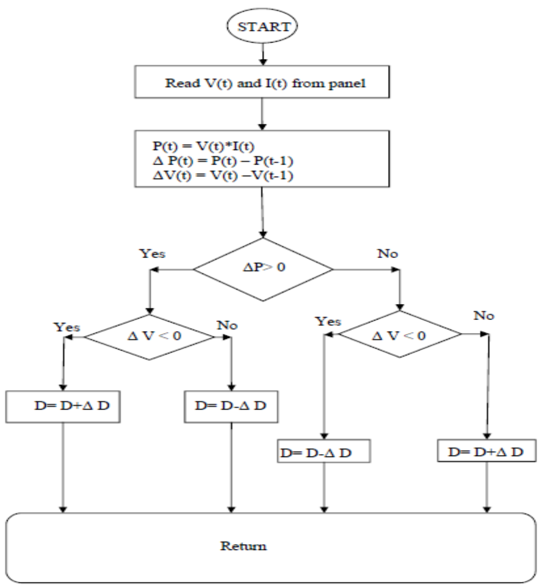

Fig -5: Flowchart

Figure 5 describes the flowchart of P&O method. At the input there are photovoltaic voltage and current. The power is then calculated from these two parameters. The sign of the power determines the duty cycle output of the MPP controller. In simulation, the duty ratio of the boost converter is the control variable. Perturbing the duty ratio of the converter perturbs the PV array current Ipv and consequently perturbs the PV array voltage. The initial value of the duty cycle and PV power are given. The voltage and current of the PV array are measured first and then the power P is calculated. The power is then compared with the previous value. If the difference is positive, the duty cycle is incremented. The switch used is ideal and the output voltage is supposed to be constant. The range of the duty cycle is limited between zero and one.

3. DC – DC CONVERTERS

The main purpose of the DC to DC converters is to convert the DC input from the PV array into a higher DC output. The maximum power point tracker uses the DC to DC converter to adjust the PV voltage at the maximum power point. DC to DC converters are of two types: Isolated and non isolated.[3] The classification of isolated DC to DC converters are given below

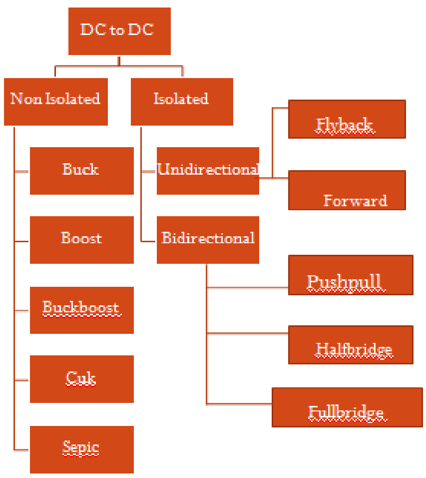

Fig -6: Classification

In this paper isolated DC to DC converters are used because of the following advantages.

- Isolated DC to DC converters provide full dielectric isolation between input and output circuits by means of a high frequency transformer.
- Safety to personnel, isolation prevents input voltage from transferring to output in the case of any internal failure.
- Isolated DC to DC converters can be configured to provide positive or negative outputs from plus or minus rails.
- Voltage transients on the input are not transmitted to the output.
- Isolated DC to DC converters have strong noise and interference capability

3.1 Series connected Forward Flyback Converter

The Series connected Forward Flyback converter (SFFB) converter is a hybrid type of forward and flyback converter sharing the transformer for increasing the utilization factor.[1] By stacking the output of them, extremely high voltage gain can be obtained with small volume and high efficiency even with galvanic isolation. The circuit diagram and equivalent circuit of SFFB circuit are given below

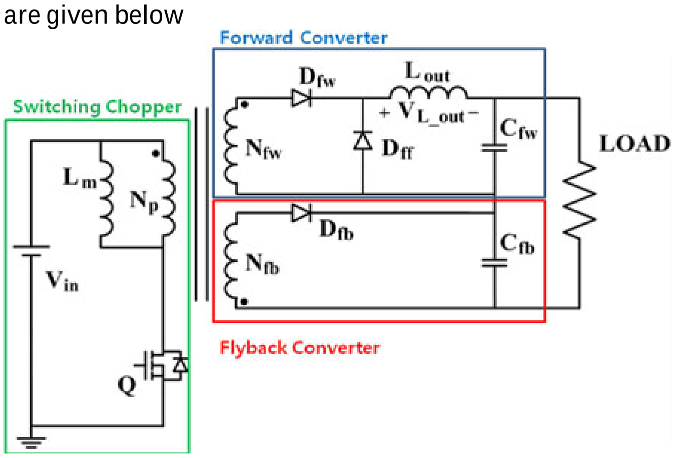

Fig -7: Circuit diagram of SFFB converter

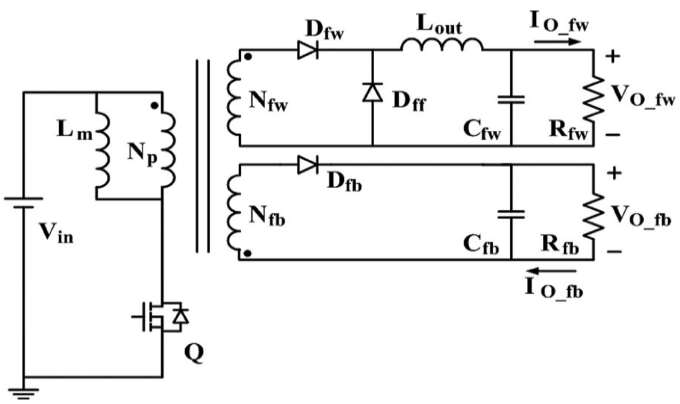

Fig -8: Equivalent Circuit of SFFB converter

The SFFB converter has four operating modes as shown in figure 9 and is explained as follows:
Mode 1: Current flows to the magnetizing inductance and the primary winding Np as a result of turning on switch Q. The primary current is transferred to the secondary Nfw

coil of the forward converter via the magnetic linkage. Then the ac power is rectified into dc which load requires through a forward diode Dfw and a low pass filter Lout

and Cfw. Since a flyback diode Dfb is reverse biased, the output capacitor provides the load current during this mode.

Mode 2: When switch Q is turned off , a forward diode Dfw is reverse biased and the energy stored in Lout is transferred to the load by the freewheeling current via Dff, and at the same time, the energy magnetically stored at Lm is also supplied to load through Dfb of the flyback converter. Thus all the freewheeling current in the magnetic devices decreases linearily.

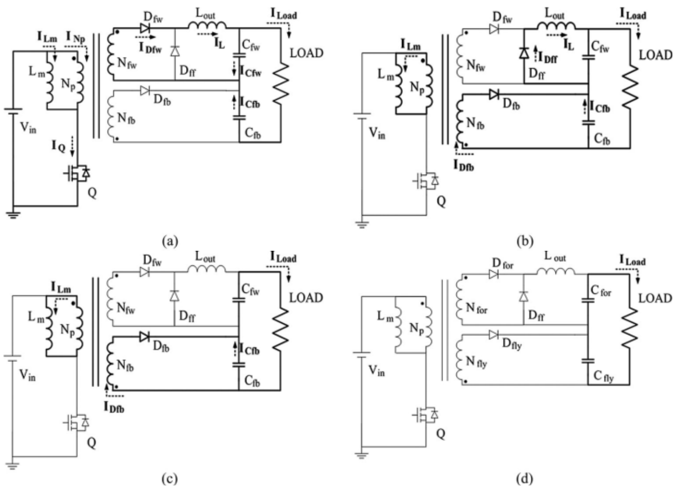

Fig -9: Modes of operation of SFFB converter

Mode 3: The forward converter starts to operate in DCM when all the energy in Lout is discharged, and then a freewheeling diode Dff is reverse biased. The energy only stored in Lm is supplied to load through the flyback converter.

Mode 4: The transformer of the forward flyback converter is demagnetized completely during this period and the output voltage is maintained by the discharge of the output capacitors Cfw and Cfb. All the rectifier diodes are reverse biased. The waveforms are shown in figure 10.

4. IMPLEMENTATION AND SIMULATION

The simulink model of SFFB converter with PV system and the model are given below. Here the boost converter is replaced by SFFB converter and MPPT algorithm used here is P&O method.[1][5] The photovoltaic system is modeled using the following equations

$$I_{PV} = I_{ph} - I_s \left(e^{\{q*(V+I*Rs)/(A*K*T)\}} - 1\right) - (V+I*R_s)/R_{sh} \quad (2)$$

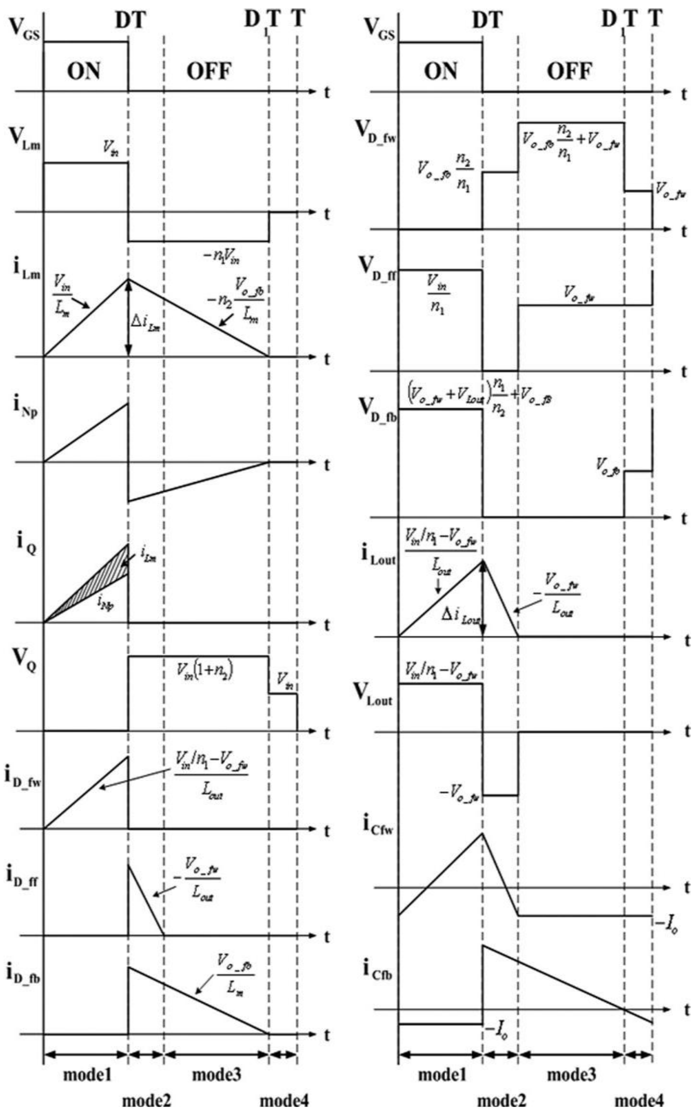

Fig -10: Waveforms of SFFB converter

$$I_{ph} = \{ I_{sc} + K_i *(T-25)\}*\lambda \quad (3)$$

$$I_{rs} = I_{scr} / \left(e^{q*Voc/Ns*K*A*T} - 1\right) \quad (4)$$

$$Is = Irs * (T/Tr)^3 * \left[e^{\{Eg*(T-Tr)/(A*Vt*Tr)\}} \right] \quad (5)$$

Equation 2, 3, 4 and 5 represents photovoltaic current, light generated current, reverse saturation current and saturation current.[2] The MPPT used is P&O method and the simulink model is given below. The model is designed for input voltage 200V and output voltage 350V. The switching frequency used is 20kHz.

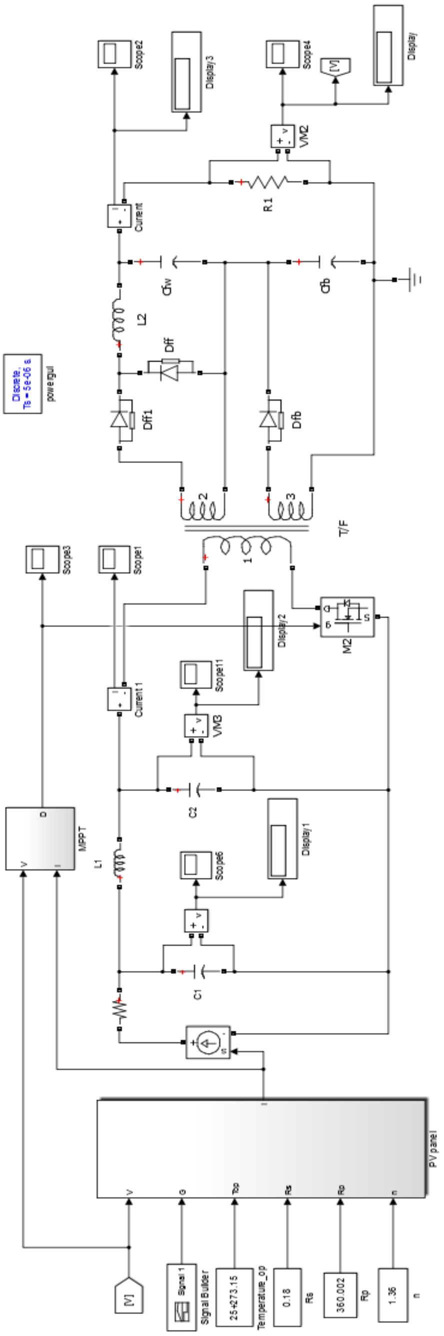

Fig -11: Simulink model of SFFB converter

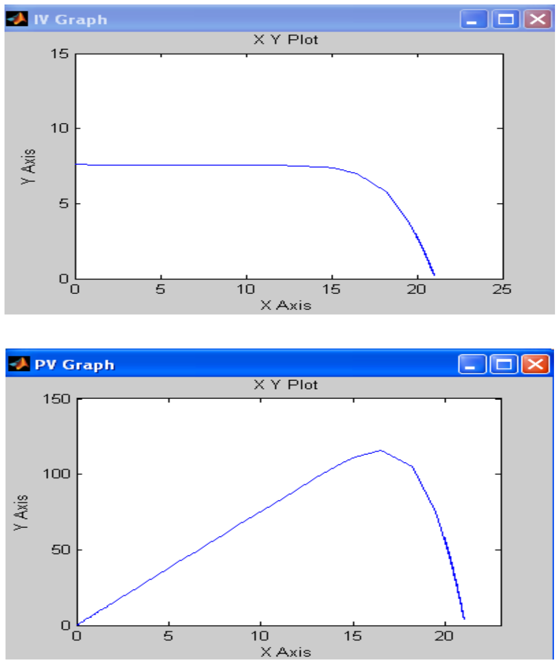

Fig -12: IV & PV Characteristics

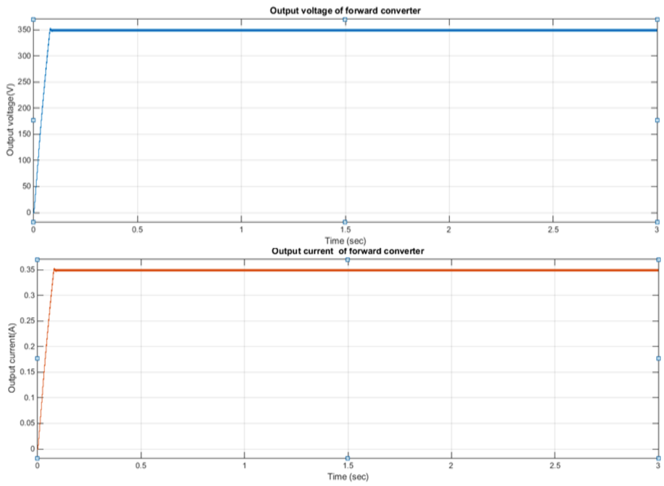

Fig -13: Output voltage and current

4.1 Results and discussions

The I-V characteristics and P-V characteristics of the PV module are shown in figure 12. The output voltage and current of SFFB converter is shown in figure 13. MPPT pulses to the switch as shown in figure 14.

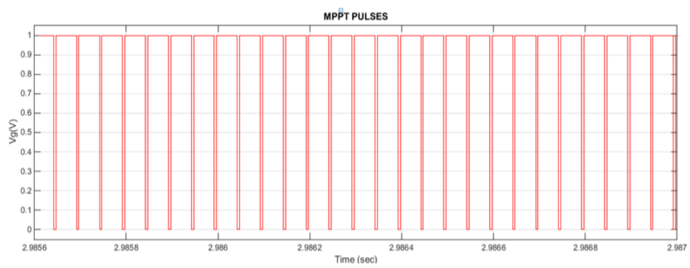

Fig -14: Output waveform of P&O method

Converter Topology	Power Efficiency	Power Loss
SFFB converter	92.38%	5.283W

Table-1: Efficiency and power loss of SFFB converter

5. CONCLUSIONS

Photovoltaic system is forefront in renewable electric power generation. PV module is designed and simulated using MATLAB/Simulink. Perturb & Observe method is used as MPPT algorithm. The efficiency obtained from the simulation is 92.38%.

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BIOGRAPHIES

Anju. C.P was born in Kerala, India in 1991.She received her B.Tech in Electrical and Electronics Engineering in 2013 from Sree Narayana Mangalam Institute of Management & Technology. She is currently pursuing Master of Technology in Power Electronics and Power System at Adi Shankara Institute of Engineering and Technology, Cochin. Her current research interests include Power Electronics and Renewable energy systems.

Vidhya. S. Menon was born in Kerala, India. She received her B.Tech degree from Mar Athanasius college of engineering, Kothamangalam. She received M.tech degree from Government Engineering college, Kannur.She is currently working as an Assistant professor in Adi Shankara Institute of Science and Technology,Kalady. Her current research interests include Renewable energy, DC to DC converters & Medical power electronics.