Performance Enhancement of PV Based Water Pumping System

Velvizhi.J, D.Padma Subramanian

Abstract— Design aspects and simulation procedure leading to Performance Enhancement of PV based Water Pumping System is presented in this paper. Design procedure for implementing maximum power from PV panel using Perturb and Observe concept is presented. Step by step methodology to design a Two Inductor boost Converter (TIBC) with auxiliary transformer is discussed. PV panel – TIBC with auxiliary transformer set up is simulated in MATLAB Simulink platform. Analysis is performed with simulation results. Analysis reveals that the efficiency of water pumping is increased with MPPT than when it is used without MPPT and hence performance of water pumping system is enhanced.

Keywords— Photovoltaic panel, Maximum power point tracking, Two inductor boost converter

I. INTRODUCTION

Solar energy is the most low cost, competition free, universal source of energy as sun shines throughout. This energy can be converted into useful electrical energy using photovoltaic technology. The steady state reduction of price per peak watt and it's simplicity with which the installed power can be increased by adding panels are attractive features of PV technology[2]. Among the many applications of PV energy, water pumping is the most promising. In a PV pump storage system, solar energy is stored, when sunlight is available as potential energy in water reservoir and consumed according to demand. There are advantages in avoiding the use of large banks of lead acid batteries, which are heavy and expensive and have one fifth of lifetime of a PV panel. A number of experimental dc motor driven PV pumps are already in use in several parts of the world, but they suffer from maintenance problems due to the presence of the commutator and brushes. Hence a pumping system based on an induction motor can be an attractive proposal where reliability and maintenance-free operations with less cost are important. The effective operation of Induction motor is based on the choice of suitable converter-inverter system that is fed to Induction Motor[3]. Converters like Buck, Boost, Buck-Boost and Cuk converters are popularly used for photovoltaic systems[1]. But these converters are limited to low power applications. For PV applications like pumping, these converters are less efficient as pumping is carried out at high power. Thus a new Two inductor boost converter which is two switch topology can do the justice by giving a high power throughput. The performance is enhanced by using maximum power point tracking (MPPT). There are several methods for implementing MPPT out of which, Perturb and Observe (P&O) method is a simple method. The control algorithm makes the system perform better with high efficiency. Thus incorporating a MPPT technique based on P&O concept and high output voltage converter like Two inductor boost converter with auxiliary transformer, the performance can be improved for water pumping systems.

II. PHOTOVOLTAIC SYSTEM

A photovoltaic system is a system which uses one or more solar panels to convert solar energy into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings by means of regulating and/or modifying the electrical output. PV cells are made of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, thus forming an electrical circuit, the electrons can be captured in the form of an electric current - that is, electricity. This electricity can then be used to power a load. A PV cell can either be circular or square in construction. Due to the low voltage generated in a PV cell (around 0.5V), several PV cells are connected in series (for high voltage) and in parallel(for high current) to form a PV module for desired output.

The equivalent circuit of a solar cell is represented by four components: a light-induced current source, a diode parallel to the source, a series resistor and a shunt resistor. The light-induced current is due to the separation and drift of the photon-generated electron–hole pairs under the influence of the built-in field[5]. The cicuit model of photovoltoic cell is shown in Fig.1.

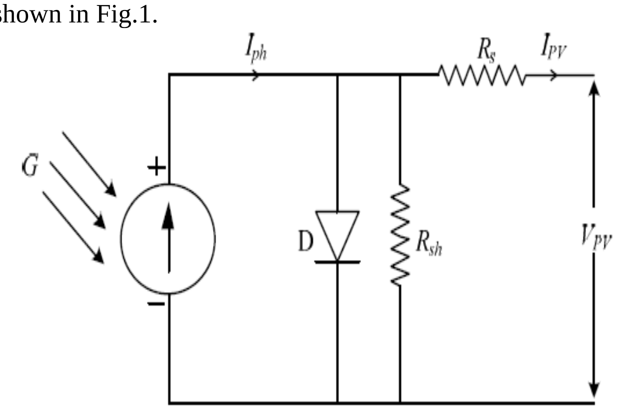

Fig.-1: Equivalent circuit of Solar cell

Manuscript published on 30 March 2014.
*Correspondence Author(s)
Velvizhi.J, Department of Electrical and Electronics Engineering, Jerusalem College of Engineering, Chennai, India.
Dr.D.Padma Subramanian, Professor/Principal, Jerusalem College of Engineering, Chennai, India.

The voltage–current characteristic curve for the *p–n* junction diode is described by the following Shockley diode equation(1).

$$I_D = I\,[\exp(q\,(V + I\,.R_S)/K.T)) - 1] \qquad (1)$$

While, the solar cell output current:

$$I = I_L - I_D - I_{sh} \qquad (2)$$

$$I = I_L - I\,[\exp(q\,(V + I.R_S)/K.T)) - 1] - (V + I.R_S)/\,R_{sh} \qquad (3)$$

Where:

I - Solar cell current (A);
I_{sh} - Light generated current (A) [Short circuit value assuming no series/ shunt resistance];
I_D - Diode saturation current (A);
K - Boltzmann constant (1.38×10^{-23} J/K);
q - Electron charge (1.6×10^{-19} C);
Rs - Solar cell series resistance (Ω);
Rsh - Solar cell shunt resistance (Ω);
T - Cell temperature in Kelvin (K);
V - Solar cell output voltage (V).

Consider a fixed environmental condition, a typical I-V characteristic of a solar cell is shown in Fig.2. The operating point on power vs. voltage curve (P-V curve) will depend on the solar array characteristic and the load as shown in Fig.3. Assuming that initially there is no load, the operating point will be at the far right at the open-circuit voltage, Voc, of the solar array with zero current (V = Voc, I = 0). As the load increase, the operating point will move up and to the left, i.e. voltage at the solar array terminal decreases, while the power increases. As the load increases further, it will reach the maximum power point (MPP), where the power drawn from the solar cell is maximized. The voltage at this point is denoted by the maximum-power voltage (Vmp), and the current by maximum-power current (Imp). If the load increases beyond this point, the voltage decreases and power drawn from the solar array decreases. Eventually, the operating point will reach the far left at the short-circuit current, Isc, with zero voltage output (V = 0, I = Isc).

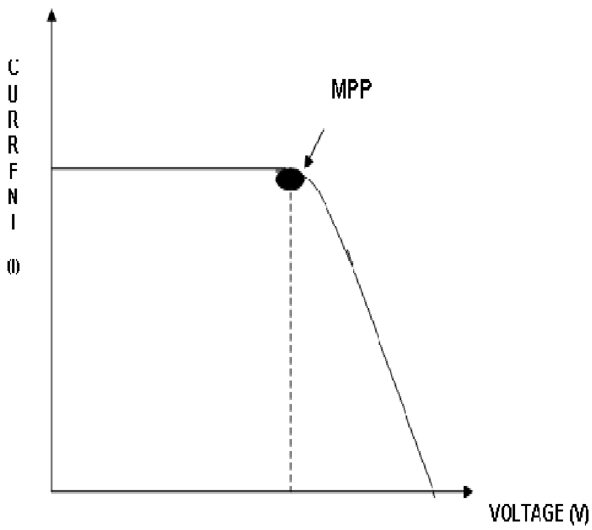

Fig.-2: Typical I-V characteristic of Solar cell

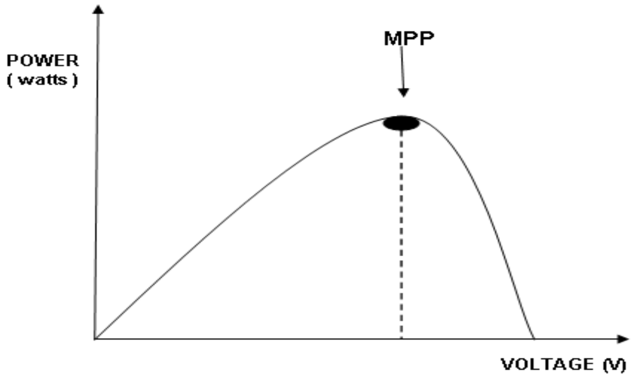

Fig. -3: Typical P-V characteristic of Solar cell

III. MAXIMUM POWER POINT TRACKING

A typical solar panel converts only 30 to 40 percent of the incident solar irradiation into Electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance. Hence the problem of tracking the maximum power point reduces to an impedance matching problem. In the source side a Two inductor boost converter is connected to a solar panel in order to enhance the output voltage so that it can be used for different applications like motor load. By changing the duty cycle of the converter appropriately the source impedance with that of the load impedance is matched.

There are various methodologies such as Perturb and Observe (P&O), Incremental Conductance, Incremental Resistance, Fuzzy, Neural networks and Optimization techniques to implement maximum power point tracking. Out of these Perturb and Observe (P&O) technique is relatively simpler method. In this method it uses only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and easy to implement. The time taken by this algorithm is very less [8]. The flowchart of the modified variable step size P&O MPPT algorithm is shown in Fig. 4, where the step size is automatically tuned according to the PV array operating point. When a step change in the solar irradiance occurs, the step size is automatically tuned according to the operating point. If the operating point is far from the MPP, it increases the step size which enables a fast tracking ability. In most applications, the MPPT is achieved by connecting a power conditioner (dc/dc or dc/ac converter) between the PV array and load.

$\frac{\Delta P}{\Delta V} > 0$ PV operating point at the lift of the MPP

$\frac{\Delta P}{\Delta V} = 0$ PV operating point at MPP

$\frac{\Delta P}{\Delta V} < 0$ PV operating point at the right of the MPP

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

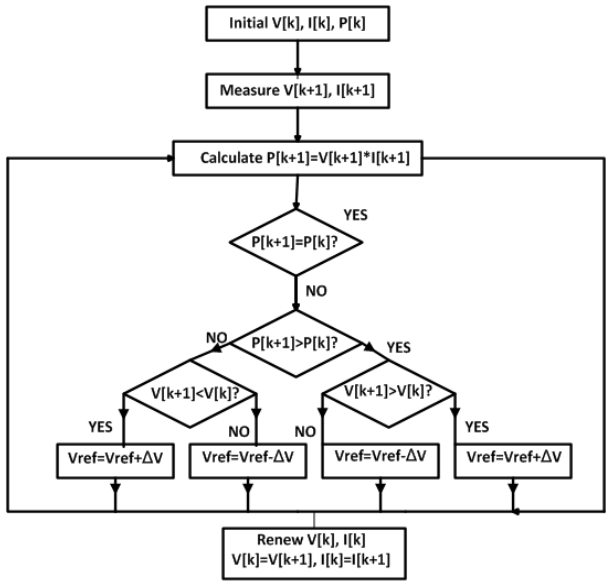

Fig.- 4: Flowchart of P&O Method

III. TWO INDUCTOR BOOST CONVERTER

DC-DC converters can be used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage. The regulation is normally achieved by Pulse Width Modulation (PWM) at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. The minimum oscillator frequency should be about 100 times longer than the transistor switching time to maximize efficiency. This limitation is due to the switching loss in the transistor. Choosing the converter switching frequency enhances the frequency. There are many converter topologies available: boost converter, buck converter, buck-boost converter, cuk converter etc. These converters are used for low power applications. In this work two inductor boost converter is used which is suitable for high power applications.

A new two-inductor, two-switch boost converter topology achieves output-voltage regulation from no load to full load in a wide input voltage range using constant-frequency control. This topology employs an auxiliary transformer with a unity turns ratio to couple the current paths of the two boost inductors so that both inductors conduct identical currents. Due to this current mirror effect of the auxiliary transformer, no energy is stored in the inductors when there is no overlapping of conduction times of the two switches, i.e., when duty cycle is equal to zero (d=0). This auxiliary transformer approach can be applied to isolated or non isolated two-inductor, two-switch topologies with any type of output rectifier [10].

The input side of the circuit consists of two switches S_1 an S_2, two boost inductors L_1 and L_2, and auxiliary transformer (ATR). In order to maximize the voltage gain of the converter, the output side of the inverter is connected to the voltage double rectifier which also converts AC into DC. It consists of boost rectifiers D_1 , D_2 and output filter capacitors C_{F1} and C_{F2} connected across load R_L. The simplified circuit is shown in the fig 5.

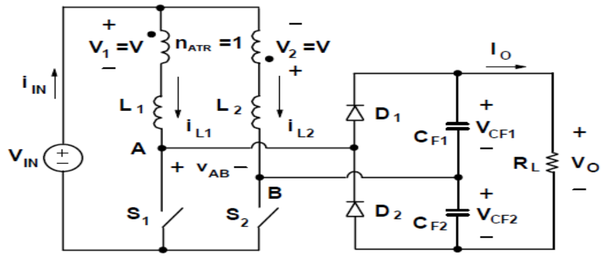

Fig -.5: Simplified model of two inductor boost converter with auxiliary transformer

The assumptions made are,

- Auxiliary transformer (ATR) is modelled as an ideal transformer with turns ratio nATR=1 by assuming magnetizing inductance is high so that it can be neglected.
- The filter capacitors CF1 and CF2 are large so that the voltage ripple is small compared to the dc voltages.
- All semiconductor components are ideal, they represent zero impedances while in the ON state and infinite impedances while in the OFF state.

The various switching modes are summarised in table 1.

Table1:Switching modes of TIBC

MODES	S1	S2
MODE1	ON	ON
MODE2	ON	OFF
MODE2	ON	ON
MODE4	OFF	ON

Explanation of various modes of operation is provided in [11]

V. RESULT ANALYSIS

The two inductor boost converter with auxiliary transformer is designed and simulated using simulink. In order to have minimum ripples in the output voltage and input current, it is assumed 2% as ripple voltage ΔV. The converter switching frequency is chosen as 40 kHz with duty cycle equal to 80%. The subsystem representing the PV panel is developed in MATLAB using equations. PV panel integrated with Two Inductor Boost Converter circuit is shown in fig 6.

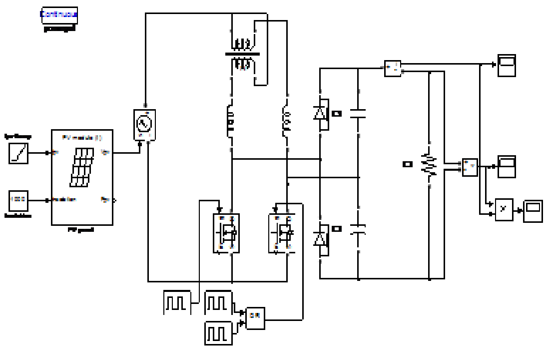

Fig.- 6: Integration of PV-TIBC without MPPT

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

The output power of a 400 W PV panel integrated with TIBC without MPPT is shown in the fig 7. From fig 7 it can be seen that the power output is not the optimum expected power from panel for water pumping system.

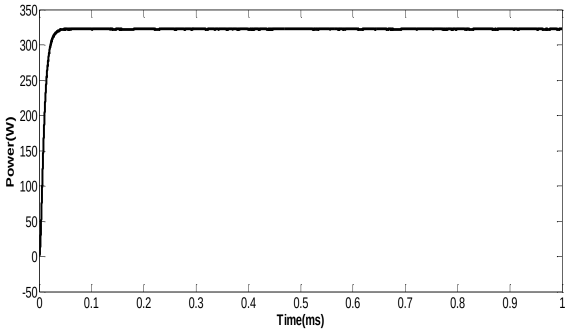

Fig.- 7: Output power without MPPT

Hence to obtain optimum power from the PV panel a closed loop simulation is performed by integrating PV panel –TIBC setup with MPPT. In closed loop , switching of TIBC is designed in accordance with maximum power from PV panel using MPPT as shown in Fig 8.

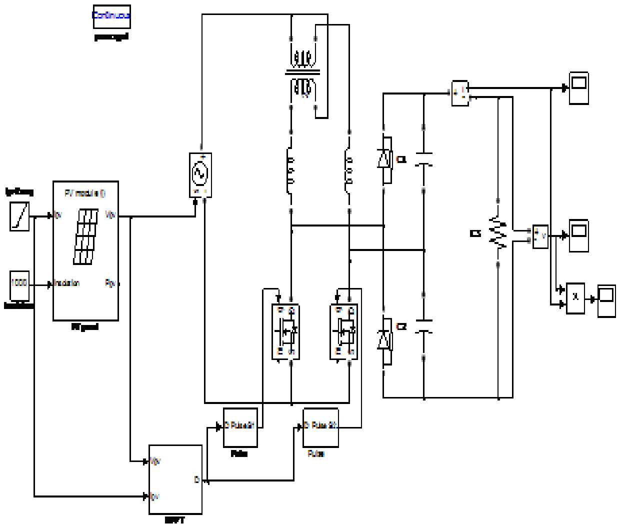

Fig .-8: Intergration of PV-TIBC with MPPT

The power vs time plot of closed loop simulation is presented in Fig 9, from the figure it can be seen that PV panel –TIBC output with MPPT is more optimum power compared to the case without MPPT.

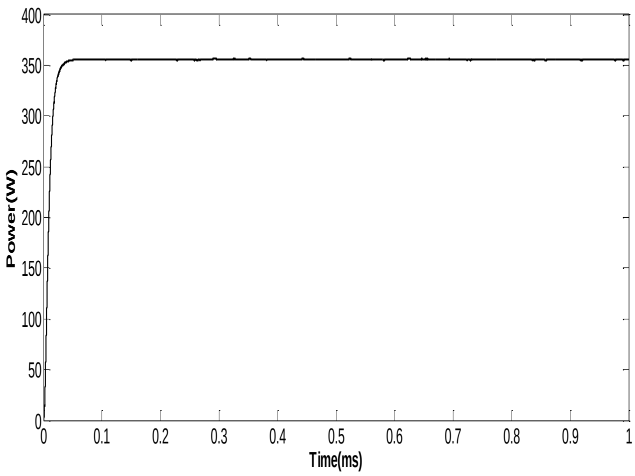

Fig.- :9 Output power with MPPT

The efficiency of water pumping system is calculated for open loop and closed loop and tabulated in Table 2.

Table 2: Comparison of Efficiency

S.no	SPECIFICATIONS	EFFICEINCY
1	PV-TIBC without MPPT	80%
2	PV-TIBC WITH MPPT	87%

From Table 2, it can be seen that the efficiency is more in closed loop simulation

In order to connect the prototype of PV panel and TIBC equipped with MPPT to three phase 415V 0.5Hp induction motor for the purpose of water pumping, a three phase 120º mode inverter is employed. This set up is shown in Fig 10.

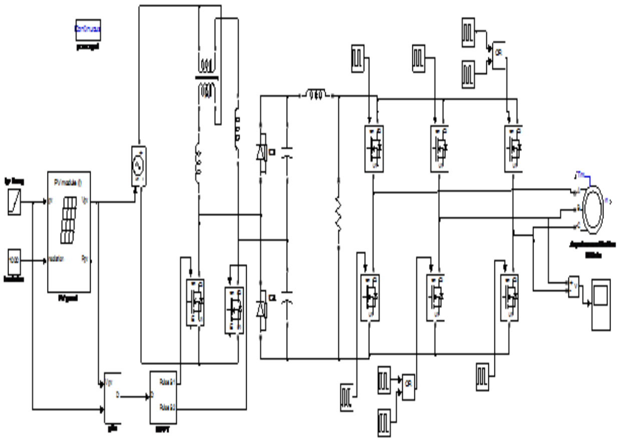

Fig. -10: Integration of PV-TIBC- inverter with three phase induction motor

The output voltage waveform for 120º mode inverter is shown in Fig 11.

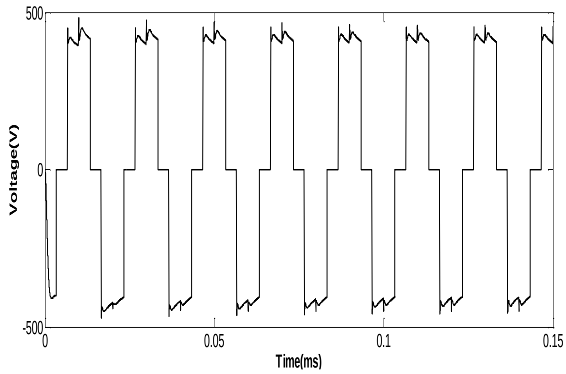

Fig. -11: Output voltage waveform from 120º mode inverter

From Fig 11 , it can be observed that the prototype of PV-TIBC equipped with MPPT and 120º mode inverter produces enough output voltage to drive a three phase 415V, 0.5 Hp induction motor which can be used for water pumping systems.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

VI. CONCLUSION

In this work the operating principles of photovoltaic, Two inductor boost converter and maximum power point tracking algorithm are presented. The concept of maximum power point tracking is implemented using perturb and observe algorithm in MATLAB environment using simulink blocks . A 400W PV panel, TIBC with auxiliary transformer are designed based on the available literature. PV panel, TIBC with auxiliary transformer, 120º mode three phase inverter are also implemented using simulink blocks. The integration of MPPT with rest of the set up in simulink is performed. Simulation is carried out for the set up designed. From the results of PV- TIBC with auxiliary transformer-120º mode three phase inverter connected to three phase induction motor, it can be observed that the set up designed is capable of driving the induction motor used for water pumping purpose. It is also established that the efficiency of water pumping is increased with MPPT than when it is used without MPPT.

REFERENCES

1. Aseem Sayal, "MPPT Techniques for Photovoltaic System under Uniform Insolation and Partial Shading Conditions", IEEE , 2012
2. Hyun-Lark Do , ' Soft Switching DC/DC Converter With High Voltage Gain', IEEE Transactions on Power Electronics, vol. 25, no. 5 , pp.1193-1200, 2010.
3. Huan-Liang Tsai , 'Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK' Proceedings of the World Congress on Engineering and Computer Science 2008, WCECS , October 22 - 24, San Francisco, USA.
4. Joao Victor , Mapurunga Caracas 'Implementation of a high efficiency, high lifetime and low cost converter for an autonomous photovoltaic water pumping system', IEEE proceedings 2013.
5. Kwon.M.J and Kwon B.H. ' High step up active clamp converter with input- current doubler and output voltage doubler for fuel cell power system' IEEE Transactions on Power Electronics, vol. 24, no.1, pp 108-115, 2009.
6. Marcelo Gradella Villalva, Jonas Rafael Gazoli,and Ernesto Ruppert Filho , 'Comprehensive Approach to Modeling and simulation of Photovoltaic Systems' , IEEE Transaction on Power Electronics , vol. 24, no. 5, 2009.
7. Moacyr Aureliano Gomes de Brito, Luigi Galotto, Jr., Leonardo Poltronieri Sampaio, Guilherme de Azevedoe Melo, and Carlos Alberto Canesin, 'Evaluation of the Main MPPT Techniques for Photovoltaic Applications', IEEE Transactions on Industrial Electronics vol. 60, no. 3, March 2013.
8. Tat Luat Nguyen and Kay-Soon Low, 'A Global Maximum Power Point Tracking Scheme Employing DIRECT Search Algorithm for photovoltaic Systems', IEEE Transactions on Industrial Electronics, vol. 57, no. 10, 2012.
9. Yie -Tone Chen ,Shin-Ming Shiu , and Ruey - Hsun Liang, "Analysis and Design of a Zero-Voltage-Switching and Zero-Current-Switching Interleaved Boost Converter", IEEE Transactions on Power Electronics , vol. 27, no. 1, January 2012.
10. Yungtaek Jang and Milan M. Jovanovic´, "New Two-Inductor Boost Converter With Auxiliary Transformer", IEEE Transactions on Power Electronics, vol. 19, no. 1, January 2004.
11. Velvizhi.J "Performance Enhancement of PV based water pumping systems", December 2013; M.E thesis submitted to Anna University.

AUTHOR PROFILE

J.Velvizhi is currently persuing her M.E Power Electronics and drives in Jerusalem college of engineering, Chennai. She received her B.E degree in Electrical and Electronics from Tagore engineering college in 2012. Her area of interest include Power electronic converters and algorithms.

Dr.D.Padma Subramanian received B.E in Electrical and Electronics Engineering and M.E in Electrical power systems with Honours from Govt. Colleg of Engineering, Thrissur in 1990 and 1992. She has done full time doctoral research from college of engineering,Guindy,Anna university during 2004-2007. She has a total of over 20 years of experience in the field of teaching industry and research. Dr.D. Padma subramaian has more than 25 publications spanning around various international/ national journals and proceedings. She is serving as a member of editorial board for a number of international journals. She is an active researcher in the field of power systems non linear dynamics, FACTS applications to power systems, modeling and analysis of micro grid, grid integration issues of renewable energy sources and self healing networks for smart grid. She is a member of doctoral committee for research in various universities and approved supervisor for guiding Ph.D/M.S in many universities including anna university. Presently she is working as principal and professor in Jerusalem college of engineering.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)