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Micro-Grid Design and Protection System under Several Fault Conditions

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Abstract*: As distributed generators and renewable energies are now becoming the fastest growing technologies in the energy industries, the technical issues and environmental aspects are to studied and examined. The large number of small scale Micro grid components with their characteristics is a vital challenge for Micro grid modelling, operation, simulation and operation. Micro-grid gives clear, economic and environmental benefits for end users, utilities, and societies. However, their implementation faces lot of challenges, such as a protection of micro-grid. Micro-grid works in two modes, grid-connected and islanded mode that operates connected with medium voltage grid or islanded from the grid with controlled coordinate manner. The major goal of this thesis is to design protection for. First, the work is done to present the detailed description of the micro grid models and lines. Then the paper will discuss the distributed generator models that have been implemented in MATLAB/Simulink including photovoltaic module, fuel cell stack system with short term storage (Li-ion battery system). Then the fault analysis is done for the whole Micro-grid, whether the micro grid is working in fault condition or not. Then Micro grid protection is done for the grid connected modes and islanding modes of Micro grid. To design the protection system for the micro grid over current relay protection scheme is used.

***Index Terms*: Micro-grid, islanded mode, fault, storage systems, protection, micro sources, distributed generation.**

I. INTRODUCTION

With the rapid development in demand of electrical energy, power networks are now demanding for more power generation. But due to the environmental aspects the energy generation transmission and distribution becomes more difficult. So modern technology based on renewable energy are becoming more popular as alternatives for energy generation [2]. The developed world is ready to access electrical energy. Electricity is a vital component in modern world; and the demand for electricity is increasing day by day. At the same time conventional energy sources for the generation of electricity is decreasing day by day. Further, environmental consequences caused by the traditional power stations are causing global issues [12]. The search of alternate energy sources, which are eco-friendly and to use existing energy resources more efficiently are the top priorities for the engineers throughout the world.

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Number of renewable energy sources such as wind energy, tidal energy and photovoltaic are used for generating electricity [1]. In conventional power plants, total energy conversion efficiency is poor due to waste heat. Recently it has been suggested to operate generators with smaller capacity from fossil fuels and to use the heat generated for local heating purposes. Such systems are called as combined heat and power (CHP) plants.Addition of renewable energy sources and CHP plants into a utility network introduces a new sort of challenges. Demand and supply matching is vital problem, when the output power of renewable energy sources depends on the environmental conditions [15]. These energy sources may be connected to weak distribution network which in turns introduces power quality challenges within the network. Additionally, the direction of power flow may be in the opposite direction to conventional power flow, thus mew protection schemes would be required. The concept of Micro grid is an optimal solution for use of alternative energy sources perfectly while enhancing the use of renewable energy sources to connect with the main utility grid [8]. Generally Micro-grid consists of different distributed generation units which can be called as micro sources. Again a Micro grid can be connected to the main utility grid to receive and give power. Micro grid is working in two concepts. Firstly, the overall power is transferred to or from the main utility grid should be controlled to enhance the overall efficiency. Secondly during the disturbances occurred in the grid the micro grid should be operated in islanded mode [16]. Electrical power systems experience regularly abnormal conditions like disturbances and faults which lead to power disruptions. To reduce the fault consequences, the protection systems are implemented. Protection systems consist of different types of relays with different functions and characteristics. The characteristics are being different for different algorithms. Some relays can operate in high currents called as over current relays, and some of are in under or over voltages or frequencies known as impedance relays. The cost of protection systems depends on the network voltage levels. Now a day's relays are using digital techniques which allow them to use many functions in one relay. The distributions of micro sources over the power network generates bi directional currents which creates a challenging issue for the over current devices. This research gives the idea of designing over current relays for the protection of micro grid during faults.

II. MICRO GRID MODELING

Ordinary power sources, loads and transmission lines have been designed individually and tested well in MATLAB/SIMULINK.

And then a variety of Micro grid models are analysed to build the entire Micro grid system. There are different types of srenewable energy. Wind power is the conversion of wind power is the conversion of wind energy into electrical energy using wind turbines. Hydroelectricity is electricity generated by the production of power via use of the gravitational force of flowing water or falling water. Photo voltaic is the conversion of energy from radiant light and heat from the sun energy to electrical energy. Fuel cell is also used for conversion of chemical energy into electrical energy [3]. A detailed description of Micro grid models will be described in this chapter. First of all, a list of DG models, short term storage models, utility model and transmission line models as given below [11].

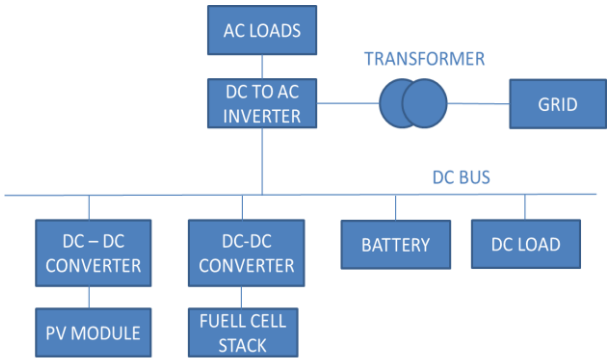

Figure 1: Typical Micro grid architecture diagram [11]

III. DG MODELING

A. Photo Voltaic System

The sun emits radiant energies with some spectral behaviours. When the radiation of solar passes through the atmosphere, some radiations are absorbed by the earth's atmosphere and partly are transmitted; when the solar spectrum reaches at the ground of earth the radiations of sun are heavily distorted. The solar radiation which is coming to the earth's atmosphere is mainly dependent upon earth's behaviour [5]. The length of the path taken by the sun's rays via the atmosphere to reach a specific spot on the surface, divided by the path length corresponding to the sun directly overhead is known as air mass ratio. The solar energy is set to play a vital role in generating the electricity. The major reason is that the solar energy systems (PV) which produce electricity from the sun radiation are becoming friendlier because of its advantages and reduction in cost factor. The concept of solar cell is solar energy is converted into electrical energy. Generally, the photons of sunlight carry the solar energy. Electromagnetic field is produced from the solar panel and it stores the electric energy. So in solar cell/module/array conversion of light takes place which the flow of photons to electric current which consists of electrons. When the photons of solar energy are reflected at the plate of solar cell, the electrons are transported from lower energy state to upper energy state where the electrons are moving freely [13]. This is known as photo electricity. Here the photons of light give sufficient energy to the electrons which are in the solar plate to escape to be free. The electrons are supposed to stay at one side of the solar cell where the current is flow through the external circuit by the negative charge. The current is collected at the other side of the solar cell, where the electrons again transferred to the ground state, and again the process is going on.

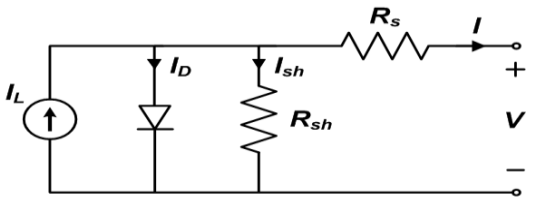

Figure 2: Equivalent circuit of single diode solar cell

B. PWM Inverter

The PWM inverter technique generates an output of sinusoidal wave form by filtering the output pulse by varying the input pulse width. High frequency filter is used to get a better filtered sinusoidal waveform. By varying the amplitude and frequency values of a reference voltage known as modulating voltage, the desired output voltage is obtained. The variation of amplitude and frequency of given voltage signal in accordance with the reference voltage, varies the pattern of pulse widths of the output voltage but keep the sinusoidal modulation as it is. A low frequency modulating signal is compared in accordance with the high frequency carrier. The switching state is changed when the sine waveform intersects with the triangular waveform. The crossing position determines the variable switching times between the states.

C. Battery Storage System

A battery is an electrochemical instrument where conversion of electrical energy to chemical energy is done and during discharging the stored chemical energy can be converted to electrical energy. Now a day we are having lots of modern electronic equipments in our daily life, such as mobile phones, laptop, computers, music players, cameras and countless number of other equipments are getting power from rechargeable cells. There are two electrodes in a typical battery cell known as positive and negative made up of chemically different materials are separated by an electrolyte which is a solution and carries the ions. Electrons which are from the positive electrode of the cell via a chemical reaction, reaches between the positive electrode and the electrolyte solution. Electrons are then returning to the negative electrode. Battery is called in discharge state when there is no chemical reaction is going on [9].

D. Fuel Cell System

Generally, in fuel cell system conversion of chemical energy to electrical energy is happened. Conceptually conversion molecules of gases of fuel to electrical energy occures when the fuel is hydrogen the end products are pure water and heat. The fuel conversion process is the reverse of water electrolysis. Generally, in electrolysis, an electric current applied to oxygen and hydrogen and water are obtained; and in reversing the process, hydrogen and oxygen are mixed and the end products are electricity and water (and heat). A fuel cell can also be called as a chemical factory in which chemical energy is converted to electrical energy till the fuel is given to the electrolyte [6]. However, fuel cells depend on the fuel that is used in chemical reaction process.

When combustion takes place hydrogen and oxygen molecules are obtained. Generally, in fuel cell the chemical energy is converted to electrical energy by separating the molecules of hydrogen and oxygen by the electrolyte called as the separator**.** The electric transfer is necessary for the bond transfer to get water as the output with large amount [17].

IV. IEEE 9 BUS SYSTEM

The WSCC three generator 9 buses is also called as PM Anderson 9 bus, represents a simple approximation and single line diagram of a typical power network of the western system coordinating council(WSCC) to an equivalent system with nine buses and three generators. This IEEE 9 Bus consists of nine different buses, three generators, three two-winding step-up transformers, six transmission lines and three loads. The base kV levels of three generators are 13.8 kV, 16.5 kV and 18 kV respectively. The line complex powers are around hundreds of MVA each. As a test case system of nine bus case is easy to control.

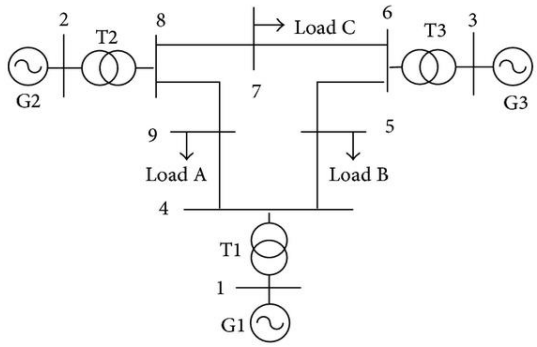

Figure 3: IEEE 9 BUS System

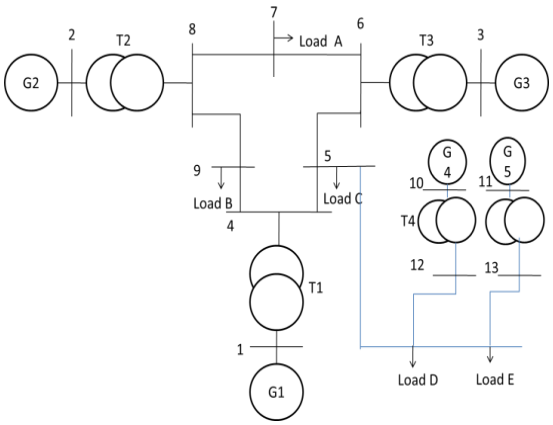

Figure 4: Modified IEEE 9 BUS System

A. Power System Faults and Protection

Electrical machines, generators and equipment's are often subjected to various types of faults when they are in operation. When the fault occurs the characteristic values such as impedance of the machines may change from existing values to different values till the fault is cleared [7]. A fault in an electric power system can be defined as any abnormal condition of the system that includes the electrical failure of the system such as transformers, generators and bus bars, etc. Under normal and safe operation, the electric equipment's in a power system network operate in normal voltage and current ratings. Once the fault takes place in the device voltage and current values are differing from the nominal voltage. The faults in an electric power system can be classified by symmetric and asymmetric faults.

B. Symmetric faults:

A symmetric fault generally adds symmetrical fault currents. Symmetrical faults are also called as the balanced fault. These types of faults occur when all the three phase are getting short circuited. These faults are rarely occurring in the circuit as compared to unsymmetrical faults. Two kinds of symmetrical faults are there, line to line to line (L-L-L) and line to line to line to ground(L-L-L-G) faults as shown in the figures below. Only 25% of the faults are of symmetrical faults. If this type of faults occurs, the system remains balanced but results in the severe damage to the equipment's of the power system network.

C. Unsymmetrical faults

These are very common faults and less severe than unsymmetrical faults. There are three types of unsymmetrical faults and they are line to ground(L-G), line to line(L-L) and double line to ground(L-L-G) faults. Line to ground fault is the maximum occurring fault.60%-70% faults are of line to line fault. The unsymmetrical faults are also called as the unbalanced fault. Unbalance of the system means that the impedance value of different in each phase causing unbalance current to flow in the phases.

D. Over Current Relay

As the name gives itself a proper definition that the over current relay protects the circuit which are having over currents. These relays take input as current from current transformers (CTs) and comparison is taking place between the calculated values and predefined values, the over current relay senses over currents and commands a trip signal to the circuit breaker which opens or closes its door to connect or disconnect the faulted part. When the fault occurs it is called fault pickup. After picking up the faults the relay operates and sends a trip signal to the circuit breaker (in case of instantaneous over current relays) or it can pause for some time to send trip signal due to the delay(in case of time over current relay) [4]. This particular time is called as the relay time, and is calculated by some protection algorithms.

E. Circuit Breaker

Electrical circuit breaker is basically a switch which can be operated for the protection of power systems manually or automatically. Two types of contacts are there in the circuit breaker such as fixed contacts and moving contacts. During normal operating condition of circuit breaker when the circuit breaker is on these two contacts are in physically connected. There are two types of coils in every circuit breaker such as tripping coils and close coils. Whenever a switching pulse is energized the coils, the plunger inside them is in movement. This plunger is typically attached to the operating coil; as a result, the mechanically stored potential energy is converted to potential energy, which makes the movement of moving contacts possible through some gear mechanism with some operating principles. After a small duration of time the overall energy is stored and kinetic energy is converted into potential energy once again.

V. SIMULATION RESULTS AND DISCUSSIONS

A. PV Simulink Model Result

After connecting to the grid the output voltage is around 5000V and current is around 16Amps.The active power of grid-connected PV model is approximately 95 Kw.

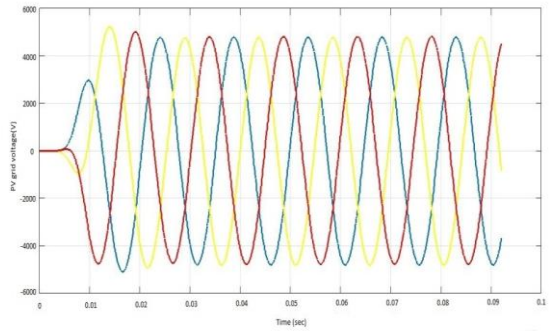

Figure 5: PV model grid voltage

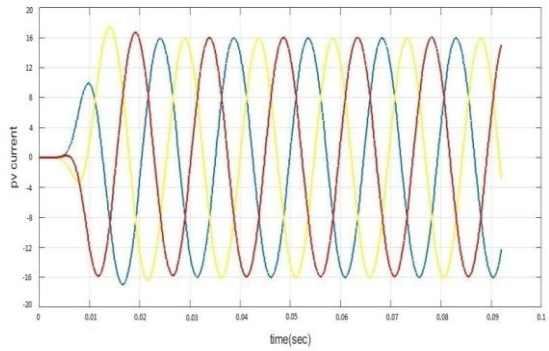

Figure 6: PV model grid current

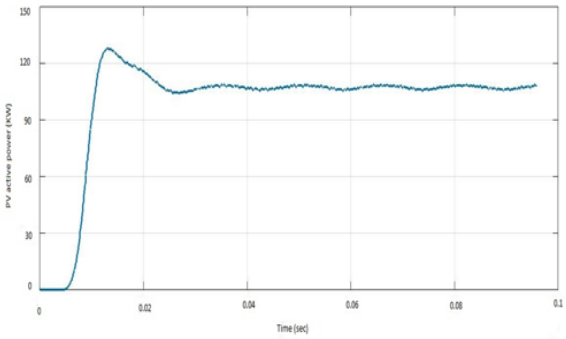

Figure 7: PV model grid active power

B. Fuel Cell Stack Simulink Model

The Simulink model of fuel cell stack is shown in figure 5. Here PEMFC-50Kw-625V_{dc} fuel cell module is used 900 cells are used in for the fuel cell stack module. The output of the fuel cell stack is given to the boost converter and three phase output is obtaining by connecting the output of the boost converter to the input of the three phase PWM inverter.Then the three phase output is connected to the grid via 28Kv step-up transformer.

C. Grid connected Fuel cell model simulation and results

When the Fuel cell is connected to the grid the output voltage is around 2000V.The grid output current is around 20Amp.The active power generated by the grid connected fuel cell is approximately 75 Kw.

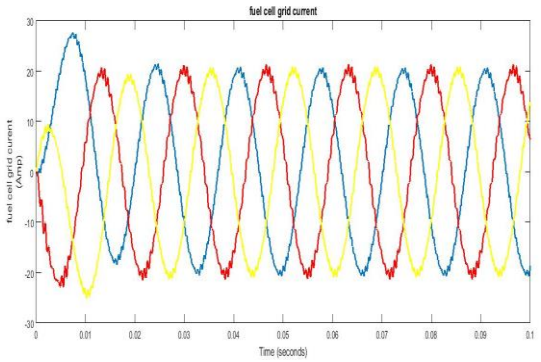

Figure 8: Fuel cell grid current

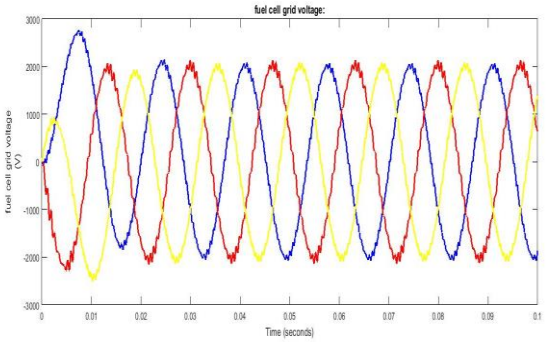

Figure 9: Fuel cell grid voltage

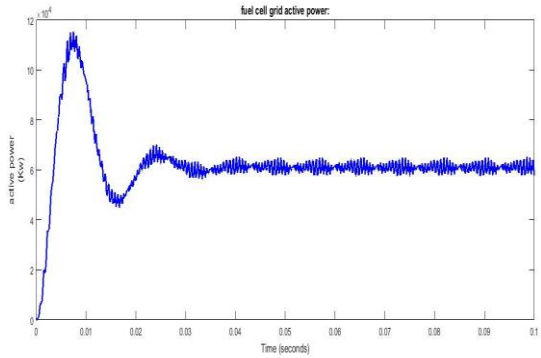

Figure 10: Fuel cell grid active power

D. Simulation results of IEEE 9 bus system before and after fault

Load C of the IEEE 9 bus system is subdivided into some additional loads. Themicro sources are supplying power to those loads. These load values are of 60Kw and 95Kw.during normal operating condition the load C current is around 30Amp.pv module current is around 60Amp.When the a 3-phase L-L-L-G fault occurs at the load C the fault current is increased to approximately 50Amp.during that time
Micro sources are supplying power to the loads. When a fault is occurred at one of the load i.e. driven by fuel cell stack, at that time another micro source is supplying the power to other loads. During the time of fault at the fuel cell the current is approximately 40Amp.During the time of fault the current of grid PV cell is same as that of before applying the fault i.e. of 60Amp.Fault is applied at the load C is of duration 0.002sec to 0.005sec, and fault at the load i.e. powered by the grid fuel cell stack is of duration 0.003sec to 0.005sec.

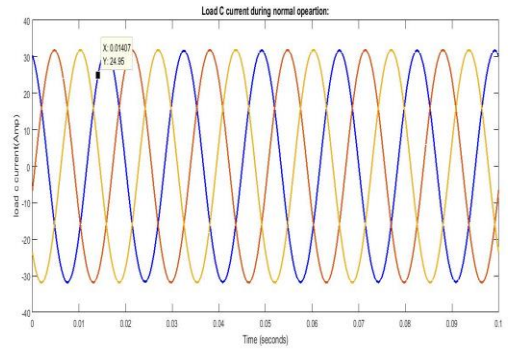

Figure 11: Load C current during normal operation

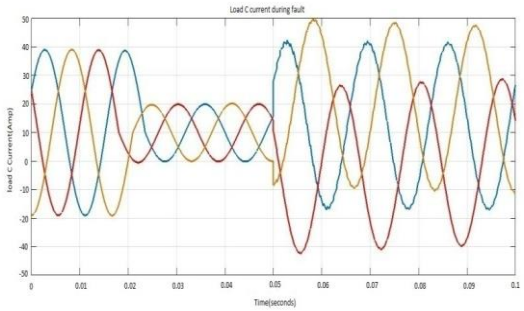

Figure 12: Load C current during the fault

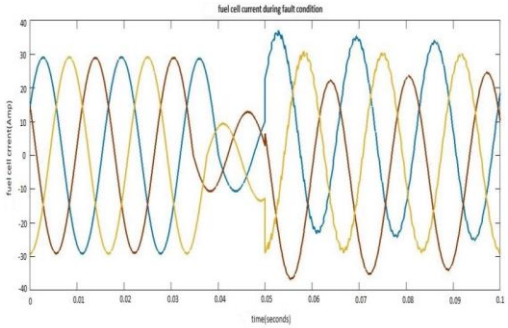

Figure 13: Fuel cell current during fault

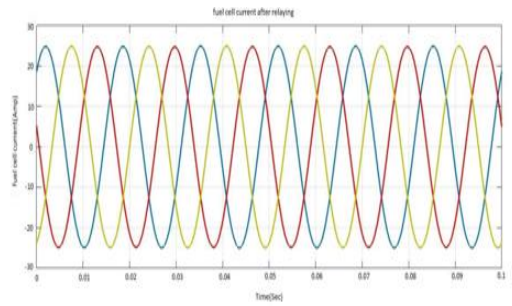

Figure 14: Fuel cell current after using the relay

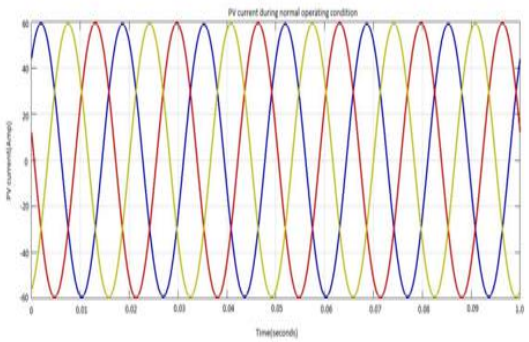

Figure 15: PV cell current during normal condition

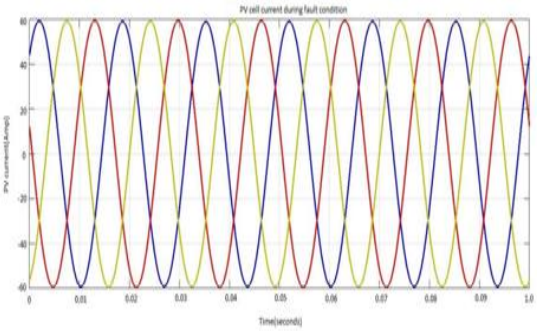

Figure 16: PV cell current during fault condition

VI. CONCLUSION

To shorten the demand supply gap of energy in generation and distribution system many ways are prescribed. Micro grid is one among them which perfectly balance between the conventional energy and renewable energy in order to produce a sustainable power to the consumer end which is described in this thesis. Generally, transmission lines are represented by three phase PI section line model which is present in the Sim power systems library. In micro grid system micro sources are vital which basically renewable energy sources are. The uses of Solar PV cell, Fuel Cells, Storage cells diminishes the burden on conventional power system and is also eco-friendly are discussed with proper specifications. To make the necessary arrangement between real and reactive power different buses are classified and used. For verification IEEE 9 bus system is used. For reliability of a grid protection is important; for fault sensing and protecting the system over current relay and circuit breaker are implemented. MATLAB/SIMULINK verifies the parameters and responses are recorded. It helps us to make the system more reliable and flexible.

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Dr. Subrat Kumar Barik working as associate professor in school of electrical engineering at Kalinga Institute of Industrial Technology, Deemed to be University, Bhubaneswar, Odisha India. Dr. Barik has thirteen years of experience in teaching in undergraduate and postgraduate level. He has also an excellent research career in the area of Solar Photovoltaic Grid Integrated System. He has a number of research publications in SCI, Scopus indexed journals and international conferences. He graduated from the VSSUT, Burla in Electrical Engineering discipline and received his PhD from SOA University.

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