*Research Result*

# Enhancement of Hybrid System Performance using SOFC and Fault Effect Analysis in Microgrid

**Sheetal Soni[1], Rahul Rathore[2]**

[1]P.G. Scholar, Shri Ram Institute of Technology Jabalpur (M.P.), INDIA
[2]Assistant Professor, Shri Ram Institute of Technology Jabalpur (M.P.), INDIA

## ABSTRACT

*A grid connected hybrid generation system (HGS) consisting of wind energy conversion System (WECS)/Photo voltaic (PV) System/solid oxide fuel cell (SOFC) is designed and simulated by using MATLAB/Simulink. SOFC is the replacement of battery, attached to produce the clean energy when these renewable energy sources are unable to produce required amount of electric power. Also, an operational control strategy (OCS) is developed to utilize maximum amount of power of PV to the required load and rest amount of power is coming from wind to fulfill the load demand. Hence, the electrolyzer is supplied by the wind power to convert the water in to H2o and oxygen. Also, the power quality factor (PQF) analysis is exercised to measure the quality of power transmission.*

## KEYWORDS

*Rural electrification, intensive electrification, micro-grid, peak load, Renewable energy, distributed energy resources*

## 1. INTRODUCTION

Distribution system is the interface between the power generation and consumption. The idea of microgrid is provided in Fig 1. A microgrid is a representation of low voltage grid which consists of low power electrical generators, loads and devices to store electrical energy (a microgrid have generation capacity of maximum 1 MVA). The microgrid provides supply to residential area, industrial site, theme park, shopping complexes, etc. The low voltage local loads are supplied by medium voltage grid by using a step-down transformer. A switch is used to change the operational modes from grid connected condition and standalone condition.

The large power generation stations are replaced by renewable energy resources dependent on the weather conditions and it is much hard to predict the power generation and to maintain the grid power balance. The micro grids are used to increase the reliability of electric grid. The energy storage devices are gets charged in grid connected conditions and get discharged to supply the loads during standalone condition. The micro grid also provides real and reactive power injection to the main grid in case of reduction in load demand or high-power generation across the DG units. The mostly used energy storage devices such as batteries, fuel cells, flywheels, etc. combined with appropriate converter forms the Energy storage systems. Moreover, the transmission losses are reduced due to the presence of microgrids (nearby populated areas) [1-5].

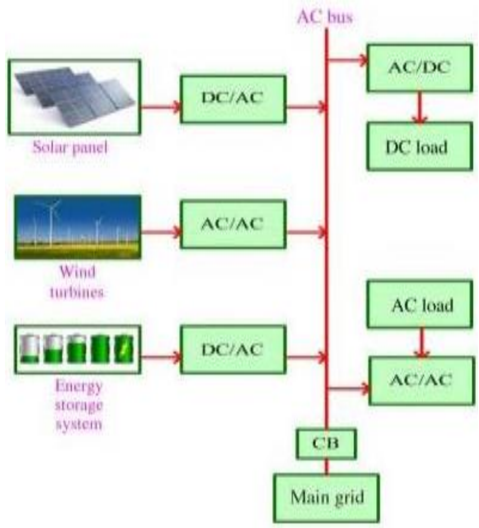


**Fig 1: The main concept of a microgrid.**

## 2. RESEARCH MOTIVATION

As the dependency on electrical and electronic equipment is increasing, the energy demand is increasing day by day.

Electricity has touched the root of men's daily life in such a way that no one can think about the world without electricity now. It is used for domestic appliances like electric stoves, A/C, fans, refrigerators etc. In factories, machines work with the aid of electricity. A revolution has come in transportation (Electric trains and battery cars) and in communication system by electricity. In the field of medicine and surgery, in defense sector, in amusement sources like television, cinema, in modern equipment like robot etc. electricity plays a crucial role. India transitioned from the being the world seventh largest energy consumer in 2000 to the 3rd largest one in one and half decade. India has 3rd place after China & U.S. in largest power generation portfolio worldwide and country has been adding generation capacity rapidly [1]. The utility electricity sector in India had an installed capacity of 329.20 GW as on 04 April 2017. According to the report of the World Bank, only 78.7 percent of India's population has access to the electricity. 260 million Indians (20 percent of the country population) still have no access to electricity, it is 21.7 percent of the world population which has no access to power [2]. To overcome such dreadful conditions, government is investigating on wind power, solar power and bio-power so that percentage of un-electrified village and household reduces sharply. Now 96% of the villages has been electrified but only 70 % of households have electricity connection. Government brings the concept of intensive electrification in which 100 percent of the household will be electrified in a village and free access to electricity will be provided to the BPL families [5-10].

## 3. CRITICAL LOADS

During the conceptual design phase, potential critical loads need to be identified. This will include discussion with all site stakeholder groups. At military installations, buildings and loads critical to the mission are well defined, although in some cases the function may be classified. The design team needs to work with the affected Command to define requirements. The challenge is often defining dependencies. Consequently, as critical loads are identified, the design team needs to identify supporting systems that, if they fail, will ultimately lead to a failure of an identified mission-critical system. Identification and prioritizing of critical loads begins with discussion of the mission. In a structured approach, the design team would facilitate discussions focused on the mission-critical equipment and systems.

Next, the design team and stakeholders would identify the buildings and systems required to support the mission - critical elements, followed by identifying the on - base resources needed to support mission-critical elements and the off-base resources needed to support the critical on -base resources. Eventually, all the stakeholders involved in the ever - expanding potential microgrid system become stakeholders of the microgrid.

Identifying critical assets and systems is a repetitive and expansionary process that must be controlled. The design team will need to continuously challenge inclusion and seek alternative strategies to control scope creep. Off - base resources are particularly problematic because they may be under the control of different entities [11-15].

### Load Analysis

Load information is used to determine microgrid resources needed and for designing the microgrid system. During the initial study, the feasibility load analysis can be challenging. An AMI system, which is increasingly used, can provide detailed data. However, for specific loads, AMI data may not be available. During the feasibility study, the engineering team will go through an estimating process using available information and, at the end of the process, assess the confidence of the estimate. If confidence is acceptable, the design team may proceed with feasibility knowing that better data may be garnered before preliminary design. Alternatively, the team may choose to pause, selectively install AMI equipment, and gather additional data before readdressing the load analysis problem

### Energy Storage

The generators that provide the foundation of the microgrid system must be supported by sufficient energy storage to meet the minimum grid power-outage operating scenario without refueling. Over the past 20 to 30 years, numerous technologies ranging from compressed air in underground caverns to pumped hydro have been investigated and demonstrated for bulk energy storage. Most have had only limited success. For purposes of a military microgrid, the energy storage systems of interest are hydrocarbon fuels and batteries.

### Planned Disconnect from Grid

- Upon operator initiation, microgrid - essential generators and emergency generators that are part of the microgrid start - up and synchronize with grid frequencies.
- The microgrid starts to build.
- Generators connect to the microgrid one at a time; as they do, the point-of-connection power meter begins to slow.
- Renewable energy sources are already engaged, synchronized, and connected to the microgrid (no change is required).
- Loads not supported by the microgrid drop off line one by one. The meter slows further and may reverse.
- If the meter has not reversed, microgrid-discretionary loads drop off line in predetermined order until the meter reverses.
- When the base's net energy is negative, that is, the utility meter is reversed, the microgrid can safely disconnect from the grid.
- Microgrid energy resources are optimized.

## 4. PROPOSED METHODOLOGY

MATLAB/Simulink model is designed for the integrated distribution system. Fig. 1 shows the MATLAB/Simulink model for the designed integrated distribution system. In this system, the three-phase ideal source is supplying power to the grid. We have considered PV as the ideal three phase source supplying power to the grid. This hybrid grid consists of IGBT based three-phase voltage source converter. This converter is controlled to supply needed reactive power and harmonic current into the system. To interface PV-Wind power system to the distribution system, inductor filters are used. These inductors are used to limit circulating current flowing in the system. To control the amount of power flow from battery/electrolyzer, its controller is designed in simulation. We have connected Fuel cell (SOFC) with PV-Wind to maintain the impedance in source and load.

Using inverter, we generate required AC voltage from fuel cell. The inverter uses hysteresis switching and controls active power by management of direct-axis current while holding reactive power at 0 MVar. The measurement blocks are rated at 50kW. Thus, an active power reference of 1pu =50kW. Ode23tb solver with the configuration parameter discrete sampled at 1e-005s is used. This model undertakes the following: (i)The fuel cell gases are ideal. (ii)Only one pressure is well-defined in the interior of the electrodes. (iii)The fuel cell temperature is invariant. There is reverse in pressure of all the reactants after 0.4s. Due to which reactive power output of the fuel cell also increases. Simulation can be extended for dynamic study of fuel cell. After 0.4 s fuel cell is able to provide the 50kw active power.

The stability of the fuel cell system will make sure the continuous power is provided throughout the day as compare to traditional energy source. Fuel cells have a promising demand within the field of renewable energy. This paper describes the autonomous control strategies of inverters connected in parallel, especially load share for isolated operation of a micro grid configured with various new energy generators. In the verification test, the system was isolated from the utility grid, and inverters connected in parallel and determined the micro grid bus voltage and frequency. Various renewable energy generators PV Wind turbine and the fuel cell were operated synchronously. The system proved stable controllability even with various loads and generation power change for around three weeks. When the fuel cell system is sufficient enough to supply the load then the system is operated on the islanded mode of operation. In this mode of operation, the controller must regulate the output voltage at the reference bus voltage and the frequency at the grid frequency. The reference values can be got by taking as a grid voltage magnitude and phase angle as reference frequency of grid. This paper implements the design of hybrid cascaded multilevel inverter for the hybrid power sources. The hybrid cascaded multilevel inverter reduces the harmonics in the output voltage. The harmonics are decreased relatively increasing the voltage levels of inverter. The effectiveness of the strategy for the cascaded multilevel inverter is studied based on the simulation results. The implemented PV-wind turbine and fuel cell provide the supply continuously and the experimental result shows the output voltage of the hybrid cascaded fed by fuel cell, PV cell and wind turbine. In this topology the non triplen lower order harmonics are reduced [15-20].

Conservation of non-renewable resources motivate to explore the new avenues of resources for electricity generation which could be clean, safe and most valuable to serve the society for a long period. The issue of renewable energy is becoming significant due to increasing power demand; instability of the rising oil prices and environmental problems. Recently, there has been rigorous research on the voltage and frequency control of squirrel cage type, but relatively little research efforts have been devoted to the use of the slip-ring induction machine for generator applications.

Ever increasing energy consumption for environmental protection and existing nature of fossil fuels, results much of the research work to focus on alternative/renewable energy sources such as wind energy, fuel cells. Wind energy has emerged as the most viable source of electrical power and is economically competitive with conventional sources. Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor (slip ring) induction generator and an ac/dc/ac IGBT-based PWM converter. To harness the wind power efficiently the most reliable system in the present era is grid connected doubly fed induction generator. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the ac/dc/ac converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.

The basic scheme adopted in the majority of systems. The stator is directly connected to the AC mains, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DFIG to operate at a variety of speeds in response to changing wind speed. The frequency of the grid voltage is always maintained constant irrespective of the wind speed (and thus the rotor speed), by the back-to-back converters. At subsynchronous speeds the stator is generating the power but part of it has to be fed back to rotor. At super synchronous speeds both the rotor and stator are producing power to the grid. The slip power can flow in both directions, i.e., to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor- or stator-side converter in both super and sub-synchronous speed ranges. As a result, the machine can be controlled as a generator or a motor in both super and sub-synchronous operating modes realizing four operating modes. [4]. the structure and the functioning of a fuel cell are similar to that of a battery except that the fuel can be continuously fed into the cell. [5]

**Fuel Cell**

A fuel cell is an electro chemical device that converts the chemical energy of the fuel (hydrogen) into electrical energy. It is centered on a chemical reaction between fuel and the oxidant generally oxygen) to produce electricity where water and heat are by-products. This conversion of the fuel into energy takes place without combustion. The efficiency of the fuel cells ranges from 40-60% and can be improved to 80-90% in cogeneration applications. Fuel cell technology is a relatively new energy-saving technology that has the potential to compete with the conventional existing generation facilities.

The design and control of fuel cell and PV-wind power system have been carried out for a three-phase distribution system. A control algorithm based on correlation and cross-correlation function has been found suitable for generating the switching signals of fuel cell in a three-phase power system. In this project, algorithms are implemented for the operation of fuel cell to eliminate harmonics in source current due to non-linear load, pulse load, and reactive load. Fuel cells convert the chemical energy of a fuel and an oxidant directly into electrical power and heat using electrochemical processes, not combustion. In fuel cell, water could be split into the hydrogen and oxygen by sending an electric current through process of electrolysis technique. A Proton Exchange Membrane Fuel Cell (PEMFC), combines hydrogen fuel with oxygen from the air to produce electricity, water, and heat. A Basic Proton Exchange Membrane Fuel Cell consists of 3 components: (i)Anode (a negative electrode that resists electrons) (ii)An electrolyte in center (iii)Cathode (a positive electrode that attracts electron). As hydrogen flows into the fuel cell anode, a catalyst, often a platinum coating on the anode helps to separate the gas into protons (hydrogen ions) and electrons. The MATLAB simulation model is designed for all power loads, and simulated results are analyzed. This system is implemented and compared for harmonic elimination, power factor correction and tracking capability to maintain DC bus voltage. With the effect of source distortion, these three algorithms are analyzed. The next step in the research is to consider Microgrid as a system. It is essential to know more about how the sources interact with each other. More specifically, their relationship to each other needs to be defined. If all goes as anticipated and the Microgrid system is developed, the control of the order will likely be embedded within the electronics. It is possible to use specialized controllers to get a more stable response and to use each power source more efficiently. This should undoubtedly be researched and considered once the power sources interaction and relationship with each other and the mains have been defined. Other aspects that could be developed further are the original sources within the Microgrid.

## 5. RESULT AND DISCUSSION

A hybrid Smart grid whose parameters are given in Fig 1 is simulated using MATLAB/SIMULINK environment.

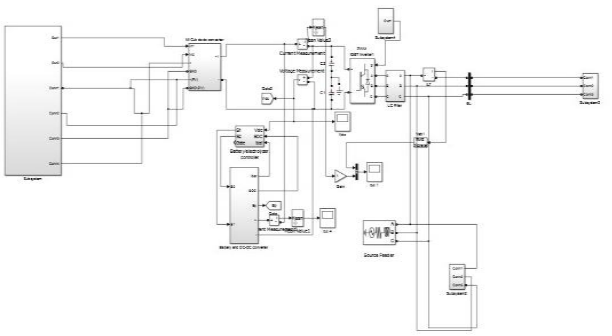

**Fig. 2 Simulink modelling.**

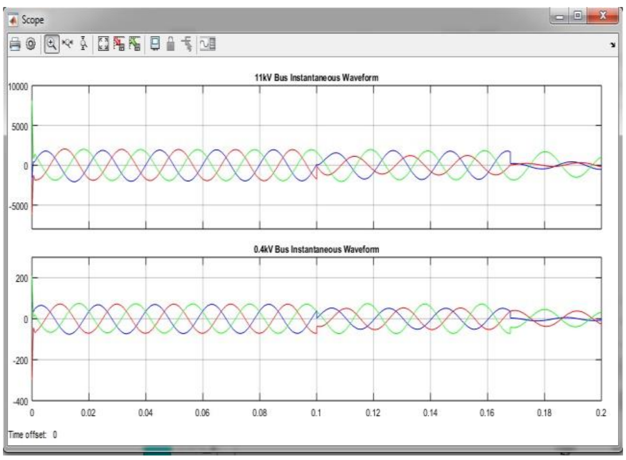


**Fig.3 Bus across variation.**

The operation is carried out for the grid connected mode. Along with the hybrid Smart grid, the performance of the doubly fed induction generator, photovoltaic system is analyzed. The solar irradiation, cell temperature and wind speed are also taken into consideration for the study of hybrid Smart grid. The performance analysis is done using simulated results which are found using MATLAB.

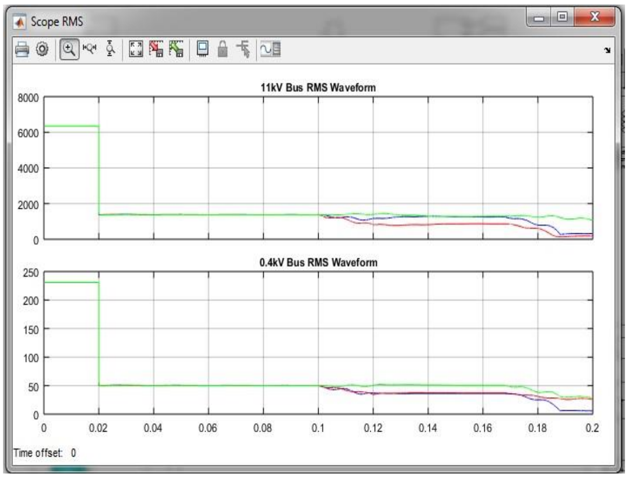


**Fig.4 Time faulty case.**

## 6. CONCLUSION

VSC scheme is very useful for controlling the grid side converter and rotor side converter; the system can work for any change in wind speed. The dc link voltage of converters, rotor speed, and active power and reactive power exchange between machine and grid is almost constant during all operations. The DFIG machine is perfectly synchronised with the grid and sudden change in the load demand is met by sharing of power as per their rating. DFIG with back-to-back connected VSC"s in rotor circuit have provided reduced converter cost, improved efficiency, suitable for large installations, high fault ride through capability during network disturbances, MPPT and flexible four quadrant operation. Distributed generation of hybrid renewable energy systems connected to the electrical grid is a good balance to the conventional energy production, which is polluting and finite. This paper has shown with its simulation results how a hybrid system composed by a wind turbine and a fuel cell satisfy such challenge.

## REFERENCES

[1] Pena R., Clare J. C., G. M. Asher, "Doubly fed induction generator using back-to-back PWM converters and its application to variable-speed wind-energy generation," IEEE Proc. Elect. Power Appl., vol. 143, no. 3, pp. 231-241, 1996.

[2] Khan M.J., Iqbal M.T. "Dynamic modeling and simulation of a small wind–fuel cell hybrid energy system" Renewable Energy 30 (2005) 421–439.

[3] Sun T.,Chen Z., Blabejerg F., "Flicker study on variable speed wind turbines with doubly fed Induction Generators," IEEE Trans. Energy Convers., vol. 20, no. 4, pp.896-905, 2005.

[4] EI-Sattar A.A., Saad N.H. and Shams M.Z. (2006), "Modelling and simulation of doubly fed induction generator variable speed wind turbine" IEEE Int. conf. on Power systems, Vol. 2, pp. 492- 497.

[5] Nagasmitha Akkinapragada and Badrul H. Chowdhury "SOFC based Fuel cells for load following Stationary Applications" IEEE vol-1, pp-4244 (2006).

[6] Ming Yin, Gengyin Li,Ming Zhou (2006), „Study on the Control of DFIG and its Responses to Grid Disturbances‟, IEEE Power Engineering Society General Meeting.

[7] Eric M. Fleming Ian A. Hiskens "Dynamics of a Microgrid Supplied by Solid Oxide Fuel Cells", Bulk Power System Dynamics and Control - VII, August 1924, 2007, Charleston, South Carolina, USA.

[8] Murthy S.S, Singh B., Goel P.K.& Tiwari S.K. (2007)"Comparative Study of Fixed Speed and Variable Speed Wind Energy Conversion Systems Feeding the Grid", IEEE conf. Power Electronics and Drive systems, pp. 736-7 43.

[9] Bhaskara Palle, Simoes G. Marcelo, " Dynamic Integration of a Grid Connected DFIG Wind Turbine with a Fuel Cell", IEEE 2007 pp 0197-2618

[10] Pena Ruben , Cardenas Roberto, Proboste Jose, Clare Jon "WindDiesel Generation using Doubly Fed Induction Machines" IEEE Transaction on Energy Conversion,vol.23, No.1 March 2008.

[11] Jun Yao, Hui Li,Yong Liao, and Zhe Chen "An Improved Control Strategy of Limiting the DC-Link Voltage Fluctuation for a Doubly Fed Induction Wind Generator", IEEE trans. on power electronics, vol. 23, no. 3, 2008

[12] Aghatehrani R., Lingling F. and Kavasseri R (2009), Coordinated Reactive Power Control of DFIG Rotor and Grid Sides Converters‟, IEEE Power & Energy Society General Meeting, pp. 1-6.

[13] Kirubakaran A., Shailendra Jain, R.K. Nema "A review on fuel cell technologies and power electronic interface" Renewable and Sustainable Energy Reviews 13, pp 2430–2440(2009).

[14] Goodarz Ghanavati, Esmaeili Saeid "Dynamic Simulation of a Wind Fuel cell Hybrid Power Generation system" IEEE No.-978,pp 4244-4702(2009).

[15] Yao X., Tian L., Xing Z. and Su X. (2009), "Dynamic Model and Simulation of Doubly Fed Induction Generator Wind Turbine", IEEE Int. conf. on Automation and Logistics, pp. 1667-1671.

[16] Gaillard A., P. Poure , S. Saadate, M. Machmoum "Variable speed DFIG wind energy system for power generation and harmonic current mitigation" Renewable Energy 34 (2009) 1545– 1553.

[17] Blaabjerg F., Iov F., Chen Z., and Ma K. (2010), "Power Electronics and Controls for Wind Turbine Systems‟, IEEE Int. Energy Conference, pp. 333-344.

[18] Breban S.,Radulescu M.& Robyns B. (2010), "Direct Active and Reactive Power Control of Variable Speed Doubly Fed Induction Generator on Micro Hydro Energy Conversion System", International Conference on Electrical Machines, pp.1-6.

[19] Goel P.K, Murthy S.S, Singh B. and Kishore N. (2010), "Modeling and Control of Autonomous Wind Energy Conversion System with Doubly Fed Induction Generator", IEEE Int. conf. on Power Electronics, Drives and Energy systems, pp. 1-8.

[20] Singh B., Aggarwal S. and Kandpal T.C. (2010), "Performance of Wind Energy Conversion System using a Doubly Fed Induction Generator for Maximum Power Point Tracking", IEEE Industry App. Society Annual meeting, pp. 1-7.

[21] Bimbhara P.S. (2009), „Generalized Theory of Electrical Machines‟, Khanna Publishers, New Delhi, 2009

[22] Bose B. K. (2002), "Modern Power Electronics and AC Drives", Prentice-Hall, Inc., New Delhi.