International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-3 Issue-1, June 2013

Integrating Non-Conventional Energy Sources to Supply a Local Load with Fuel Cell as Backup System

Manoj Kumar, S. K. Suman, Vinita Vasundhara

Abstract—The electrical energy is distributed worldwide by overhead transmission lines or cables from generating stations. However, power systems are still needed at locations which are isolated or far from electrical energy suppliers. Renewable energy resources in micro-grid power systems are interesting topics of recent research as environmental pollution and scarcity of energy resources come to the fore. Moreover the integration of renewable energy systems (RESs) in smart grids (SGs) is a tough task, mainly due to the intermittent, varying and unpredictable nature of the sources, typically wind or sun due to changing weather conditions throughout the year. Sometimes there are low wind speeds and lesser sunny conditions and therefore power generation by solar and wind energy is reduced. This paper proposes a system in which solar and wind energy is integrated with fuel cell to provide a continuous power supply to a small local load to enhance reliability of power supply. Here PV and wind energy is used as the primary source of power with the fuel cell section acting as a current source, feeding only the deficit power. The proposed system is analyzed with a case study using MATLAB.

Index Terms - Fuel Cell Backup System, Micro-Grid, Renewable Energy Sources, Solar Energy, Wind Energy.

I. INTRODUCTION

In the past, centralized power generation was promoted. The power generation units were generally built away from the populated areas but close to the sites where the fuel (i.e., fossil fuel) was available. This kept the transportation cost (of the fuel) to a minimum and eliminated the possibility of pollution in populated areas. Such schemes remained quite popular until recently despite drawbacks such as Ohmic (I^2R) losses (due to transmission of electricity through transmission lines over long distances), voltage regulation problems, power quality issues and expansion limitations. With the power demand increasing consistently, a stage has come when these centralized power generation units can be stressed no further. As a result, the focus has shifted to generation (and consumption) of electric power “locally” leading to “distributed power generation systems” feeding the micrograms. These distributed power generation systems associated with microgrids covering small areas have become popular nowadays. The pollution and global warming issues have put a stress on the importance of clean environment.

Also vanishing fossil fuels have given force to the idea of local power generation by the renewable energy sources (e.g., fuel cells (FC), geothermal, tidal, pumped hydropower, wind energy, photovoltaic (Solar) cells, etc.) which may suit a particular region or remote areas and provide power at various load centers along the main power grid. Most of these sources are pollution-free and abundant. Unfortunately, they are not so reliable due to their mere dependence on the weather conditions. For example, the PV source is not available during the night hours or during cloudy conditions. Wind energy may or may not be available and is less prevalent in winter conditions. Other sources, such as fuel cells may be more reliable, but have monetary issues associated with them. Because of this, two or more renewable energy sources are required to ensure a reliable and cost effective power solution. The integration of renewable energy sources (RES) with new technologies (fuel cells and hydrogen) will lead to situations involving different equipment with different electric interfaces, opening clear paths for more suitable devices and techniques to be implemented [4]. In this paper an integrated system comprising of solar and wind energy as primary sources with fuel cells acting as a backup system has been proposed.

Microgrids [2] offer the possibility of coordinating the distributed resources in a more or less decentralized way, so that they behave as a single, controlled entity. In this way, distributed resources can provide their full advantages in a consistent way. Microgrids comprise Low Voltage (LV) distribution systems with distributed energy sources, such as micro-turbines, fuel cells, PVs, etc., together with storage devices, i.e. flywheels, energy capacitors and batteries, and controllable loads, that behave as a coordinated entity, thus offering considerable control capabilities over the network operation. These systems are interconnected to the Medium Voltage Distribution network, but they can be also operated isolated from the main grid, in case of faults in the upstream network. Thus, Microgrids can provide network support in times of stress by relieving congestions and aiding restoration after faults. From the customer point of view, Microgrids provide thermal and electricity needs, and in addition enhance reliability, reduce emissions, improve power quality by supporting voltage and reducing voltage dips, and potentially lower costs of energy supply.

II. WIND POWER ENERGY

Winds are caused because of two factors: (a) the absorption of solar energy on the earth’s surface and in the atmosphere, and (b) the rotation of earth about its axis and its motion around the sun. Because of these factors, alternate heating and cooling cycles occur, differences in pressure are created, and the air is caused to move. Wind energy is thus an indirect manifestation of solar energy. The advantages of using wind energy are that its potential as a source of power is reasonably good and that its capture produces no pollution. Several

Revised Manuscript Received on June 06, 2013.

Manoj Kumar, Department of Electrical Engineering, PEC University of Technology, Chandigarh, India.

Prof. S. K. Suman , Department of Electrical Engineering, PEC University of Technology, Chandigarh, India.

Vinita Vasundhara, Department of Electrical Engineering, PEC University of Technology, Chandigarh, India.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

wind turbine generators have been installed throughout the world. Unit ratings of wind-turbine generators cover a wide range from 0.5 kW to 14 kW. The classification of wind turbine systems is given in Table. I. Wind is a non-uniform, intermittent, erratic form of energy. Wind speeds in the range of 4 to 30 m/s are considered as useful. Average speed (10 m/s) is considered to be suitable for proper generation. Important parameters for calculation of generated wind power are: (i) Velocity of wind (V) in m/s (ii) Efficiency of gearbox (iii) Efficiency of bearings. (iv) Rotor swept area exposed to the wind (v) Air density. Wind Power (in watts) can be calculated as:

$$P_w = 0.5\ \rho\ A\ Cp\ V^3\ N_g\ N_b \qquad (1)$$

Where,
P_w = power in watts
ρ = air density (about 1.225 kg/m³ at sea level, less higher up)
A= rotor swept area, exposed to the wind (m²)
Cp =coefficient of performance (0.59 [Betz limit] is the maximum theoretically possible, 0.35 for a good design)
V = wind speed in meters/sec
N_g = generator efficiency (50% for car alternator, 80% or possibly more for a permanent magnet generator or grid connected induction generator)
N_b = gearbox/bearings efficiency (It could be 95%).

TABLE I: Classification of wind turbine system

Category	Size (kW)	Applications
Very small	0.5 to 1	Domestic use like Radio, T.V., Fan etc
Small	1 to 15	Electricity, Small-scale Industries, Pumping water
Medium	15 to 200	Electricity, Small-scale Industries like Grinding flour
Large	250 to 1000	Electricity for Industries
Very large	1000 to 6000	Electricity for Industries

III. SOLAR ENERGY SYSTEM

There are several technical options and probably the most feasible one for the immediate future is the use of solar (photovoltaic) cell. Solar photovoltaic route facilitates direct conversion of sunlight into electricity. Semiconductor materials such as silicon act as the best substance conversion of photon energy to Electric Current [1] Electricity can be generated by photovoltaic effect using solar cells. By joining large numbers of these cells together (modules and arrays), significant amount of power can be generated whenever the sun shines. The number of solar modules (N) or units depends on the power requirement of the system. Apart from number of solar panels the power generated by these panels depends on many factors such as percent sunshine (S) at the considered time or location, number of sunshine hours (T) and the sunshine decreasing factor (D) in the morning and evening hours. So, power output of solar panels is given as:

$$P_s = N * Power/panel * S * T * D \qquad (2)$$

IV. FUEL CELL SYSTEM

Fuel cells are widely recognized as one of the most promising technologies to meet the future power generation requirements. Since fuel cells directly convert fuel and an oxidant into electricity through an electrochemical process, they can achieve operating efficiencies approaching 60% - nearly twice the efficiency of conventional internal combustion engines. Fuel cells produce very low levels of pollutant emissions (NO, SO, and CO). There are several types of fuel cells, distinguished by the type of electrolyte material used and the required power level as shown in Table 2.[3]

TABLE.II: Classification of fuel cells

Fuel cell	Electrolyte	Power level
Proton Exchanger Membrane	Polymer membrane (ionomer)	100 W- 500 kW
Alkaline Fuel Cell	Aqueous alkaline solution	10-100 kW
Phosphoric Acid Fuel Cell	Molten H_3PO_4	<10 MW
Molten Carbonate Fuel Cell	Molten alkaline carbonate	100 MW
Solid Oxide Fuel Cell (SOFC)	O^{2-}-conducting ceramic oxide	<100 MW

In this paper, the solid oxide fuel cell is used as it best suits the power requirements of the scheme. The solid oxide fuel cell (SOFC) is an electrochemical conversion device that produces electricity directly from oxidizing a fuel. Fuel cells are characterized by their electrolyte material; the SOFC has a solid oxide or ceramic, electrolyte. Advantages of this class of fuel cells include high efficiency, long-term stability, fuel flexibility, low emissions, and relatively low cost. The hydrogen is used as fuel. Solid oxide fuel cells are a class of fuel cells characterized by the use of a solid oxide material as the electrolyte. SOFCs use a solid oxide electrolyte to conduct negative oxygen ions from the cathode to the anode. The electrochemical oxidation of the oxygen ions with hydrogen or carbon monoxide thus occurs on the anode side.

The SOFC reactions are:
Anode:
$2\ H_2 + 2\ O^{-2} \rightarrow 2\ H_2O + 4\ e^-$
Cathode:
$O_2 + 4\ e^- \rightarrow 2\ O^{-2}$
Overall:
$2\ H_2 + O_2 \rightarrow 2\ H_2O$
Combustion of 1 mole of hydrogen to form 1 mole of water releases an energy equal to 285 kJ.

V. CASE STUDY

The proposed technique is applied to a wind farm in Gujarat considering an average local load of 250 kW. So, the energy required for 24 hours is 6000 kWh The solar and wind data is accessed from the site and the scheme is studied on that distribution system.

1. The specifications of the system and calculations without fuel cell backup:

(a) Wind energy system

Number of turbines = 7
Wind speed (August) = 7.4 meter/second
Rotor swept area = 227.07 m²
Power generated (24 hours) = 2833 kWh

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Table.III: Average wind speed of site

Month	Wind Speed(m/s)
January	5.9
February	6.1
March	6.5
April	8.0
May	9.1
June	8.8
July	8.6
August	7.4
September	7.1
October	5.5
November	5.5
December	5.9
Annual	6.49

(b) Solar energy system

Number of panels = 2800
Power per panel =110 W
Percent sunshine = 62
Sunshine hours =12.88
Power generated =1955.5 kWh
Battery storage capacity = 2000kW
Sunshine (percent) for the considered area is as shown in the Table.IV and daily sunshine hours are given in Table.V

TABLE.IV: Percent sunshine at the selected site

Month	Sunshine(%)
January	49
February	54
March	58
April	62
May	68
June	67
July	63
August	64
September	62
October	66
November	58
December	50
Annual	60

TABLE.V: Average sunrise and sunset time

Month	Sunrise(Hrs.)	Sunset(Hrs.)
January	7:27	18:24
February	7:18	18:43
March	6:54	18:56
April	6:27	19:07
May	6:07	19:19
June	6:03	19:31
July	6:12	19:32
August	6:24	19:17
September	6:33	18:50
October	6:43	18:21
November	6:59	18:04
December	7:18	18:06

A. Micro-grid system with fuel cell backup:

The fuel cell system is operated under certain conditions associated with the system. In the proposed scheme, the system starts with an initial power equal to 1000 kW.

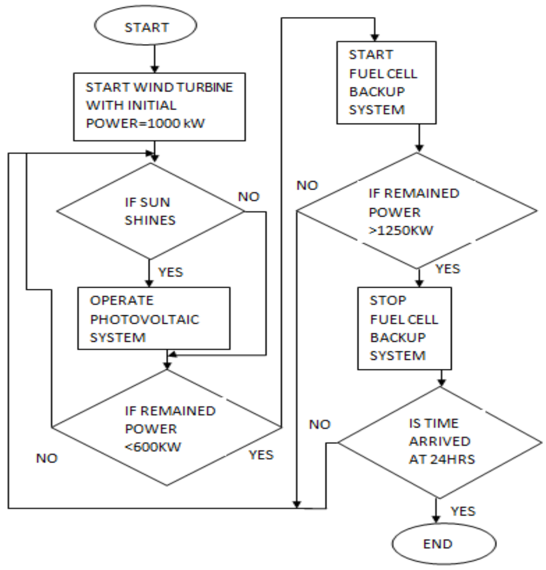

Figure.2: The schematic flow chart for the proposed system.

As shown in fig.2, the wind turbine system works all the day i.e. for 24 hours depending on the prevailing wind conditions in the area. At the sunrise time, the photovoltaic system starts power generation.

Fuel cell backup system starts when the power stored goes down the 600 kW mark and when 1250 kW mark is reached fuel cell system stops. With these conditions a certain amount of backup power remains available for emergency conditions. Now the micro-grid system is operated with the fuel cell backup system and the battery condition with simultaneous working of micro-grid system, backup system and the operating load is shown in Figure.3

VI. RESULTS

The power generated is stored in a battery and with simultaneous load of 250 kW on the battery. The power level of battery over 24 hours for the month of August without any backup system is shown in fig.3.

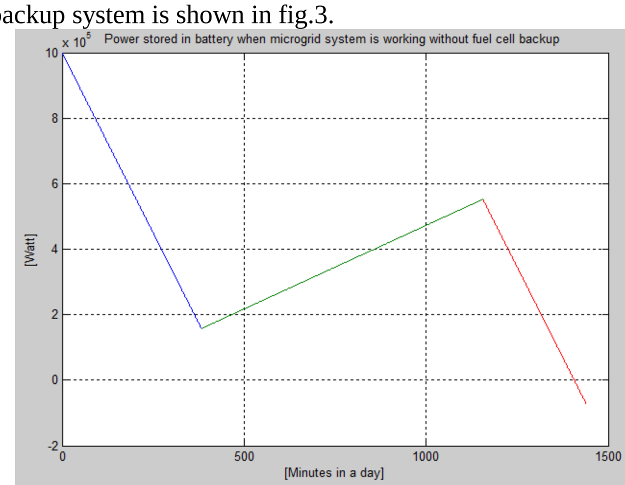

Figure.3: Energy level of battery without fuel cell backup system.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

The micro-grid system is operated with the fuel cell backup system and the battery condition with simultaneous working of micro-grid system, backup system and the operating load is shown in Fig.4

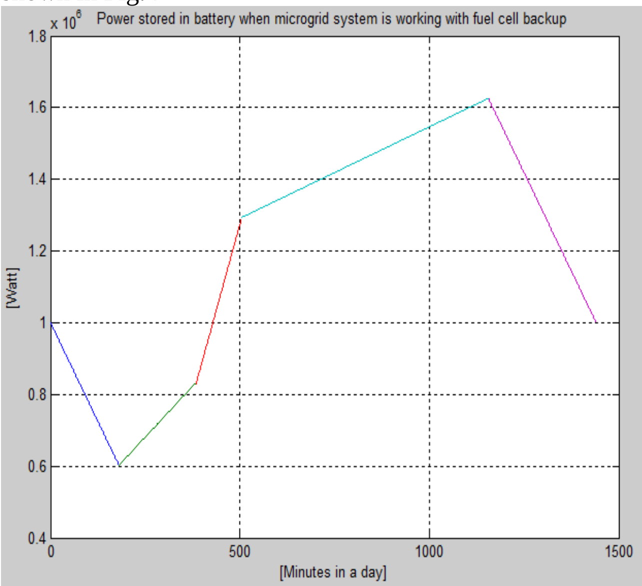

Figure.4: Energy level of battery with fuelcell backup system

VII. CONCLUSION

Generally most renewable resources systems use only one renewable source (like wind or solar) and use a back up source (like diesel or fuel cell). As shown by discussion above such systems are not able to provide full power requirement and also cannot provide continuous electricity due to dependence on the vagaries of weather changes. It can be concluded that the need for intelligently integrating solar, wind and a fuel cell back up enables not only to supply the full power requirement but also safe guards it against the seasonal variations which can be clearly proven by simultaneously simulating the integrated system for the considered month of August. Also, this intelligently integrated system provides continuous electricity without failures and thus improves the reliability. The system has been so designed that the fuel cell operates only when the power of the battery falls below 600 kW (which is minimum 30% of the total battery capacity). This helps to reduce the operating hours of the fuel cell, thus making it cost effective. This also ensures a better performance and longer operational life of the battery. This system seems to be highly Green Energy Compliant as both the wind turbine and solar energy systems are Clean Energy sources because those systems do not use any fuel source while most of the thermal power generation systems use fuel based on petroleum producing pollution materials. This kind of system helps in meeting the energy requirement without any consequences of depleting the fossil fuels or facing the potential hazards of Nuclear Setups and also reducing harmful emissions compared to conventional back up sources. Therefore, micro-grid power systems are Environment-Friendly. Fuel cell systems are also clean energy sources because combination between air and hydrogen only produces water which does not produce any pollutant materials. However, the initial cost of the system is on the higher side and a cause for some concern but further research is still on to reduce the cost. However the initial cost disadvantage can be virtually offset by almost negligible operating and maintenance cost of the system. Micro-grid power systems are in favor with cost effectiveness. Both wind turbine system and photovoltaic system in micro-grid systems will generate electricity continuously almost without any extra cost after its construction. The only cost for those is maintenance cost to repair or inspect them. It is relatively a little money compared with thermal power generation systems. Fuel cell system is the only one that needs continual replenishing of the fuel related costs; however, even this cost is minimized by reducing the operating hours by using intelligent control mechanisms. The payback period for the above system works.

ACKNOWLEDGMENT

I take this opportunity of thanking my dissertation guide Mr. S. K. Suman, Associate Professor, Department of Electrical Engineering, PEC University Of Technology, Chandigarh, for his indispensable guidance, generous help, perpetual encouragement, constant attention offered throughout this research work. I am grateful for the support and guidance provided by him.

REFERENCES

1. Anne Maczuluk, "*Renewable Energy Sources and Methods".*
2. Zhu, Y. Tomsovic. K, *Development of Models for Analyzing the Load following Performance of Micro turbines and Fuel Cells Electric Power Systems Research*, 2002.
3. Kaushik Rajashekara , Hybrid Fuel-cell Strategies for Clean Power Generation," *IEEE Transactions on Industry Application*, vol. 41, no. 3, May/ June 2005.
4. J. J. Brey, A. Castro, E. Moreno and C. Garcia Smith, "Integration of Renewable Energy Sources as an Optimized Solution for Distributed Generation", *28th Annual Conference of the Industrial Electronics Society*, 2002, vol. 4, 5-8 Nov. 2002.
5. Rao, S. and Parulekar, B.B, "Energy Technology: Non-conventional, Renewable and Conventional", Third Revised and Updated Edition, Khanna Publishers, pp. 13-14, 25-28, 976-977 & 989-993.
6. Sathyajith Mathew, 2006, "Wind Energy Fundaments, Resource Analysis and Economics". 1st ed., vol.1, Springer.

AUTHORS PROFILE

Manoj Kumar: currently pursuing his M.E in Electrical Engineering with specialization in power system from PEC University of Technology, Chandigarh. He had done his B.E. degree from DCRUST, Murthal, Haryana in 2009. His special fields of interest are power system, nonconventional energy sources. Published paper in the area of power system.

S. K. Suman: B. Tech, M. Tech from PEC University of Technology, Chandigarh. Currently and Associate Professor in the Electrical Engineering Department of PEC University of Technology, Chandigarh. His areas of interest is Networks, Transmission and Distribution and Grounding.

Vinita Vasundhara currently pursuing her M.E in Electrical Engineering with specialization in power system from PEC University of Technology, Chandigarh. She had done her B.E. degree from SDDIET, Panchkula, Haryana in 2011. Her special fields of interest are power system, power Quality issues. Published paper in the area of power quality enhancement.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication