# RELIABLE OPERATION OF A HYBRID DC MICRO GRID FOR CRITICAL APPLICATIONS

[1]Sankeerth Sudhan , [2]Prof . Manikandan.P
[1,2]Department of Electrical and Electronics,Christ University, Faculty of Engineering
Bangalore, India
Email:[1]sankeerth24@gmail.com, [2]manikandan.p@christuniversity.in

***Abstract*—Renewable Energy Sources are becoming more significant in the present era to meet growing energy demands and also to decrease environmental pollution. Reliability is an important factor for any power system. Micro grids with Distributed Generation is developed to provide power in remote areas as well as for military, college institutional applications to improve reliability even when isolated from the main grid. This paper mainly deals with the reliable operation of a stand-alone DC Micro grid with two Renewable Energy Sources, Solar Photovoltaic array and Fuel cell array to meet the generation capacity of the micro grid so as to supply the load without any interruptions along with an energy storage device to store excessive energy when demand is less.**

**Keywords—Renewable Energy Sources,Solar PV array,Proton Exchange Membrane Fuel cell array,DC Micro grids,Battery**

## I. INTRODUCTION

Due to rapid increase in population and industrial growth, there has been tremendous increase in power requirements as well as various power quality problems associated with the same. So the use of Renewable Energy Sources (RES) for power generation has become a hot topic nowadays. Distributed Generation (DG) is the use of small power generation technologies located close to the load that has to be served. DG of RES helps to reduce environmental pollutions. Due to the advancements in RES and Energy Storage, integration of RES into Micro grids have become possible. Micro grids are basically any isolated electrical system that has its own generation. They can work in isolated mode from the main grid or stay connected with the main grid.[1],[4],[6].

In this paper we consider a stand-alone DC Micro grid with two RES technologies mainly Solar Photovoltaic array and PEM Fuel cell array supplying DC power for telecommunication applications for military purposes. Micro grids are developed mainly to improve the reliability and quality of power supplied. Any excessive power generated is stored in a battery storage device which provides power when any of the RES are not active. Emerging Smart grid technologies helps the utilities to easily control the DG systems. The RES technologies used in this paper are connected to a DC grid via DC-DC converters. An energy storage device is also connected to the DC grid via a controller to store excessive power when demand is less and provide power when demand is more.

## II. SOLAR PV ARRAY MODELING

Solar cells convert light into electricity. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. The electrons flow through the external circuit to produce electricity. Power generation from solar energy using Photovoltaic (PV) has emerged in last decades since it has many advantages and less maintenance, no wear and tear. The main applications of PV systems are in either stand-alone systems such as water pumping, domestic and street lighting, electric vehicles, military and space applications or grid-connected configurations like hybrid systems and power plants.

The equivalent circuit for a PV cell is shown in the figure. It consists of a current source, a diode, shunt resistance $R_{sh}$ and series resistance $R_s$. [8], [2] and [1].

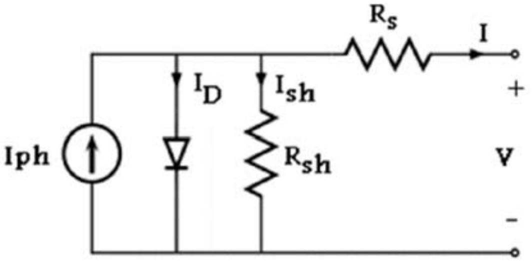

Fig1: Equivalent model of a solar cell

Each solar cell behaves as a p-n diode. When sunlight strikes a solar cell, the incident light energy is converted directly into electrical energy without any mechanical effort. For simplicity, a single diode model is used in this paper. $I_{ph}$ represents the cell photocurrent.[1] and [8].

Nomenclature

$V_{PV}$ – Output voltage of a PV module (V)

$I_{PV}$ – Output current of a PV module (A)

$T_R$– Reference temperature=298 K

T – Module operating temperature

$I_{ph}$ - light generated current in a PV module (A)

$I_o$ - PV module saturation current (A)

A = B is an ideality factor = 1.6

k - Boltzmann constant = 1.3805 × 10-23 J/K

q - Electron charge = 1.6 × 10-19 C

$R_s$ is the series resistance of a PV module

$I_{SCr}$ is the PV module short-circuit current at $25^0$C, 1000W/m2

$K_i$ - short-circuit current temperature co-efficient at $I_{SCr}$ = 0.0017A /$^0$ C

λ-PV module illumination (W/m2) = 1000W/m2

$E_{go}$- Band gap for silicon = 1.1 eV

Number of cells per module=60 s

$N_s$ - Number of cells connected in series

$N_p$ - Number of cells connected in parallel

Photocurrent: The module photocurrent Iph of the photovoltaic module depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation-

$$I_{ph} = [ I_{sr}+k_i (T - 298)] * \frac{\lambda}{1000} \qquad (1)$$

Module reverse saturation current – $I_{rs}$ :

$$I_{rs} = I_{rs} /[\exp (q^v{}_{oc}/N_s KAT) - 1] \qquad (2)$$

The module saturation current $I_o$ varies with the cell
temperature, is given by

$$I_o = I_{rs\,[T/Tr]}{}^3 \exp\ [q*E_{go}/B_k\{1/T_r-1/Tr\}]$$

The output current of a PV module is given by –

$$I_{pv} = N_p * I_{ph} - N_p * I_o [\exp \{\overset{*(\quad)}{\frac{q*(v_{pv}+I_{pv}R_s)}{N_s AKT}}\}$$

(4)

Module reverse saturation current – $I_{rs}$ :

$$I_{rs} = I_{scr} / \exp (q^v oc/NsKAT)-1] \qquad (5)$$

The module saturation current $I_o$ varies with the cell temperature, is given by

$$I_o = I_{rs}\ [T/T_r]^3 \exp [q*Ego/B_k\{1/T_r-1/Tr\}] \qquad (6)$$

The output current of a PV module is given by –

$$I_{pv} = Np * I_{ph} - N_p * Io\ [\exp\{q*(vpv+IpvRs)/NsAKT\}] \qquad (8)$$

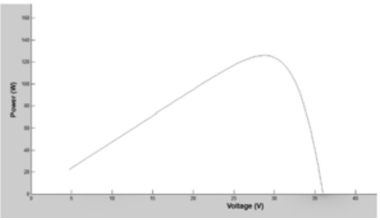

Fig2: P-V curve

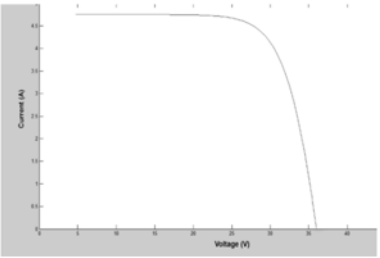

Fig3: V-I curve

## III. BOOST CONVERTER

The PV modules are always used with DC-DC converters to obtain the maximum power point operation. [1] and [8]. For battery charging applications buck-boost configuration is preferred. Boost converters are used for grid-connected applications to step up the low module voltage to higher load voltages. Hence, DC-DC boost converter is used for the design of MPPT controller .Typical Boost converter configuration is shown in figure. It consists of a DC input voltage source *Vs*, boost inductor *L*, controlled switch *S*, diode *D*, filter capacitor *C*, and load resistance *R*. If the switch operates with a duty ratio *D*, the DC voltage gain of the boost converter is given by

$$M_v = V_o / V_s \qquad (9)$$

Where $V_S$ is input voltage, $V_O$ is output voltage, and *D* is the Duty cycle of the pulse width modulation (PWM) signal used to control the MOSFET ON and OFF states.[8]

Inductance value is given by the equation

$$L = (1-D^2)DR/2f \qquad (10)$$

The minimum value of the filter capacitance that results in the ripple voltage $V_C$ is given by

$$C_{min} = DV_o / V_rRF \qquad (11)$$

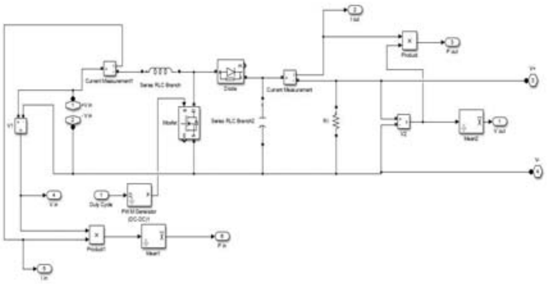

Fig4: Boost Converter SIMULINK model

## IV. FUEL CELL MODELING

Proton Exchange Membrane Fuel cell (PEMFC) is used in this simulation. PEMFC is widely used as DG for solving the problem of clean power requirement.[7], [9] and [10]

### *A. Steady State model*

The cell voltage of a PEMFC can be represented by a the equation

$$V = E - V_{act} - V_{ohm} - V_{con} \qquad (12)$$

Where $V_{act}$, $V_{ohm}$ and $V_{con}$ are in the form of voltage drop (better for representing losses). The cell voltage equations can also be written as

$$V = E + \eta_{act} + \eta_{ohm} + \eta_{con} \qquad (13)$$

Where η , η and η are in the form of voltage gain

So we have

$$\eta_{act} = -V_{act}, \eta_{ohm} = -V_{ohm}, \eta_{con} = -V_{con} \qquad (14)$$

The open circuit voltage in equation (12) can be expressed by Nernst potential:

$$E = 1.229 - 8.5 * 10^{-4} (T - 298.15) + 4.308 * 10^{-5}T + 0.5\ln_{po2} \qquad (15)$$

The losses in equation (10) can be expresses as referred in [7],[9] and [10].

Activation loss:

$$-V_{act} = -0.9514 + 3.12 * 10^{-3}T - 1.87 * 10^{-4}T\ln i + 7.4 * 10^{-5}c_{o2} \qquad (16)$$

Ohmic loss:

$$-V_{ohm} = -i - R_{int} \qquad (17)$$

Where $R_{int}$ = is the internal resistance which can be expressed by

$$R_{int} = 1.605 * 10^{-2} - 3.5 * 10^{-5}T + 8 * 10^{-5}i \qquad (18)$$

Concentration loss:

$$-V_{con} = B\ln(l - i/i_{lim}) \qquad (19)$$

Here T is cell temperature in Kelvin, $i_{lim}$ is current and the limit current.

The output voltage of a single PEM fuel cell will be in the order of 0.7 to 0.9V. TO obtain high voltages, cells are connected in series to form arrays.

Parameters used in simulation are shown in the TABLE 1

TABLE 1
Model parameters of PEMFC

| Parameters | Values |
|---|---|
| Number of cells | 50 |
| Fuel cell resistance | 0.76218 ohms |
| Nernst voltage of one cell $(E_n)$ | 1.2037V |
| Operating temperature | 55 |
| Nominal power | 2496W |
| Nominal stack efficiency | 46% |

## V. BATTERY MODEL AND CHARGE CONTROLLER

“Batteries are one of the most cost-effective energy storage technologies available, with energy stored electrochemically. A battery system is made up of a set of low-voltage/power battery modules connected in parallel and series to achieve a desired electrical characteristic. Batteries are “charged” when they undergo an internal chemical reaction under a potential applied to the terminals. They deliver the absorbed energy, or “discharge,” when they reverse the chemical reaction. Advantages of using batteries for storage applications include: high energy density, high energy capability, cycling capability, life span, and initial cost.”[8]

Battery model is directly available from MATLAB SIMULINK library. Battery type used is Lead acid battery. Lead acid batteries are cheaper than lithium ion batteries and have better tolerance to voltage fluctuations. A battery bank is used in a DC Micro grid to store excessive power during low demand times and to supply power during peak load times. The battery banks are to be designed to supply the load for a day or two even when there is no power generation from the RES in the case of any natural calamities. Battery banks play an important role in improving the reliability of the entire power system.

TABLE 2
Model parameters of Battery

| Parameters | Values |
|---|---|
| Nominal Voltage (V) | 230 |
| Rated Capacity (Ah) | 500 |
| Initial State Of Charge | 100 |
| Fully Charged Voltage (V) | 250.4275 |
| Nominal Discharge Current (A) | 100 |
| Internal Resistance (ohms) | 0.0046 |

A charge controller is modeled using MATLAB and is used to protect the battery from over charging. It also helps to improve the life span of the battery. Based on the State Of Charge (SOC) of the battery, charging and discharging of the battery is controlled by switching process.

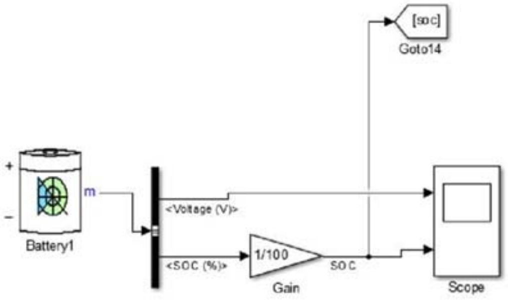

Fig5: Battery model in SIMULINK

## VI. MAIN CONTROLLER

A Main Controller is designed in MATLAB SIMULINK to control the operation of the two RES (Solar PV array and PEMFC array) to meet the load requirements in the most reliable manner [3] and [4]. Total power generated is given by:

$$P_{Total}= P_{Solar} + P_{Fc} + P_{Bat}$$

The controller always keeps track of the solar power generated and the load demand. If the load is less than that of the power generated by the Solar PV array, the load is supplied by Solar alone. Any excessive power is stored in Battery Banks.

$$P_{Loud}= P_{Solar}$$

If Load exceeds the generation of solar power, Fuel cell is turned on to meet the excessive load demand.

$$P_{Loud=} P_{Solar} + P_{Fc}$$

Any excessive energy is stored in the Battery banks depending on the SOC of the Battery banks.

When the load increases even more, the battery banks can supply the load within its capacity limit.

$$P_{Loud=} P_{Solar} + P_{Fc} + P_{Bat}$$

During night time, when solar power is not available, the load is driven by fuel cell power and battery bank power. During any natural calamities, battery bank supplies the entire power to the load.

## VII. INTERCONNECTION

The output from Solar PV array and PEMFC array are connected to DC-DC Boost converters and then to a DC grid. From the DC grid, the Main controller supplies it to the load based on demand and switches the input power sources based on the demand. Energy storage system is integrated with the DC Micro Grid to supply power during low generation periods as well as to store excess energy.

## VIII. SIMULATION RESULTS

The Solar PV Array is designed to have 2.7KW capacity and Fuel cell array is designed to have 2.2KW capacity. The battery storage is of 230V with 500Ah capacity. When load is less than solar power, solar PV array supplies the load. When load is more than that of PV array, Fuel cell also takes up the load. Any excessive energy is stored in battery. When solar is not available, Fuel cell and battery supplies the load. When both the RES are not available, the battery supplies the load as it is designed to have a backup capacity for two days.

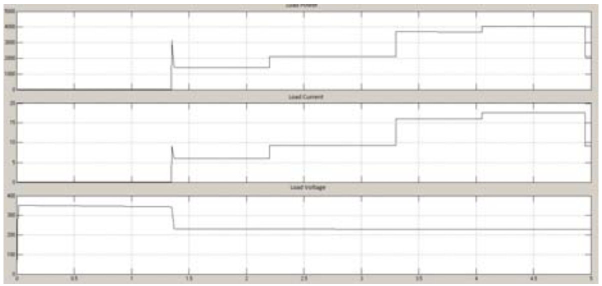

Fig6: Load voltage, load power.

## IX. OVERALL SYSTEM MODEL AND SIMULINK BLOCKS

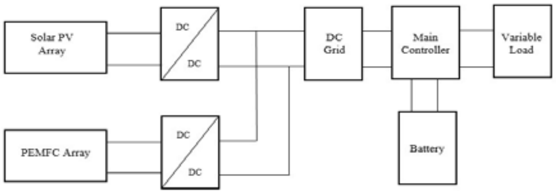

Fig-7 Overall system model of DC Micro grid with RES

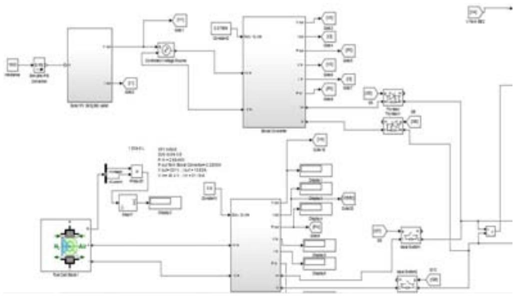

Fig8: Solar PV Array and PEMFC SIMULINK model with Boost converters connected to a DC bus

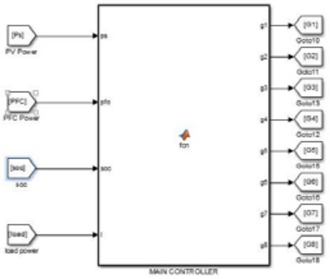

Fig9: Main Controller for Power Flow Control

## X. CONCLUSION

Since the Renewable Energy Sources are highly varying in nature, the reliability of the system using only one RES as power source is very low. This paper deals with the simulation of a DC Micro grid for critical applications like military communications, in hospitals to provide continuous power supply at all costs. Battery energy storage system is also used to store any excess energy and supply power during peak loads.

REFERENCES:

[1] Caisheng Wang, "Modelling and Control of Hybrid Wind/Photovoltaic/Fuel cell Distributed Generation Systems." July 2006. Montana State University, Bozeman,Montana.

[2] Manuela Sechilariu, Baochao Wang and Fabrice Locment, "Building Integrated Photovoltaic System with Energy Storage and Smart Grid Communication" IEEE Transactions on Industrial Electronics, vol.60, no.4, April 2013.

[3] Y. Jaganmohan Reddy, Y. V. Pavan Kumar, K. Padma Raju, and Anilkumar Ramsesh, "Retrofitted Hybrid Power System Design With Renewable Energy Sources for Buildings" IEEE Transactions on Smart Grid, vol. 3, no. 4, December 2012.

[4] Caisheng Wang, M. Hashem Nehrir, "Power Management of a Stand AloneWind/ Photovoltaic/ Fuel cell Energy system, IEEE Transactions on Energy Conversion, vol. 23, no. 3, September 2008.

[5] Paulo F Rebeiro ,Brian K Johnson, Mariesa L Crow, Aysen Arsoy and Yilu Lui "Energy Storage Systems For Advanced Power Applications" Proceedings of the IEEE, vol. 89, no. 12, December 2001.

[6] Mesut E Baran, Hossein Hooshyar, Zhan Shen and Alex Huang, "Accommodating High PV Penetration on Distribution Feeders" IEEE Transactions on Smart Grid, vol. 3, no. 4, June 2012.

[7] Caisheng Wang, M. Hashem Nehrir, and Steven R. Shaw, "Dynamic Models and Model Validation for PEM Fuel Cells Using Electrical Circuits" IEEE Transactions on Energy Conversion, vol.20, no.2 June 2005.

[8] Natarajan Pandiarajan, Ramabadran Ramaprabha and Ranganath Muthu "Application of Circuit Model for Photovoltaic Energy Conversion System "International Journal of Photo Energy, vol.2012, article ID

[9] J. M. Correa, F. A. Farret, L. N. Canha, M. G. Simoes "An electrochemical- based fuel-cell model suitable for electrical engineering automation approach". IEEE Transactions on Industrial Electronics 2004, 51 (5), 1103-1112.

[10] Yancheng Xiao, Kodjo Agbossou, "Interface Design and Software Development for PEM Fuel Cell Modelling based on Matlab/Simulink Environment" World Congress on Software Engineering.