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Research Article

Optimal DG Source Allocation for Grid Connected Distributed Generation with Energy Storage System

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Abstract: This study proposes an Energy Management System (EMS) for allocation of DG source in a grid connected hybrid power system. Modeling and simulation for EMS is implemented using MATLAB/SIMULINK package. The objective of proposed EMS for micro grid is to optimize the fuel cost, improving the energy utilization efficiency and to manage the peak load demand by scheduling the generation according to the availability of the fuel. The proposed intelligent energy management system is designed to optimize the availability of energy to the load according to the level of priority and to manage the power flow. The developed management system performance was assessed using a hybrid system having PV panels, Wind Turbine (WT), battery and biomass gasifier. Real time field test has been conducted and the parameters i.e., solar irradiance, temperature, wind speed are gathered from 4.05 KW off grid and 2.0 KW On grid Solar Photovoltaic systems (SPV) system and wind turbine. The dynamic behavior of the proposed model is examined under different operating conditions. The simulation results of proposed EMS using fuzzy logic expert system shows the minimization on the operating cost and emission level of micro grid by optimal scheduling of power generation and maintains the State of Charge (SOC) of batteries in desired value which improves the battery life. The proposed multi objective intelligent energy management system aims to minimize the operational cost and the environmental impact of a micro grid.

Keywords: Distributed Generation (DGs), Energy Management System (EMS), Micro Grid (MG), Photovoltaic (PV), Renewable Energy (RE), Wind Turbine (WT)

INTRODUCTION

Micro Grid (MG) is a discrete energy system consisting of Distributed Energy Sources (DER) and loads capable of operating in parallel with, or independently from, the main power grid. Micro grids are becoming important constituents of electric power distribution networks. The key characteristics of MG include Grid optimization, sustainability, system reliability and operational efficiency. The idea of MG is to make the existing grid infrastructure as efficient and robust as possible, through the use of intelligence and automation. Schematic diagram of micro grid is shown in (Fig. 1) and a proposed EMS) is shown in (Fig. 2). The objective of proposed EMS is to:

- Minimizing the fuel cost by forecasting the load and generation
- Reducing the harmful gas emission and operational cost of a plant
- Improving the energy utilization efficiency

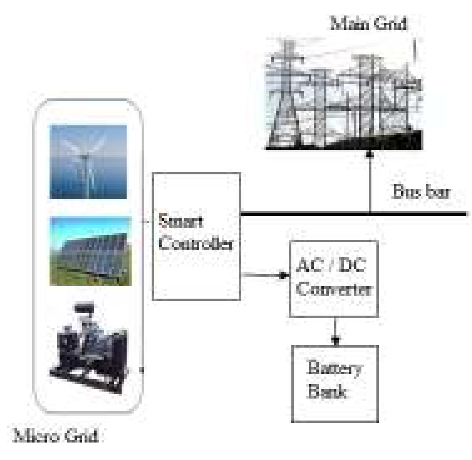

Fig. 1: Micro grid

- Maximizing the micro grid operation profit by scheduling the generation in different mode of operation by optimal scheduling Glavin *et al*. (2008) proposed a standalone photovoltaic super capacitor battery hybrid energy system. Lu and

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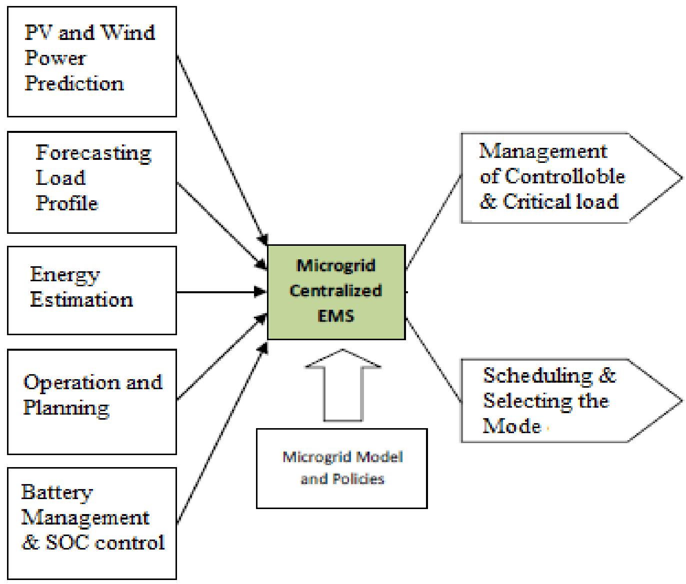

Fig. 2: Architecture of proposed EMS

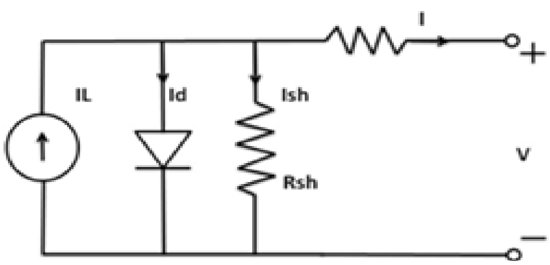

Fig. 3: Single diode equivalent circuit of PV

Francois (2009) presented a energy management of a micro grid with photovoltaic based active generator management of a micro grid with photovoltaic based active generator (Fig. 3)

This study proposes an Energy management system shown in (Fig. 4) which includes power generators, energy storage equipments, bidirectional inverter and load management system (Ahmed *et al*., 2008) The overall aim is to optimize the power flow from source to load by scheduling the generation according to the availability of fuel. Hybrid system will try to utilize the energy generated from solar and wind which is consider to be a primary energy sources. If the energy fed by solar and wind is not enough to meet the load requirement then the system will make use of battery backup power, EMS will try to make use of gasifier in case when SOC of battery is in critical level AC loads and DC loads are connected to the AC and DC grids. Load profile for the study area, Power System simulation lab in Periyar Maniammai University and the availability of solar potential and wind power in study area has been calculated for effective control.

METHODOLOGY

Modeling of hybrid system:

Modeling of solar cell: Over recent years several research and investment has been carried out in hybrid management system. Among them Liserre *et al*. (2010) presented future. Energy system, integrating renewable energy sources into smart power grid through industrial electronics:

$$I = I_L - I_D - I_{sh} \tag{1}$$

Single diode equivalent model of solar cell is shown in (Fig. 3) I_L represents the light generated current in the cell, I_D represents the voltage dependent current lost to recombination and I_{sh} represents the current lost due to shunt resistance, I_D is modeled using the shockey equation for an ideal diode (Li *et al*., 2009):

$$I_D = I_0\left[\exp\left(\frac{V + IRs}{\eta V_T}\right) - 1\right] \tag{2}$$

where,
n = The diode ideality factor
I_0 = The saturation current
V_T = The thermal voltage given by $V_T = \frac{KT_c}{q}$

where, K is the Boltzmann's constant (Tiwari, 2002):

$$I_{sh} = \frac{(V + IRs)}{R_{sh}} \tag{3}$$

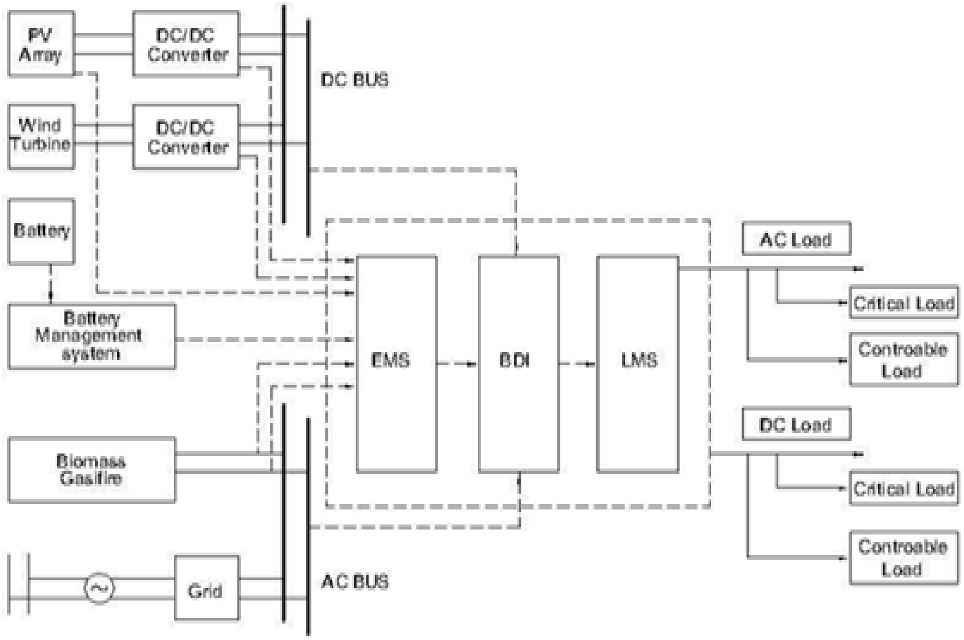

Fig. 4: Block diagram of proposed energy management system

$$I = I_L - I_0\left[\exp\left(\frac{V + IRs}{\eta V_T}\right) - 1\right] - \frac{(V + IRs)}{R_{sh}} \quad (4)$$

where,
I_L = Light current (A)
I_0 = Diode reverse saturation current (A)
R_s = Series resistance in (Ω)
n = Diode ideality factor

Mathematical formulation of turbine model: The kinetic Energy (In joules) in air of mass m moving with a velocity V (Wind) can be calculated from the expression:

$$E = \frac{1}{2} m v^2 \quad (5)$$

The power P in the wind is given by the rate of change of kinetic energy (Wang and Nehrir, 2008):

$$P = \frac{dE}{dt} = \frac{1}{2}\frac{dm}{dt} vw^2 \quad (6)$$

But mass flow rate is given by:

$$\frac{dm}{dt} = \rho A v w \quad (7)$$

where, A is the area through which the wind in this case is flowing and ρ is the density of the air. With this expression equation becomes:

$$P = \frac{1}{2}\rho A v^3 w \quad (8)$$

$$P_w = \frac{1}{2}\rho A v w (v_u^2 - v_d^2) \quad (9)$$

where,
v_u = Upstream velocity entered in blade in m/sec
v_d = Downstream velocity entered in blade in m/sec:

$$\rho A v_w = \frac{\rho A (v_u + v_d)}{2} \quad (10)$$

$$P_w = \frac{1}{2}\rho A (v_u^2 - v_d^2)\frac{(v_u + v_d)}{2} \quad (11)$$

$$P_w = \frac{1}{2}\left[\rho A\left\{\frac{v_u}{2}(v_u^2 - v_d^2) + \frac{v_d}{2}(v_u^2 - v_d^2)\right\}\right] \quad (12)$$

$$P_w = \frac{1}{2}\rho A v_u^3 C_p \quad (13)$$

Power co-efficient analysis: The output power of the wind turbine is given by (Johnson, 2004):

$$P_m = C_p(\lambda, \beta)\frac{\rho A s}{2} v^3 \text{ Wind} \quad (14)$$

where, C_p is performance coefficient of wind turbine, β is blade Pitch angle, ρ is air density, A_s is swept area and V wind is velocity of the wind. This equation based on the modeling turbine characteristics of (Anderson and Bose, 1983):

$$C_p(\lambda,\theta) = C_1(C_2\frac{1}{\beta} - C_3\beta\theta - C_4\theta^x - C_5)e^{-C_6\frac{1}{\beta}} \quad (15)$$

$$\frac{1}{\beta} = \frac{1}{\lambda + 0.08\theta} - \frac{0.035}{1+\theta 3} \quad (16)$$

MODEL DEVELOPMENT

The objective of the proposed optimization model is to optimize the availability of energy to the loads according to the level of priority. It is also proposed to maintain the SOC of the battery to meet peak load demand during the period where renewable energy sources failed to supply. The loads are classified as critical load and controllable load. In this study Fuzzy Logic (FL) based expert system is applied for multi objective functions like allocation of different sources according to the availability. The fuzzy based expert system is based on the following factors Battery state of charge, wind velocity, solar insolation and availability of biomass fuel and load demand. A fuzzy logic controller is used to decide the optimum operation of DG systems as shown in the fig there are four possible mode of operation DG mode, gasifier mode, battery mode and grid mode. The battery management system maintains State of charge of battery at reasonable value.

Load constraint: The distribution of energy from different source at period t to each load is given as:

Q_{pv} Q_{wt}, Q_g, Q_b

where,
Q_{pv} = The energy supplied by the PV
Q_{wt} = The energy supplied by the Wind turbine
$Q_{g\ is}$ = Energy supplied by the gasifier
Q_b = The energy supplied by the battery

PV array constraint: E p (t) is the sum of energy supplied by the PV array to the load and battery bank in hour t (Li *et al*., 2009):

$$Q_{pv}, B\ (t) + (\textstyle\sum_i Qpv, i\ (t)\ ) = E\ p\ (t) \quad (17)$$

where,
Q_{pv}, B (t) = The energy supplied by the PV array to the battery
Q_{pv}, I (t) = The energy supplied by the PV array to load

Since the energy generated by the system varies with insolation, therefore the available array energy Ep (t) at any particular time is given by:

$$Ep\ (t) = V\ s\ (t) \quad (18)$$

where,
V = The capacity of the PV array
S (t) = The isolation index

Gasifier constraint: E p (t) is the sum of energy supplied by the gasifier based power generation system to the load and battery bank in hour (t):

$$Q_g, B\ (t) + (\textstyle\sum_i Qg,\ i\ (t)) = E\ p\ (t) \quad (19)$$

where,
Q_{pv}, B (t) = The energy supplied by the gasifier to the battery
Q_{pv}, i (t) = The energy supplied by the gasifier to load

Wind energy constraint: E p (t) is the sum of energy supplied by the wind energy based power generation system to the load and battery bank in hour t:

$$Q_{wt}\ B\ (t) + (\textstyle\sum_i Qwt, i\ (t)) = E\ p\ (t) \quad (20)$$

where,
Q_{wt}, B (t) = The energy supplied by wind
Q_{pv}, i (t) = The energy supplied by the wind turbine to the load

Battery bank constraint: The Battery bank serves as a energy source entity when discharging and load when charging. The net energy balance to the battery determines its State of Charge (SOC).
The state of charge is expressed as follows:

$$Q_B\ SOC\ (t) = Q_B SOC_{(t-1)} + Q_{pv}\ (t) + Q_g\ (t)$$
$$Q_{wt}\ (t) - \textstyle\sum_i QB\ i\ (t) \quad (21)$$

where, Q_B is the capacity of the battery Bank.

The battery has to protected against overcharging and deep discharging therefore, the charge level at (t-1) plus the incursion of energy from PV, Wind and gasifier at the period (t-1) should not exceed the capacity of battery, E p (t) is the sum of energy supplied by the gasifier based power generation system to the load and battery bank in hour t:

$$Q_g, B\ (t) + (\textstyle\sum_i Qg, i\ (t)) = E\ p\ (t) \quad (22)$$

where,
Q_{pv}, B (t) = The energy supplied by the gasifier to the battery
Q_{pv}, i (t) = The energy supplied by the gasifier to load

Fuzzy control: The Fuzzy Logic Controller (FLC) is applied in the proposed micro grid supply system, membership function is shown in (Fig. 5 to 8). The input and output membership functions of fuzzy control

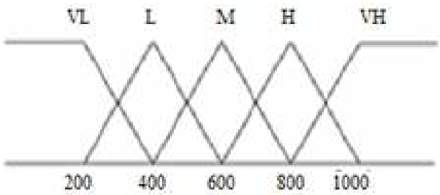

Fig. 5: Membership function of FLC solar irradiance (W/m^2)

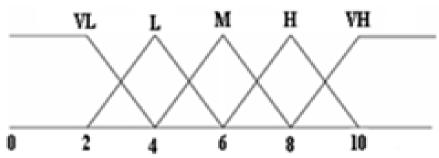

Fig. 6: Membership function of FLC wind speed (m/sec)

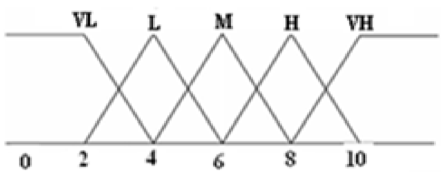

Fig. 7: Membership function of FLC load (KW)

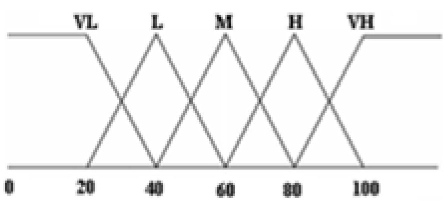

Fig. 8: Membership function of FLC state of charge of battery (%)

contain five grade VL (Very Low), L (Low), M (Medium), H (High) and VH (Very High). FLC is used to decide the optimum operation of the micro grid system with different mode of operation i.e.:

- DG mode
- Gasifier mode
- Battery charging/discharging mode
- Grid mode

FLC is also used for battery management system which maintains the SOC at reasonable (Fig. 9 and 10).

Control algorithm: A control algorithm is developed and implemented in the power conditioner hardware. This algorithm is used to control the entire operations of the hybrid energy systems. Monitoring the load demand and solar insolation, wind speed, biomass fuel availability, battery state of charge and grid availability are the major tasks of the control algorithm (Ahmed *et al.*, 2008). The control algorithm is developed to satisfy the load demand by optimally allocate the sources. The control algorithm first checks the availability of solar and wind power and calculates the power from solar and wind. It measures the demand and if the demand matches with the availability then the sources are allocated (Kanchev *et al.*, 2011) accordingly. After the allocation, the excess power if any is used for charging the battery bank. The power conditioner checks the state of charge of battery, once it is maximum, then the control algorithm is developed in such a way that the excess power is fed into the utility

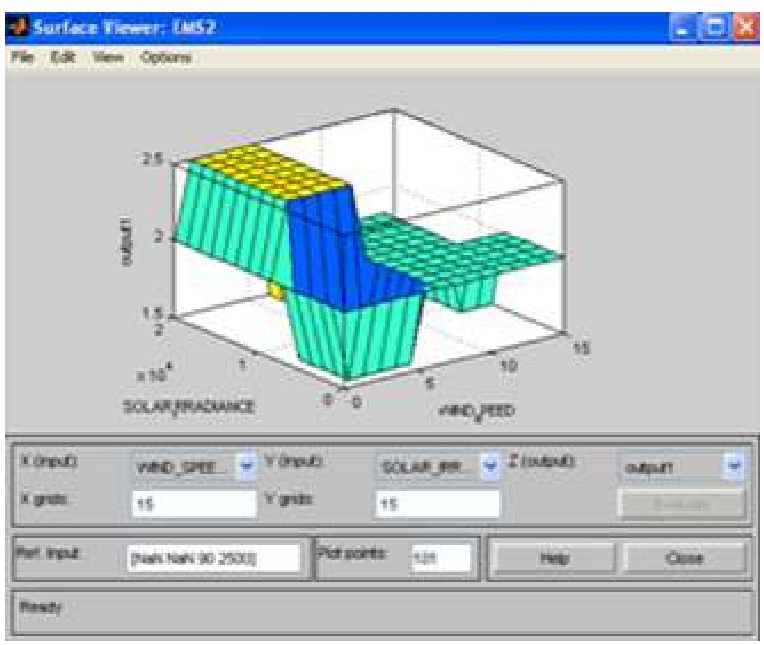

Fig. 9: Surface viewer

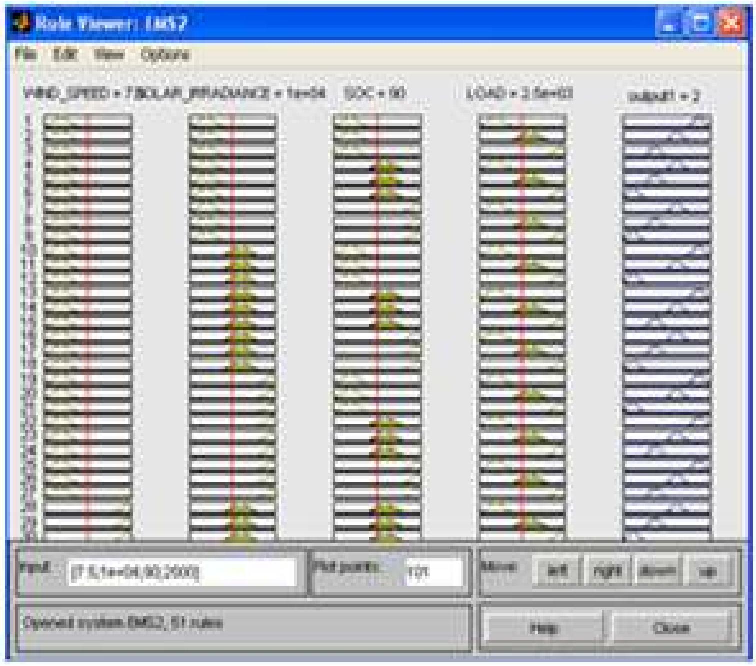

Fig. 10: Rule viewer

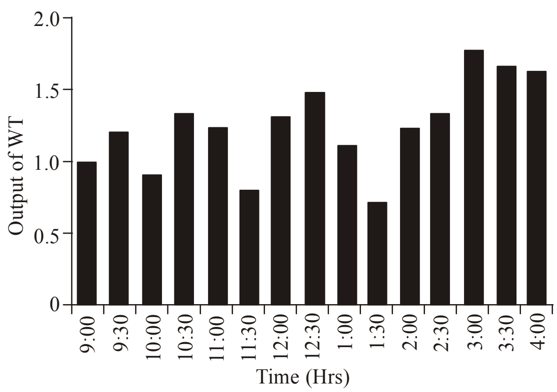

Fig. 11: Load demand profile

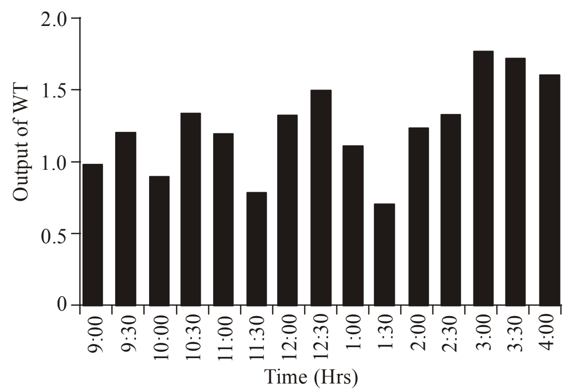

Fig. 13: Output of wind turbine

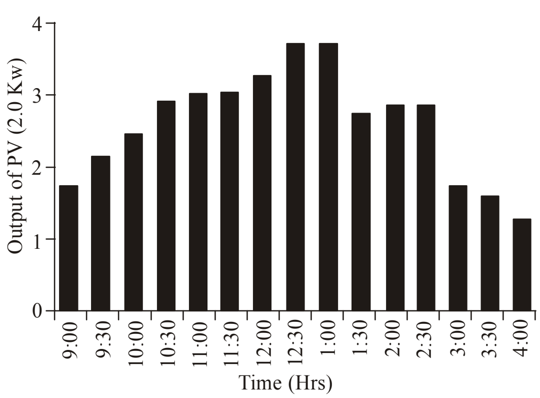

Fig. 12: Output of SPV system

grid. If the demand is high then the power conditioner allocates battery together with wind and PV to meet the load demand (Li *et al*., 2009). Before the allocation, the state of charge of battery is checked. Biomass gasifier is allocated only when the demand is high or during when the demand cannot be met by the wind, PV and battery bank. Sudden increase in load demand is taken care by the battery before the starting of biomass gasifier (Fig. 11 to 14).

SIMULATION AND RESULTS

MATLAB/SIMULATION model for a proposed EMS is shown in (Fig. 14) to investigate the performance of system. Load profile of the study area is shown in (Fig. 11). Availability of solar and wind potential is shown in (Fig. 12 and 13). During the simulation all possible electrical power system transient were studied. During the interval 9.00 to 10.00 h DG power capacity is not sufficient to meet the load requirement and batteries meet the power demand

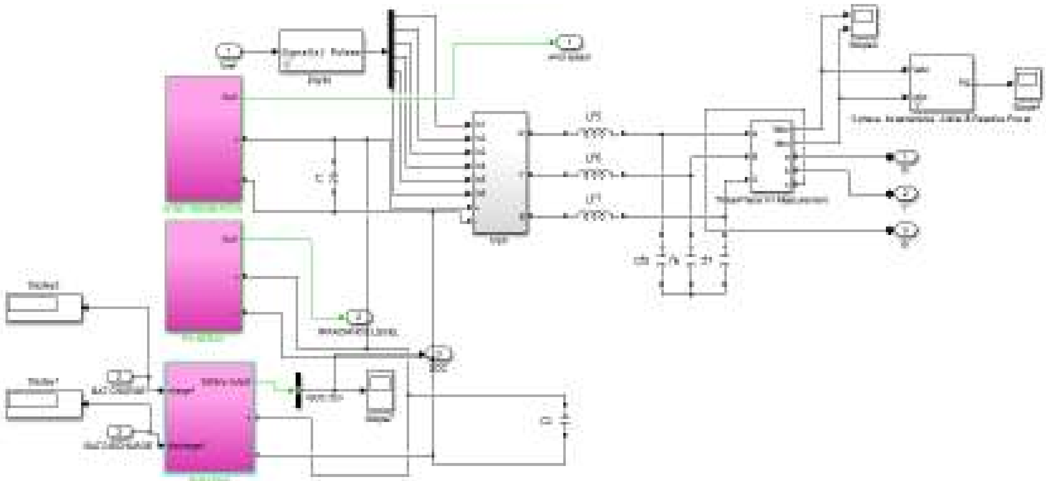

Fig. 14: MATLAB model for proposed EMS

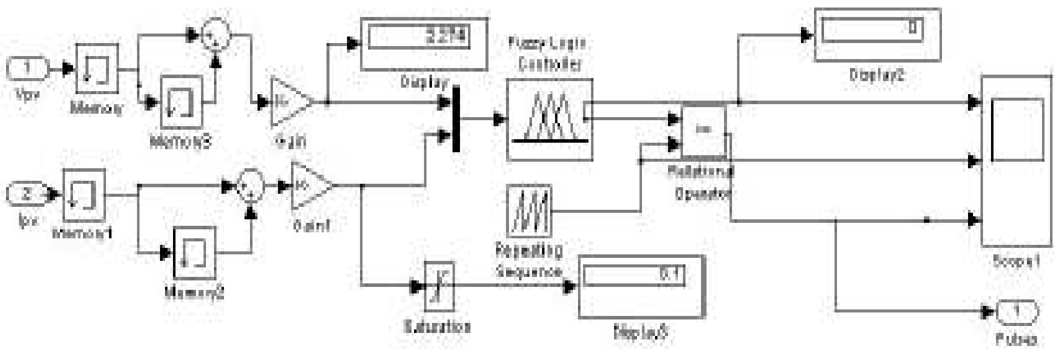

Fig. 15: MATLAB model for PV system

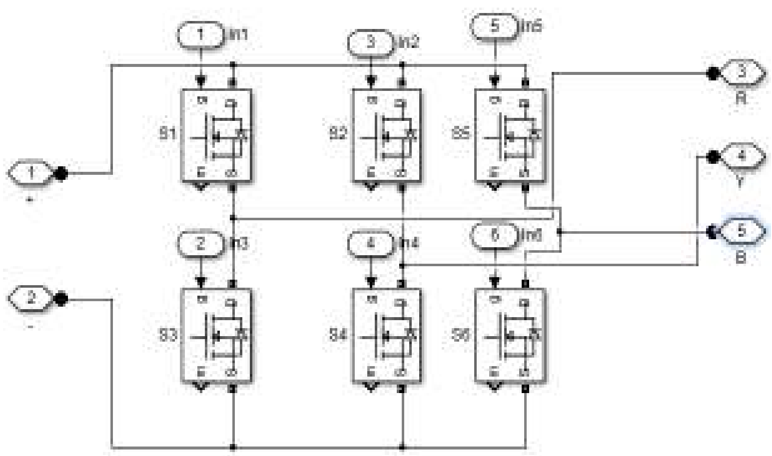

Fig. 16: Circuit for inverter model

which is in battery mode, The objective of the energy scheduling. Is to schedule the day-ahead operation of the DERs and the loads such that:

- The total load utilities are maximized
- The total costs of generation and energy purchase are minimized
- The DER constraints, the load constraints and the supply-demand matching constraint are satisfied, at time instant 10.00 h the SOC of battery is in critical level in which the EMS turns on gasifier to satisfy the load requirement

MATLAB model for PV is shown in (Fig. 15) and Bidirectional converter is shown in (Fig. 16),

Table 1: Specification of PV

Specifications	
Typical peak power	P_{max} = 250 W
Maximum peak power current	I_{mp} = 6.94 A
Maximum voltage	V_m = 36.00 V
Open circuit voltage	V_{oc} = 44.00 V
Short circuit current	I_{SC} = 7.60 A

USL solar module; Module type: KL 250; Rating: 2 KW

Fig. 17: Experimental setup

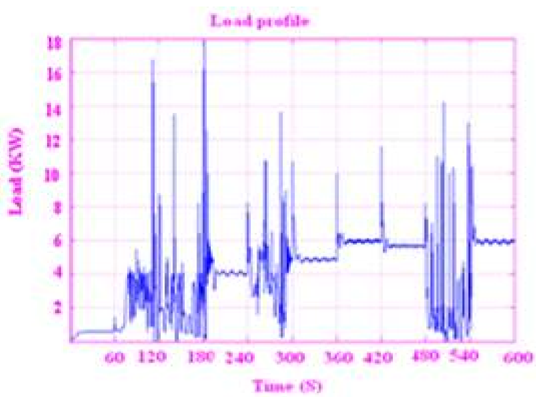

Fig. 18: Simulated output for change in load

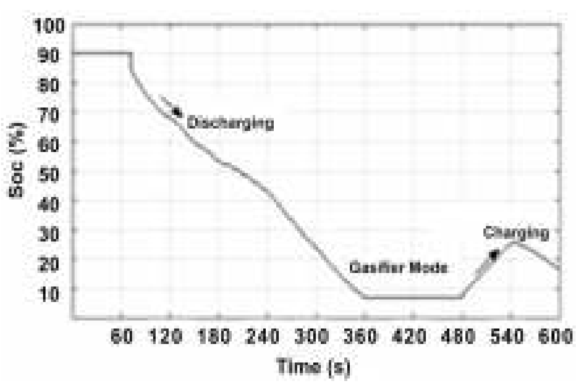

Fig. 19: Simulated output for SOC

Experimental set up is shown in (Fig. 17), the major input for the proposed EMS were solar irradiation, wind speed, load demand profile. In this study USL solar module of rating 2 KW PV panel is taken as example and specification of a solar panel shown in (Table 1) and the simulated out for change in load and state of charge of batteries in different mode of operation is shown in Fig. 18 and 19.

CONCLUSION

In this study, optimized energy management system is designed and modeled for a micro grid. A power conditioner algorithm for the optimal control and operation of the hybrid energy system is presented. The developed algorithm comprises system components and an appropriate power flow controller. The model has been implemented using the MATLAB/SIMULINK software package; a system consists of PV/wind/Biomass gasifier and battery setup. The parameters i.e., Solar irradiance, temperature and wind speed data is gathered from a 4.05 kW grid connected solar power system and 5 kW_e biomass gasifier located in Periyar Maniammai University, Tamilnadu. Real time field test is conducted for a period of 24 h. It is found that the implemented algorithm allots the sources effectively and the hybrid energy system supplies the demand of the particular site effectively.

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