Control of Microgrid With Enhancement of Wind Power Evacuation

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ABSTRACT

Out of the available renewable energy sources in India, wind energy plays a dominant role accounting for nearly 68% of the total renewable power produced in the country. Out of which Tamil Nadu produces 7162 MW (38%) of the total capacity. A major problem faced by all wind farms in the state is that of evacuation of wind power due to limited power transmission capacity of existing transmission lines. Kudimangalam, one such wind farm in Coimbatore is taken up for study in this paper. By transforming this windfarm into a microgrid, wind power evacuation problems can be mitigated or minimized to a larger extent. The goal of this paper is to suggest the capacity of solar plant, gas power plant and battery storage to be used for the proposed microgrid. Energy Management Algorithm (EMA) is incorporated in MATLAB Simulink and is tested for different conditions. Finally implementation of EMA is done with the help of PIC microcontroller. From the study, it can be concluded that it is feasible to convert the considered wind farm into a microgrid with solar and gas power plants of appropriate capacity so that wind power is utilized to its maximum without power evacuation problems.

Keywords: microgrid, windfarm, solar plant, energy management algorithm, microcontroller, battery

1. INTRODUCTION

Power grid management is a challenging task from the perspective of maintaining the balance between electricity generation and demand. This is especially emphasized in a micro grid environment with limited load aggregation and possibly high proportion of weather dependent generation capacity. Global electricity consumption is set to increase to about 24763 TWh by 2025. The future demand can no longer be simply met by traditional power generation methods of burning fossil fuels like coal etc. This presents a significant opportunity for the development of renewable energy based generating systems.

One such system is the use of microgrids. Microgrids are low voltage intelligent distribution networks comprising of various distributed generators, storage devices and controllable loads which can be operated as interconnected or as islanded system. A Centralized controller along with micro source controllers and power electronic interfaces ensure that the microgrid operates as a single aggregated system to maintain the specified power quality and energy output. The microgrid under normal operating conditions is connected to the grid. It can import or export power from the grid as required. Microgrid disconnects itself from the main grid and operates in islanded mode in case of any fault occurring in grid or microgrid, during which power supply to critical loads is ensured. The objective of this paper is to design a microgrid configuration for an existing windfarm in Kudimangalam, Coimbatore by installing a solar plant, gas power plant and energy storage unit and to coordinate the generators and controllable loads and hence achieve the maximum utilization of wind power and enhance the wind power evacuation.

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2. MODELING OF THE PROPOSED MICROGRID

Figure 1 shows the block diagram of the proposed microgrid consisting of wind farm, solar plant, gas power plant and battery storage unit. The details of Kudimanagalam site are given in Table 1.

In the assumed model of microgrid, Wind turbine gets the current wind speed as input; current temperature and incident solar radiation are inputs to the solar plant. The output of the gas turbine is to be controlled by fuel control method depending on the wind power output fluctuations. Hence the current fuel consumption is given as input to the gas turbine. Each of these sources has been modeled in MATLAB. The centralized controller gets the current power outputs of wind farm, gas plant and solar plant as inputs. The demand has to be met by these energy sources. So, a short term load forecast model has been formulated which will predict the load one hour ahead. So the current demand and the future demand will also be given as inputs to the centralized controller. In the considered microgrid, it is assumed that a fixed percentage of loads are controllable loads. So, regulatory actions can be performed even on the demand side. Also there is provision of battery storage unit. The microgrid can function in two modes:

1. Grid connected - Normal operating condition
2. Islanded Mode - Microgrid disconnects itself from the main grid and operates in islanded mode in case of any fault occurring in grid or microgrid. Power can be exported or imported from the microgrid. In case where import is not possible, power stored in the battery can be utilized. A separate controller can be implemented which delays or advances the loads according to the algorithm.

The assumptions made are

(i) Reactive power requirements are met by the microgrid itself.
(ii) The microgrid is assumed to be stable under all operating conditions.

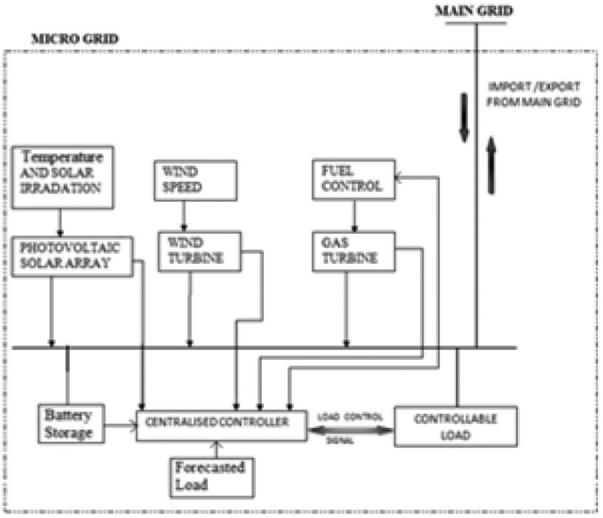

Figure 1. Block diagram of microgrid under study

Table 1. Kudimangalam site details

1	Installed wind power capacity	90 MW
2	Average wind power generated	50 MW
3	Max wind power Generated	79 MW
4	Minimum wind machine rating	225 kW
5	Maximum wind machine rating	850 kW
6	Types of load around the site	Agricultural Loads, Domestic Loads and Industrial Loads

2.1. Modeling of windfarm

The installed capacity of windfarm in the considered site is 90 MW. A wind farm usually consists of a large number of Wind Turbine Generators (WTGs) connected through an internal electrical network and operating simultaneously. Figure 2 shows the overall 9 MW wind farm Simulink model. This model is run for different wind speeds and the wind power outputs are tabulated. Table 2 shows the results.

As the installed wind power capacity is 90 MW as per site details, ten 9 MW blocks were made and integrated together. Wind farm consists of many WTGs. Wind speed differs at each turbine-generator set. The simulation model is developed considering this fact. The wind speed to all turbines is not the same and differs from 0.1 to 0.3 m/s. Table 3 shows the input wind speed values given for each wind farm.

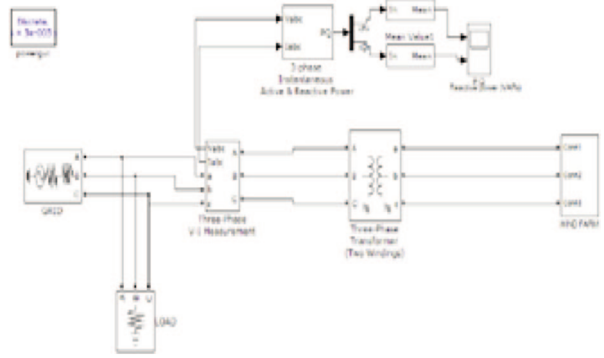

Figure 2. Simulink model of 9 MW wind farm

Table 2. Wind power output of 9 MW windfarm

Wind speed(m/s)	Wind power output (MW)
14.5	8.937
14	8.937
13.5	8.937
13	8.937
12.5	8.937
12	8.937
11.5	8.937
11	8.937
10.5	8.937
10	8.7
9.8	8.182
9.6	7.655
9.4	7.128
9.2	6.604
9	6.084
8.8	5.56
8	3.592
7.8	3.127
7.5	2.458
7.2	1.827
7	1.43
6.7	0.875
6.5	0.533
6.3	0.214

Table 3. Wind speeds given as input to all WTGs in windfarms

Wind Fann No.	Wind speed (m/s)
Farm 1	[9.34, 8.812, 7.65, 4.12, 6.6, 3.3, 2.7, 0, 5.4]
Farm 2	[9.14, 9.012, 7.35, 4.86, 6.3, 3.1, 1.8, 0, 6.4]
Farm 3	[9 8, 10.20, 7.5, 4.6, 6.7, 3.6, 1.2, 0.3, 6.9]
Farm 4	[8.8, 11.20, 8.5, 5.6, 7.7, 4.6, 2.2, 1.3, 7.2]
Farm 5	(7.8, 12.20, 9.5, 6.6, 8.7, 5.6, 3.2, 1.6, 7.8]
Farm 6	[10, 9.2, 9.74, 8.93, 8.05, 7.96, 8.53, 6.94]
Farm 7	[8, 10.2, 9.4, 9.94, 9.13, 8.35, 8.26, 8.83, 7.24]
Farm 8	[8, 10.42, 9.44, 10.94, 10.13, 9.35, 9.26, 9.83, 8.24]
Farm 9	[8, 10.12, 9.24, 9.44, 9.23, 8.15, 8.96, 3, 7.24]
Farm 10	[8, 11.02, 9.44, 11.94, 9.33, 9.85, 9.43, 9.03, 10]

2.2. Modeling of solarfarm

Currently there are solar power projects in the Nevada Desert of ratings 48 and 64 MW. There is an on-going proposal for a 354 MW plant. Solar plant capacity for the proposed microgrid is based on the details of microgrid configuration suggested in [1], whose details are given in Table 4.

So, for the proposed microgrid, a PV panel of capacity 30 MW needs to be simulated. Figure 3 shows the simulink model of 5 MW solar module. There are 96 solar cells connected in the module. Table 5 shows the details of used solar cell rating.

Table 4. Capacities of microgrid sources in kW and percentage

Total microgrid capacity	3126 kW	100 %
Wind power	1700 kW	53 %
Solar plant	626 kW	20 %
Gas plant	800 kW	27 %

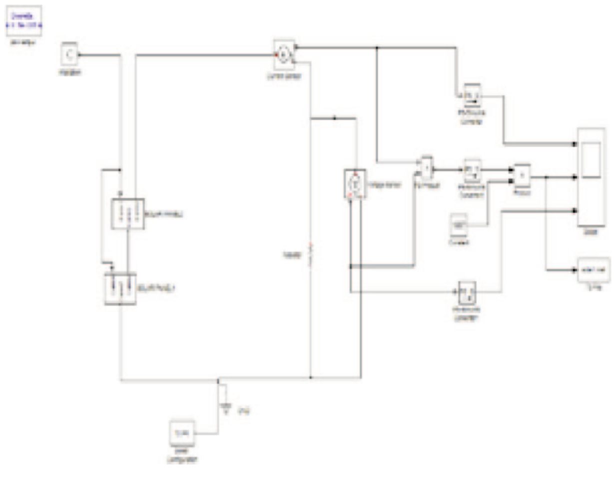

Figure 3. Simulink model of 5 MW solar module

Table 5. Details of solar cell

Open Circuit Voltage Voc (V)	64.8
Short Circuit Current Isc (A)	6.24
Voltage at Maximum Power Vmp (V)	54.7
Current at Maximum Power Imp (A)	5.86

Six such modules have been interconnected to obtain 30 MW. By varying irradiance, solar output power is varied. For the 5 MW simulation model, incident radiation versus output power reading was obtained. Table 6 shows the readings obtained.

2.3. Modeling of gas power plant

The Rowens model of a gas turbine is considered here, which is shown in Fig. 4 [2]. The single shaft gas turbine along with the control and fuel system is represented in the model. Control system of the gas turbine has three control loops; the speed control, temperature control and acceleration control. These three control functions are all inputs into a minimum value selector (represented by the low value select block). Output of the low value select represents the least fuel control actions among the three control actions. The speed control loop corresponds directly to the governor and can be operated either in the standard droop configuration or in isochronous mode. The temperature control loop represents the limitation of the gas turbine output due to temperature. An acceleration control loop, in order to prevent the over-speeding of the generator in the event of a sudden loss of load, is also implemented in the model and represented by the third input into the low value select. The simulation of basic gas turbine is done by assuming temperature is within limits and acceleration will not exceed specified limits.

Speed/load control determines the fuel demand according to the load reference and the rotor speed deviation. The adjusting speed is slow compared with the fuel flow. The airflow is proportional to the rotor speed. As shown in Fig. 5, the simulink model of gas turbine is to control the mechanical torque output with respect to the load torque.

The above model needs to be coupled to a permanent magnet synchronous generator from which output power is obtained. Input to the gas turbine is load torque and it gives the mechanical torque as output. This mechanical torque is given as input to the PMSG. So whenever the gas turbine mechanical torque varies, the generator output power varies.

Table 6. Solar output power for different values of solar irradiance

Irradiation (W/m^2)	Output (MW)
100	0.0897
200	0.3519
300	0.8070
400	1.4330
500	2.2153
600	3.0400
700	3.6969
800	4.1301
900	4.4400
1000(rated)	4.6700
1100	4.8386
1200	4.9886

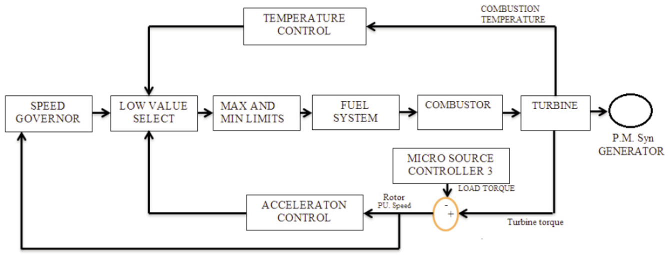

Figure 4. Rowens model of gas turbine

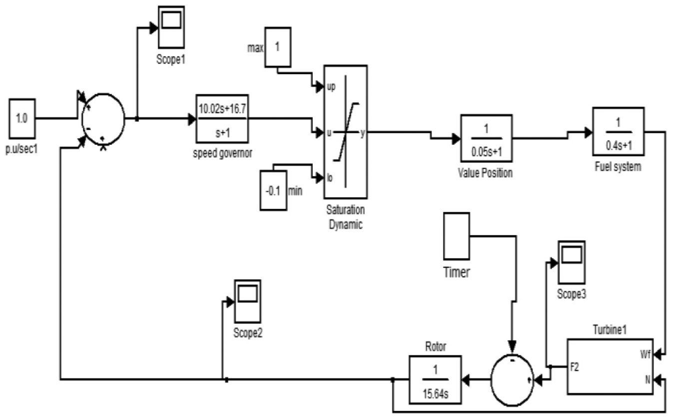

Figure 5. Simulink model of gas turbine

2.4. Model of forecasted load

Electrical load forecasting is an important tool used to ensure that the energy supplied by utilities meets the load plus the energy lost in the system. Load forecasting is defined as basically the science or art of predicting the future load on a given system, for a specified period of time ahead.

For this study, a short term load forecast model is best suited since demand needs to be predicted on an hourly basis for the controller. The model is a multiple linear regression model taking into account the temperature deviation, base load, and a chillness factor dependent on wind velocity. It expresses the load at any discrete time instant t as a function of a base load and a weather-dependent component. The base load is assumed to be constant for each discrete time interval. This model will be used for both winter and summer load forecast simulations. Because the relationship between load and weather differs significantly over these two seasons, a different load formulation will be required in each case [5].

Let Yi(t) = load at time t I interval i of day,
W(t) = wind-chill factor at time t;
Ai = base load at time t;
Bi through Li = regression coefficients of weather sensitive components
Td(t) is the dry bulb temperature at time t, in °C;
Tp(t) is the dew point temperature at time t.
Tava is the average dry bulb temperature of previous 24 hrs till time t
Tavb is Tava lagged 3 hours
Tci is the cut off dry bulb temperature
Tpi is the cut off dew point temperature
V(t) is the wind speed in miles/hr.

2.4.1. Winter model

Mathematically, the load at any discrete instant t, where t varies from 1 to 24, can be expressed as in Equation (1)

$$Yi(t) = Ai + Bi(Td(t) - Tci) + Ci(Td(t) - Tci)2 + Di\,(Td(f) - Tci)3 + Ei(Tp(t) - Tpi) + Fi(Tava - Tavb) + Gi(Td(t) - Td(f - 1)) + Hi(Td(t - 1) - Td(t - 2)) + Ii(Td(t - 2) - Td(t - 3)) + Ji(Wc(t)) + Ki(Wc(t - 1)) + Li(Wc(t - 2)) \qquad (1)$$

W(t) is the wind chill factor given by

$$W(t) = 33 - [10.45 + 10\sqrt{0.477}\ V(t) - 0.44\ V(t)] \times [(33 - 0.556(Td(t) - 32))/22.04]$$

2.4.2. Summer Model

The winter equivalent of the load model given above can be modified for summer model to get Equation (2).

$$Yi\,(t) = Ai + Bi(Td(t) - Tci) + Ci(Td(t) - Tci)2 + Di(Td(f) - Tci)3 + Ei(Tp(t) - Tpi) + Fi(Tava - Tavb) + Gi(Td(t) - Td(f - 1)) + Hi(Td(t - 1) - Td(t - 2)) + Ii(Td(t - 2) - Td(t - 3)) \qquad (2)$$

Given below is the generalized Equation (3) for obtaining the regression coefficients.

$$\begin{bmatrix} Y1 \\ Y2 \\ . \\ . \\ . \\ . \\ . \\ . \\ . \\ . \\ . \\ Yn \end{bmatrix} = \begin{bmatrix} 1X1A\ X1B\ X1C\ldots\ldots X1L \\ 1X2A\ldots\ldots\ldots\ldots X2L \\ . \qquad\qquad\qquad\qquad . \\ . \qquad\qquad\qquad\qquad . \\ . \qquad\qquad\qquad\qquad . \\ . \qquad\qquad\qquad\qquad . \\ . \qquad\qquad\qquad\qquad . \\ . \qquad\qquad\qquad\qquad . \\ . \qquad\qquad\qquad\qquad . \\ . \qquad\qquad\qquad\qquad . \\ . \qquad\qquad\qquad\qquad . \\ 1XnA\ XnB\ XnC\ldots\ldots XnL \end{bmatrix} \begin{bmatrix} A \\ B \\ C \\ D \\ E \\ F \\ G \\ H \\ I \\ J \\ K \\ L \end{bmatrix} \qquad (3)$$

where Y1 to Yn denote the value of load at time t.

A, B … L denote the regression coefficients to be found.

X1A to XIL denote the coefficients of regression constants corresponding to the values of load.

To obtain the regression coefficients for the summer season the hourly dew point and dry bulb temperature data and the corresponding load values are needed. Table 7 shows the sample data for the month of August 2011, based on which the values of the regression coefficients are calculated.

Substituting the necessary values from the data in Equation (2), coefficients of the regression constants to be used in the matrix mentioned in the Equation (3) are obtained.

Apart from the variables involved in the summer season, one more variable has been introduced in the winter model which in short is called the wind chill factor. Proceeding in a manner similar to that explained in the summer model, the winter model is arrived. Table 8 shows the sample set of data used for finding the values of regression coefficients for a day in the month of October.

Thus the load models for winter and summer season have been formulated by obtaining the values of the regression coefficients which are shown in Table 9. The data set used for load forecasting is that of a 110 kV substation in Coimbatore. We need a maximum power output of 79 MW. So a conversion factor needs to be included. So the forecasted load value using this model should be multiplied by $1.65 * 10^3$ in order to bring to megawatt range. Using these models load can be forecasted up to 1 hour ahead and this forecasted value of load is given as input to the controller. To apply this model for predicting future load, a Simulink model shown in Figure 6 has been developed. On inputting the values of required variables, it will give the load as output.

Table 7. Sample data set for summer month

TIME	LOAD(KwHr)	DRY BULB (°C)	DEW POINT (°C)
2:30 am	0.0216	23	22
5:30 am	0.0250	23	21
8:30 am	0.0318	26	22
11:30 am	0.0375	31	21
2:30 pm	0.0362	33	17
5:30 pm	0.0388	29	21
8:30 pm	0.0401	25	22
11:30 pm	0.0285	24	22

$T_{ci} = 22°C$, $T_{pi} = 16°C$ for summer season. $T_{ava} = 27°C$. $T_{avb} = 26°C$

Table 8. Sample data set for winter month

TIME	LOAD(Kw)	DRY BULB(ºC)	DEW POINT(ºC)	Velocity(m/s)
2:30 am	0.0216	24	21	3.31
5:30 am	0.0250	24	21	2
8:30 am	0.0318	26	22	3.17
11:30 am	0.0375	32	21	2.52
2:30 pm	0.0362	34	19	3.26
5:30 pm	0.0388	31	20	5.43
8:30 pm	0.0401	28	22	4.65
11:30 pm	0.0285	29	21	4.92

$T_{ci} = 21$, $T_{pi} = 19$ for winter season $T_{ava} = 29$ºC, $T_{avb} = 28$ºC

Table 9. Values of regression coefficients for summer and winter models

Summer Model	
A_i	0.0227
B_i	0.0041
C_i	–0.0006
D_i	0
E_i	0.0005
F_i	0 0010
G_i	0 0001
H_i	–0.0006
I_i	0.0014

Winter Model	
A_i	0.0155
B_i	0.0023
C_i	0.0007
D_i	0
E_i	–0.0047
F_i	–0.0068
G_i	–0.0016
H_i	–0.0008
I_i	0.0003
J_i	0.001198
K_i	0.0012
L_i	0.00119

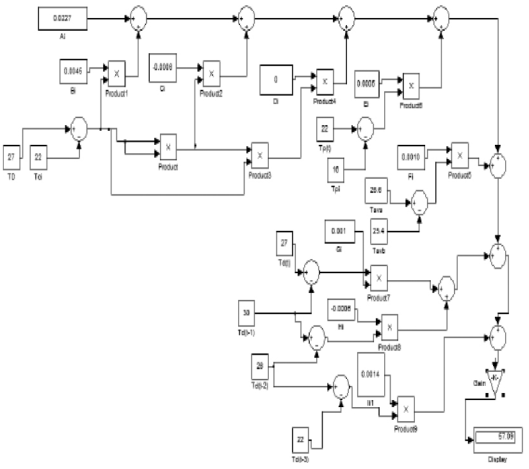

Figure 6. Simulink model for load forecasting

3. SELECTION OF BATTERY TECHNOLOGY AND ITS CAPACITY

There are a wide variety of storage technologies, with differing technology and market characteristics. There are four key characteristics of energy storage devices: Energy Density, Energy Rating, Power Capability and Discharge Time. NaS battery is the battery technology that has been selected as they have relatively high energy densities, designed for long discharge cycles, estimated lifetime of 15 years and approximately 2500 cycles (charge/discharge/recharge) and depth of Discharge for NaS can be as high as 96% [3]. In Tohoku district of Japan 34 MW NaS batteries for 51 MW wind farm has been developed. Its purpose is to stabilize the fluctuations in output power of wind turbines. 17 units of 2MW NaS Batteries have been utilised. Total NaS battery storage Capacity 244.8 MWhr. DC operating voltage 470 – 750 V.

In the scenario that energy from different energy resources or from the grid is not sufficient, battery storage comes into play. In such a scenario, power supply to critical loads must be ensured. 10% of connected load is considered as critical load (i.e) 8MW. The entire power supply cannot be managed by a single battery system. Considering a scenario where there are 3 sets of modules each capable of supplying energy for 7.5 hours, the switches can be used for operating one module at a time and power can be supplied for 23 hours.

Number of hours for which each battery should be able to supply power = 7.5
Let Inverter efficiency = 85%
Battery efficiency = 80%
Battery rating of a single module = 8 * 7.5/0.8= 88.235 MWhr
DC Power Rating = 88.235/0.85 = 11.764 MW
Commercially 2 MW units of NaS batteries are available.
So number of units required = 11.764/2 = 6 units
After combining such modules the system operating voltage = 700 V

In the case where energy requirements from the grid or from the energy sources do not suffice, energy stored in the battery has to be used. In such a case first whether the battery is charged fully that is if it is ready for use has to be verified. This is indicated by a parameter called state of charge. SOC should not exceed 100% since it indicates overcharging which is harmful and at the same time it should not be below 20%.

4. CENTRALIZED CONTROLLER AND ENERGY MANAGEMENT ALGORITHM

Microgrid needs a controller with advanced automation engine and control functions to be able to apply different commands to distributed energy resources and control their parameters at the desired level [4]. A supervisory controller is required to run the real-time optimal dispatch every several minutes thereby providing optimal set-points for microgrid. In the microgrid under study, control actions only on the gas power plant and on the load side are being done. That is, output of the gas power plant can be modified according to the demand and regulatory actions on the load side such as advancing or delaying the load as per demand can be performed.

The different inputs given to controller are

(i) Current power output of wind farm, solar and gas plant
(ii) Current load demand and future value of load (load predicted half an hour ahead)
(iii) Necessary load which is connected
(iv) SOC of battery as percentage
(v) Grid Availability

In the proposed microgrid, the gas power plant capacity is found to be 40 MW. In any gas power plant, there will be not be a single turbine but a number of turbines of different capacities. In the system considered, there are 4 turbines of rating 20, 10, 5 and 5 MW respectively. The gas turbine power output has to be met by a combination of these or by any one of these units. Basically what optimum usage of gas turbine means selecting the best combination out of the available options such that system efficiency is maximized and cost is minimized. The variables involved in the optimization of gas turbine are (i) Current demand and future load (ii) Delayed load and Controllable load and (iii) Current gas turbine output. Detailed flow chart of the energy management algorithm is given in Fig. 7.

The limits of the operational capacities of the considered micro grid units are provided in Table 10. The minimum operating values are assumed to be zero. It is assumed that 10 percent of the load is critical, 40 percent is necessary and 50 percent of the total load is controllable. A simulation based on selected values from the entire data would normally be a very limited approach. However, as the considered micro grid is not a real structure and the intention is only to demonstrate the micro grid management, it is considered to meet its purpose. The entire simulation is run for time period scaled

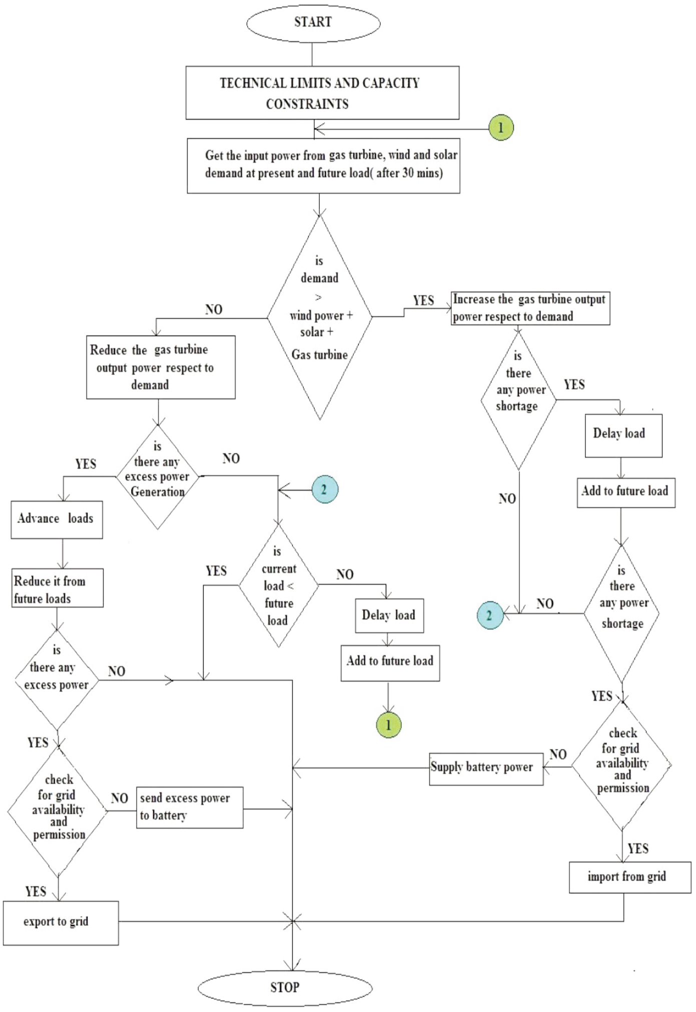

Figure 7. Flow chart for energy management algorithm

Table 10. Operational capacities of the proposed microgrid

Supply Unit	Rated Unit Capacity	Total Capacity
Wind Turbine	250 kW–850 kW	90MW
Solar Panels	5MW	30MW
Micro Gas Turbine	5,20,10MW units	40MW

down to 40 seconds during which variations in wind power, solar and gas turbine, future demand, controllable loads, grid availability and the SOC of the battery are given as continuous time variable inputs to the controller. Figure 8 shows the simulink model of the centralized controller.

5. TEST CASES OF ENERGY MANAGEMENT ALGORITHM

Table 11 shows the different cases of energy management algorithm for which the simulation outputs are obtained. Following are the description of each case.

In CASE 1, the total power produced is more than demand that is there is excess power. In this case demand is 50 MW and future demand is same as current demand. Grid availability is taken as 1 that is power can be exported or imported to or from grid. 25 MW of load is necessary. The SOC of battery is assumed to be 50%. Giving these values as inputs to the controller the simulation is carried out. As expected due to availability of surplus power output of gas turbine is zero. So power can be exported to grid and loads can be advanced. So 35 MW can be exported

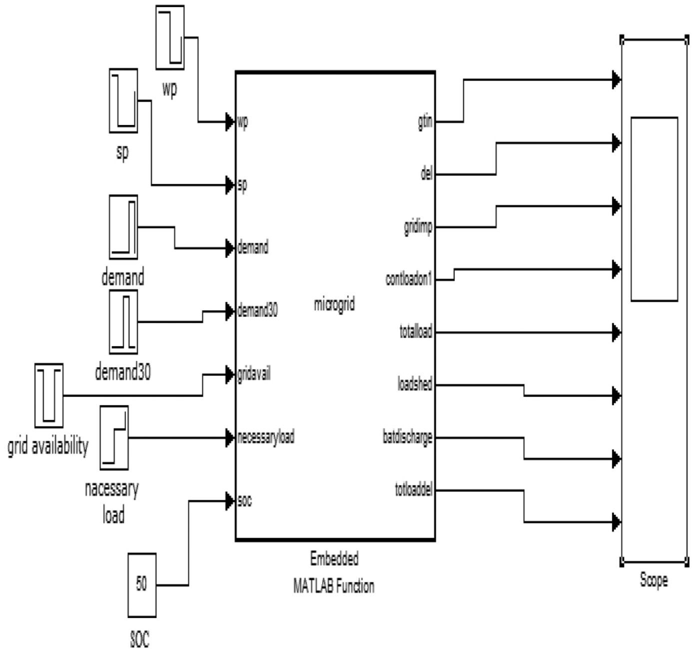

Figure 8. Simulink model of centralized controller

Table 11. Test case inputs and outputs for energy management algorithm

INPUTS								OUTPUTS						
CASE	WP (MW)	SP (MW)	DEM (MW)	DEM30 (MW)	NES LOAD (MW)	GRID STATICS (1 OR 0)	BAT SOC %	GTIN (MW)	LOAD DEL (MW)	GRID IMPORT (MW)	CONT LOAD (MW)	TOT LOAD (MW)	BAT DISCHARGE (MW)
1.	70	30	50	50	25	1	50	0	–15	–35	40	65	0
2.	70	30	50	50	25	0	50	0	–15	0	40	65	–35
3.	10	0	50	70	35	0	50	40	0	0	15	50	0
4.	10	0	70	50	35	1	50	Same inputs for case 4(a) & 4(a)					
(i)	WITH GAS TURBINE OPTIMIZATION							30	30	0	5	40	0
(ii)	WITHOUT GAS TURBINE OPTIMIZATION							40	20	0	15	50	0

DEM – Demand
DEM30 – Demand after 30 minutes
NES LOAD – Neccessary load
BAT SOC – Battery state of charge
GTIN – Gas turbine input

LOAD DEL – Delayed load
CONT LOAD – Controllable load ∞
TOT LOAD – Total load

and 15 MW loads are advanced. Case 1 occurs in the time period 0 to 10 seconds as shown in Figure 9.

In CASE 2, the total power produced is more than demand that is there is excess power. In this case demand is 50 MW and future demand is same as current demand. Grid availability is taken as 0 that is power cannot be exported or imported to or from grid. 25 MW of load is necessary. The SOC of battery is assumed to be 50%. Giving these values as inputs to the controller the simulation is carried out. Since excess power is available but grid availability is zero it can used to delay the loads and charge the battery. Case 2 occurs in the time period 10 to 20 seconds as shown in Figure 9.

In CASE 3, the total power produced is less than demand that is there is shortage of power. In this case demand is 50 MW and future demand is 70 MW. Grid availability is taken is 0 that is power cannot be exported or imported to or from grid. 35 MW of load is necessary. The SOC of battery is assumed to be 50%. Giving these values as inputs to the controller the simulation is carried out. Since power obtained from renewable sources is limited gas turbine is run at full capacity. Controllable load connected are 15MW. Case 3 occurs in the time period 20 to 30 seconds as shown in Figure 9.

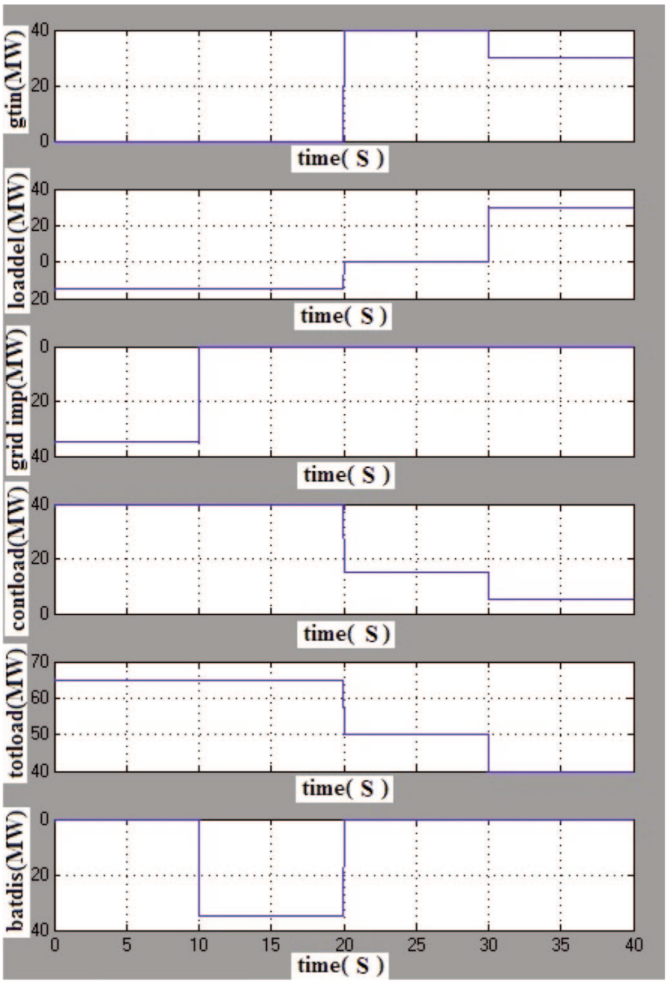

Figure 9. Test case output with gas turbine optimization

In CASE 4, the total power produced is less than demand that is there is shortage of power. In this case demand is 70 MW and future demand is 50 MW. Grid availability is taken is 1 that is power can be exported or imported to or from grid. 35 MW of load is necessary. The SOC of battery is assumed to be 50%. Giving these values as inputs to the controller the simulation is carried out. So this case, demand is more than power produced and future demand is less than current demand hence gas turbine optimization has to be done. The outputs obtained with and without optimization are shown in Figure 9 and 10. It is observed that by optimization, gas turbine power consumption is reduced. This case is seen in the time interval of 30 to 40 seconds.

6. HARDWARE IMPLEMENTATION OF ENERGY MANAGEMENT ALGORITHM

The microgrid configuration under study is just a model and does not exist in reality. Hence for Fig. 10 Test case output without Gas Turbine optimization verification of EMA in laboratory a small setup is done using PIC microcontroller, LCD display and a 5 V dc supply. The EMA is coded in PIC using mplab using C coding. For convenience purposes the inputs to the controller are hardcoded instead of obtaining them externally. The voltage rating of PIC ranges from 0–5 V. The inputs are in MW range so they are correspondingly scaled down that is 16 MW is equivalent to 1Volt. The EMA code is converted into a hex file using HI-TEC compiler and burnt in to the PIC. On running the EMA the outputs are displayed in the LCD screen. Figure 11 shows the hardware setup of the Energy Management Algorithm controller.

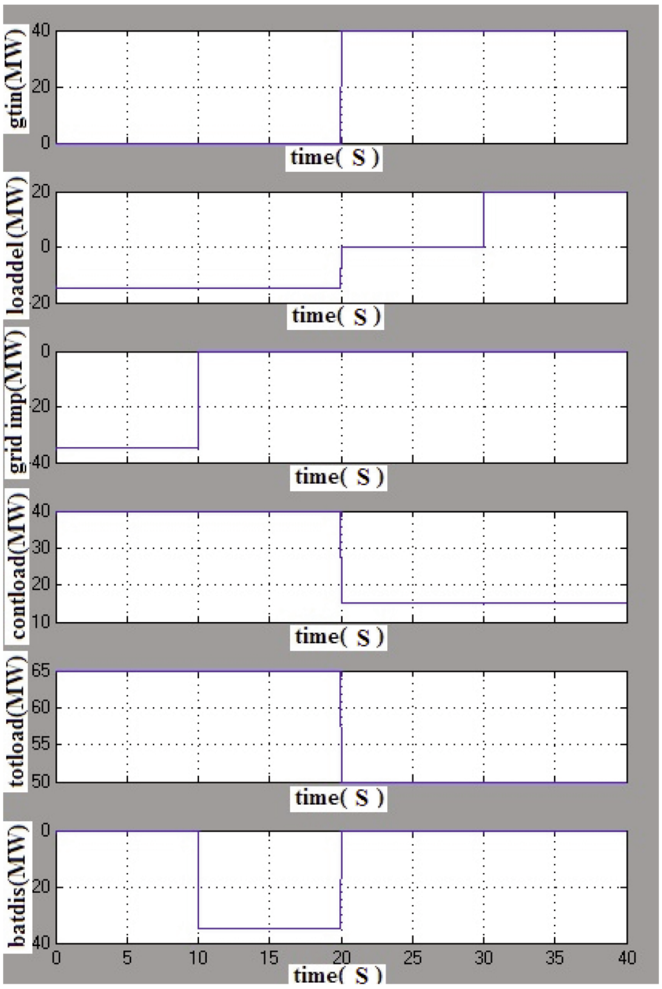

Figure 10. Test case output without gas turbine optimization

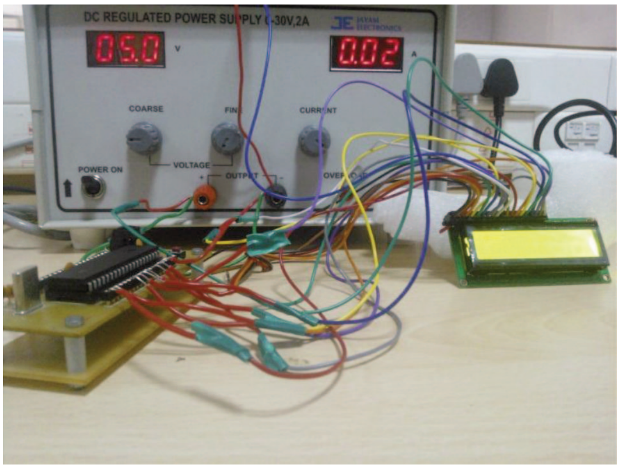

Figure 11. Hardware setup of energy management algorithm controller

7. CONCLUSION

In this study, a wind farm in Kudimangalam was taken up and a micro grid configuration containing photovoltaic solar panels and gas turbines is proposed. Capacity of solar and gas power plants, battery storage are suggested for this site. In first part of the study the different elements involved in the microgrid were studied and modelled. After that an energy management algorithm was proposed and simulation of the energy management system was done. Load forecasts were done using linear regression. The energy manager takes care of controlling gas turbine, advancing and delaying the loads, checks grid availability and battery storage. It was tested for different cases and the output was verified using both simulation and hardware.

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