INTELLIGENT ENERGY MANAGEMENT FOR HYBRID SYSYTEM BASED ON MICROGRID

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ABSTRACT

A microgrid can be operated in on-grid or off-grid, mode using distributed energy resources (DER), among which combined heat power can play an important role in increasing the total energy efficiency. This paper reports the total solutions to the problem of scheduling DER including CHP and their dispatch, called a generation application package. To increase the accuracy of forecasting, this paper proposes the methods of electrical or heat load forecasting and photovoltaic forecasting using a pattern recognition algorithm by *k*-means clustering. In response of the forecasted data, the formulation and solution of generation scheduling and dispatch of DER are provided in two operation modes of a microgrid. The formulation and the detailed solution of the economic dispatch of the DER are presented. Finally, field tests of the generation applications package were performed and the results shown of the the proposed solutions are very effective in the real fields. This paper proposes the dynamic optimal schedule management method for an isolated or grid-connected microgrid system with renewable power generations such as PV systems and wind power systems, and with back-up and storage sources such as micro-turbine generators and electricity storage, which is able to consider forecast errors with uncertainties of solar radiation, wind speed and local user demands. The energy management system (EMS) structure for accumulation interms of the economic and stable operation in the microgrid is proposed. Optimization problem for the power from micro-turbine generators or the grid and electricity storage in EMS is resolved by dynamic programming (DP) and equal incremental fuel cost method. The proposed method is confirmed by matlab study that used forecast data and realization data of renewable power generations and local user demands. In conclusion, this paper presented a practicable method for the operation of a microgrid.

Keywords-Distributed energy resources, Economic dispatch, Generation scheduling, Microgrid EMS

1.INTRODUCTION

A microgrid is a low-voltage distribution network consisting of a variety of energy components including distributed energy resources (DERs) and controllable loads. With these components, a microgrid can either be connected to the grid (i.e., grid-connected mode) or use the DERs to supply the loads without the grid (i.e., islanded mode). Integrating DERs and controllable loads within the distribution network introduces unique challenges to the microgrid management and control which are implemented by an energy management system (EMS). A microgrid EMS can be significantly different from the EMS used in conventional power systems due to these challenges. As the penetration of distributed energy resources (DER) increases, the role of efficient and totally integrated management is becoming increasingly important [1]. For high energy efficiency, renewables, such as photovoltaic or wind power and electrical energy storage system (ESS) are prevailing rapidly. In addition, combined heat power (CHP) can be an alternative, where the heat load and electrical load need to be considered together [2]-[4].

For systematic and efficient operation of DER, accurate forecasts, e.g., electrical or heat load forecasts, and renewables forecasts, are needed. Many studies have examined electrical or heat load forecasts [5]-[9]. From the perspective of the forecasting methodology, extensive researches have been performed based on the autoregressive moving average (ARMA) model in the early days [6]. Thereafter, artificial intelligence, such as neural network or fuzzy system, was used for forecasting [7], [8]. From the perspective of the forecasting horizon, load forecasting can be categorized into three classes: very short term load forecasting (VSTLF), short term load forecasting (STLF), and medium term and long term load forecasting (MTLF and LTLF) [5], [6]. For more precise generation scheduling, several hours ahead VSTLF is preferred, and this paper proposes a methodology using a pattern recognition algorithm by *k*-means clustering [10], [11]. The same approach is applied to renewables forecasts, especially photovoltaic forecasts.

The generation scheduling or unit commitment is a very important application for the economic and efficient operation of DER. Several studies have examined generation scheduling [12]-[16]. Fu *et al.* [12] studied generation scheduling with a variety of security constraints. Zendelhdel *et al*. [13] proposed the linearized unit commitment problem. In the perspective of a microgrid, additional DER, such as ESS, renewables like photovoltaic (PV), and wind turbine (WT), are considered in generation scheduling [14]-[16]. In particular, the operation

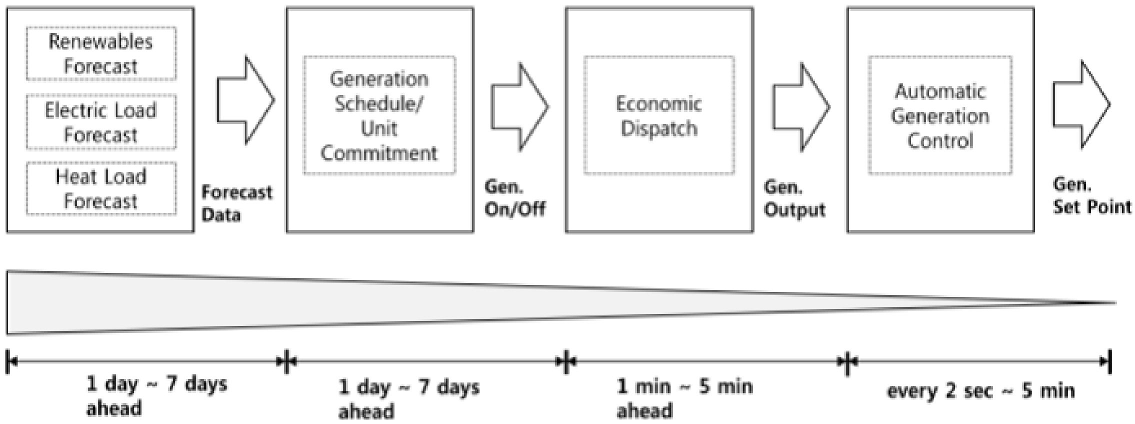


Fig. 1. Process flow of the generation applications package

strategy in islanded microgrid has been studied [14]-[15].

In response of the forecasted data, the formulation and solution of generation scheduling and dispatch of DER are provided in two operation modes of microgrid in this paper. The formulation of generation scheduling is proposed considering DER including CHP and ESS in two operation modes of a microgrid, i.e., on-grid mode and off-grid mode, and it is linearized for a general mixed integer linear programming (MILP) solver. Economic dispatch is for power sharing of the only working DER at a certain time, which is reported elsewhere [17]-[19]. Guo *et al*. examined the economic dispatch with CHP. Wu *et al.* proposed the formulation of economic dispatch in

the transition from on-grid mode to off-grid mode [18]. Shi *et al*. proposed the distributed optimal solution by co-operational computation over a central energy management system (EMS) and local EMS [19]. This paper presents the formulation and the detailed solution of economic dispatch of DER including CHP in an on-grid and off-grid microgrid, which can be implemented in a centralized microgrid EMS. The total solutions of the problem of scheduling DER including forecast and their dispatch are called the generation application package in this paper.

2. FORECAST AND GENERATION SCHEDULING OF MICROGRID EMS

The generation applications package consists of a load forecast, renewables forecast, generation scheduling, economic dispatch (ED), and automatic generation control (AGC), which were performed periodically. Fig. 1 shows the typical period of each application and the sequential flow of a generation applications package. The formulation and solution to the generation application package except AGC are described. In particular, this study focuses on the generations scheduling and ED including CHP in the on-grid and off-grid operation modes of a microgrid.

A. Very Short Term Load Forecast and Renewables Forecast

STLF predicts the one day ahead electrical or heat load, or a few days ahead electrical or heat load from historical load data. On the other hand, the forecasted load can contain

large errors. Therefore, it might be better to use the historical load around the time at which the forecasted load will be predicted. The VSTLF is performed hourly or at least three times a day and produces a forecast for several hours ahead. The main algorithm in this paper is based on the pattern recognition algorithm by *k*-means clustering. The methodology of electrical or load forecast is to find the most similar pattern among the clustered patterns, which are update with the recent data until *k*-means

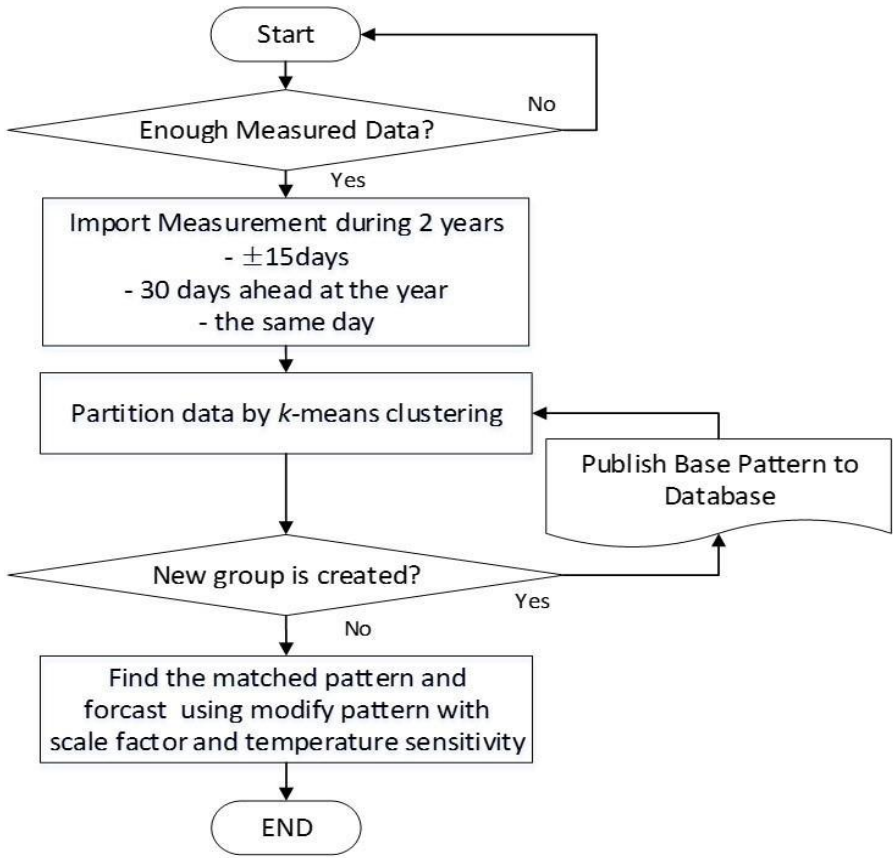


Fig. 2. Flowchart of the VSTLF for the electrical and heat load.

clustering is impossible, as shown in Fig. 2. For a photovoltaic forecast, 5 reference classes of sky conditions, i.e., C0, C1, C2, C3, and C6 at each of three fixed times, i.e., 11h, 13h, and 15h, were categorized; a total of fifteen patterns of solar irradiations are generated [20]. The most similar solar irradiation is then selected and modified using the recent updated data. Finally, the PV power output can be forecasted or calculated from the equation, which is a function of the solar irradiation.

B. Generation Scheduling

Generation scheduling aims to determine when the DER operates or not, and how much power the DER produces to minimize the cost of operation or maximize the benefit of selling power. The objective function is as follows:

$$\min_{x,p} \sum_{t\in\tau} \sum_{i\in G} \sum_{b\in B_i} x_i^t cost_{i,b}^t + \sum_{t\in B_i} \hat{p}_{buy}^t \hat{P}_{buy}^t - \sum_{t\in\tau} \hat{p}_{sell}^t \hat{P}_{sell}^t$$

The cost function is described including the fuel cost of DER *i* in (2). Note that the fuel cost function is in the form of a linear function, not a quadratic function.

$$\cos t_{i,b}^t = b_{i,b} p_i^t + c_{i,b} x_i^t + UC_i u_i^t + DC_i d_i^t$$

1) Demand supply balancing constraint

Demand supply balancing constraint is required depending on the operation modes of a microgrid. The electrical supply of all DER and demand do not have to be equal in the on-grid mode of microgrid; the electrical supply of all DER and demand have to be equal only in the off-grid mode of a microgrid.

$$\mathbf{D_{elec}} = \sum_{i\in\{G_e,G_{chp}\}} \mathbf{P_i}\ ,\ \mathbf{D_{heat}} = \sum_{i\in\{G_{chp},G_h\}} \mathbf{H_i}$$

2) Spinning reserve constraint

$$\sum_{i\in G} \mathbf{R^t_{0,i}} \geq \mathbf{R^t_0}$$

3) Minimum up time and down time constraint

$$\sum_{t=k}^{k+UT_i-1} x_i^t \geq UT_i u_i^k$$

$$\sum_{t=k}^{k+DT_i-1} x_i^t \geq DT_i d_i^k$$

Where,

$$u_i^t - d_i^t = x_i^t - x_i^{t-1}$$

$$u_i^t + d_i^t \leq 1$$

4) Ramp-rate constraint

$$-DR_i \leq P_i^t \leq x_i^t P_i^{max}\ , \forall t \in \tau, \forall i \in G$$

5) Minimum and maximum output constraint

$$\mathbf{x_i^t P_i^{min}} \leq \mathbf{P_i^t} \leq \mathbf{x_i^t P_i^{max}}, \forall \mathbf{t} \in \boldsymbol{\tau}, \forall \mathbf{i} \in \mathbf{G}$$

6) ESS constraint

Given the initial charged electrical energy, or Energy_i^o,

$$\mathbf{Energy_i^t} = \mathbf{Energy_i^{t-1}} + P_i^t$$
$$Energy_{min,i} \leq \mathbf{Energy_i^t} \leq Energy_{max,i}$$

For $\forall t \in \tau, \forall i \in G$

7) Interface line capacity constraint

$$\left| \mathbf{D^t_{elec}} - \sum_{i\in G} \mathbf{P^t_i} \right| \leq \mathbf{c^t}, \forall \mathbf{t} \in \boldsymbol{\tau}$$

3. ECONOMIC DISPATCH OF MICROGRID EMS

A. On-Grid Mode of Microgrid

The amount of flow at the point of common coupling (PCC) can be determined from the generation scheduling process. The objective function of economic dispatch does not include the flow at the PCC for evaluating the selling power or buying power. For simplicity, it is assumed that the thermal output of CHP, or DER *i* is proportional to its electrical output by αi. ESS can be dealt with as a type of electrical generator with a very low production cost or it can be assumed to follow the pre-determined schedule from generation scheduling or by an operator manually. The objective function can be stated as follows [21]:

$$\max_{p} \hat{p}_{buy} - \sum_{i \in \Omega} \cos t_i \quad for \Omega = \{G_e, G_{chp}, G_h\}$$

where $\cos t_i$ is the quadratic cost function of DER i and

$$D_{elec} = \sum_{i \in \Omega_h} P_i = \sum_{i \in G_{chp}} \alpha_i P_i + \sum_{i \in G_h} H_i \quad for \quad \Omega_h = \{G_{chp}, G_h\}$$

The Lagrange function can be described as

$$\mathcal{L} = \hat{p}_{buy} \hat{P}_{buy} - \sum_{i \in \Omega} \cos t_i + \gamma \left(D_{heat} - \sum_{i \in G_{chp}} \alpha_i P_I + \sum_{i \in G_h} H_i \right)$$

The first-order conditions are as follows:

$$\frac{\partial \mathcal{L}}{\partial P_i} = \hat{p}_{buy} - \frac{\partial \cos t_i}{\partial P_i} = 0, for\ i \in G_e$$

$$\frac{\partial \mathcal{L}}{\partial P_i} = \hat{p}_{buy} - \frac{\partial \cos t_i}{\partial P_i} - \alpha_i \gamma = 0, for\ i \in G_{chp}$$

$$\frac{\partial \mathcal{L}}{\partial H_i} = -\frac{\partial \cos t_i}{\partial P_i} + \gamma = 0, for\ i \in G_h$$

$$D_{heat} = \sum_{i \in G_{chp}} \alpha_i p_i + \sum_{i \in G_h} H_i, for\ i \in G_h$$

Purchasing an insufficient amount of electrical generation in a microgrid can be beneficial if the total fuel costs are greater than the buying price, or the system marginal price from (14), which means that finding the optimal solution depends on the system marginal price. The output of CHP is determined by the Lagrange multiplier γ in (16). The solution procedure of optimization in the on-grid mode of microgrid is as follows:

1) Calculate the initial value γ_o^t

$$\gamma_o^t = \frac{D_{heat} + \sum_{i\in G_{chp}} \alpha_i \frac{b_i - \hat{p}_{buy}^t}{2a_i} + \sum_{i\in G_h} \frac{b_i}{2a_i}}{\sum_{i\in G_{chp}} \frac{\alpha_i^2}{2a_i} + \sum_{i\in G_h} \frac{1}{2a_i}}$$

2) Calculate the initial output of DER i.

The minimum and maximum output of DER and their ramp rates have an effect on the update by (19)-(21). Note that $Pi(i\in Ge)$ is not required to update independently of λt.

$$P_i^t = \max\left\{\min\left(\frac{\hat{P}_{buy}^t - b_i}{2a_i}, P_i^{max}, P_i^{t-1} + UR_i\right), P_i^{min,t}, P_i^{t-1} - DR_i\right\}$$

for $i \in G_e$

$$P_i^t = \max\left\{\min\left(\frac{\hat{P}_{buy}^t + \alpha_i\gamma_o^t - b_i}{2a_i}, P_i^{max}, P_i^{t-1} + UR_i\right), P_i^{min,t}, P_i^{t-1} - DR_i\right\}$$

for $i \in G_{chp}$

$$H_i^t = \max\left\{\min\left(\frac{\alpha_i\gamma_o^t - b_i}{2a_i}, H_i^{max,t}, H_i^{t-1} + UR_i\right), H_i^{min,t}, H_i^{t-1} - DR_i\right\}$$

for $i \in G_h$

3.Determine the new value of γ_{new}^t.

If the total heat demand is less than the sum of the heat supply of DER, i.e.$D_{heat}^t < \sum_{i\in G_{chp}} \alpha_i P_i^t + \sum_{i\in G_h} H_i^t$, P_i^t and H_i^t are adjusted by decreasingγ^t. Otherwise, P_i^t and H_i^t are adjusted by increasing γ^t. This is repeated to update γ^t until the total heat demand is equal to the sum of the heat supply of DER.

4) Check the stop criteria and if the following condition is not satisfied, then, repeat 1).

$$|\gamma_{new}^t - \gamma_{old}^t| \leq \epsilon_\gamma$$

B. Off-Grid Mode of a Microgrid

In the off-grid mode of a microgrid, there is no flow at the PCC. The objective function, or (11), is changed to (23). In addition to the heat load balancing constraint in (12), the electrical load balancing constraint in (24) is also required.

$$\min_P \sum_{i\in\Omega} \cos t_i\, , \ \Omega = \{G_e, G_{chp}, G_h\}$$

Such that

$$D_{elec} = \sum_{i\in\Omega_e} P_i, \Omega_e = \{G_e, G_{chp}\}$$

$$D_{heat} = \sum_{i\in\Omega_h} H_i = \sum_{i\in G_{chp}} \alpha_i P_i + \sum_{i\in G_h} H_i$$

Ω_h=$\{G_{chp}, G_h\}$

The Lagrange function is described as follows:

$$\mathcal{L} = \sum_{i\in\Omega} \cos t_i + \lambda\left(D_{elec} - \sum_{i\in\Omega_e} P_i\right) + \gamma\left(D_{heat} - \sum_{i\in G_{chp}} \alpha_i P_i + \sum_{i\in G_h} H_i\right)$$

The first-order conditions are as follows:

$$\frac{\partial\mathcal{L}}{\partial P_i} = \frac{\partial \cos t_i}{\partial P_i} - \lambda = 0, \text{ for } i \in G_e$$

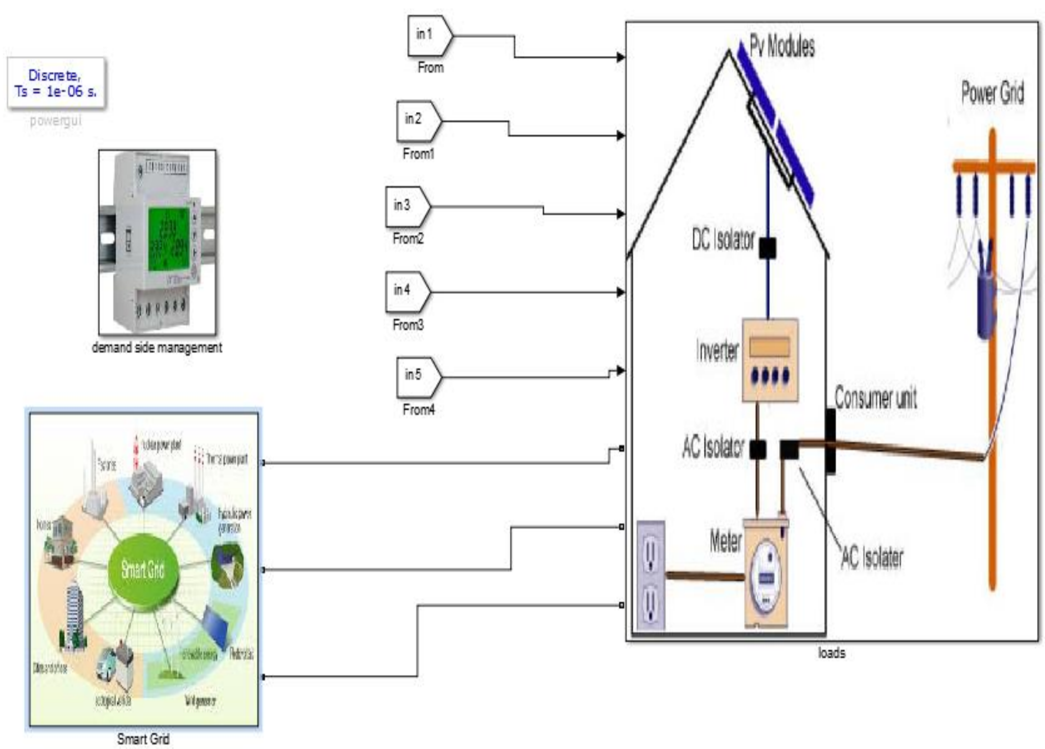
$$\frac{\partial\mathcal{L}}{\partial H_i} = \frac{\partial \cos t_i}{\partial H_i} - \gamma = 0, \text{ for } i \in G_h$$

$$\frac{\partial\mathcal{L}}{\partial P_i} = \frac{\partial \cos t_i}{\partial P_i} - \lambda - \alpha_i\gamma = 0, \text{ for } i \in G_{chp}$$

$$D_{elec} = \sum_{i\in\Omega_e} P_i \text{ , } for\ \Omega_e = \{G_e, G_{chp}\}$$

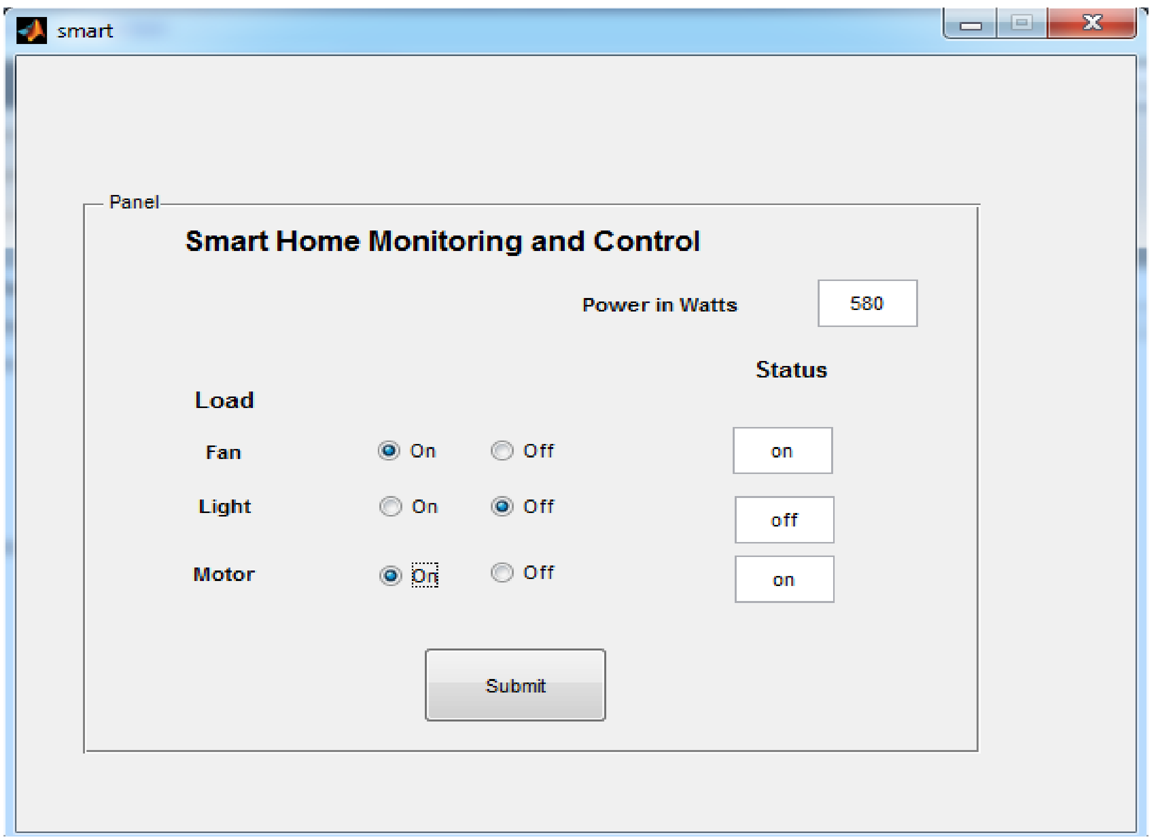
$$D_{heat} = \sum_{i\in G_{chp}} \alpha_i P_i + \sum_{i\in G_h} H_i$$

PROPOSED SIMULATION MODEL



RESULTS OF TESTS AND DISCUSSIONS

The proposed mathematical formulation of generation scheduling is in the form of mixed integer linear programming (MILP), which can be solved using MATLAB. Also the proposed model is simulated by means of smart home monitoring control which can be used to reduce the overall comsumption of the power in demand, can be used to save the energy for our future use.The load can be switched off and on by matlab view panel i.e smart home monitoring control to avoid wastage of power and can be economically used easily to reduce the overall electricity cost of the bill.This smart home monitoring control can be operated from any part of the world and it can be implemented in android application so that we can view what amount of power is consuming in our absence and we can shut down any appliances or load in case it is running uselessly so as to avoid power comsumption and for the economic bill as well.



Change the load status and get output power in watts

Load management is through internet (smart and green building)

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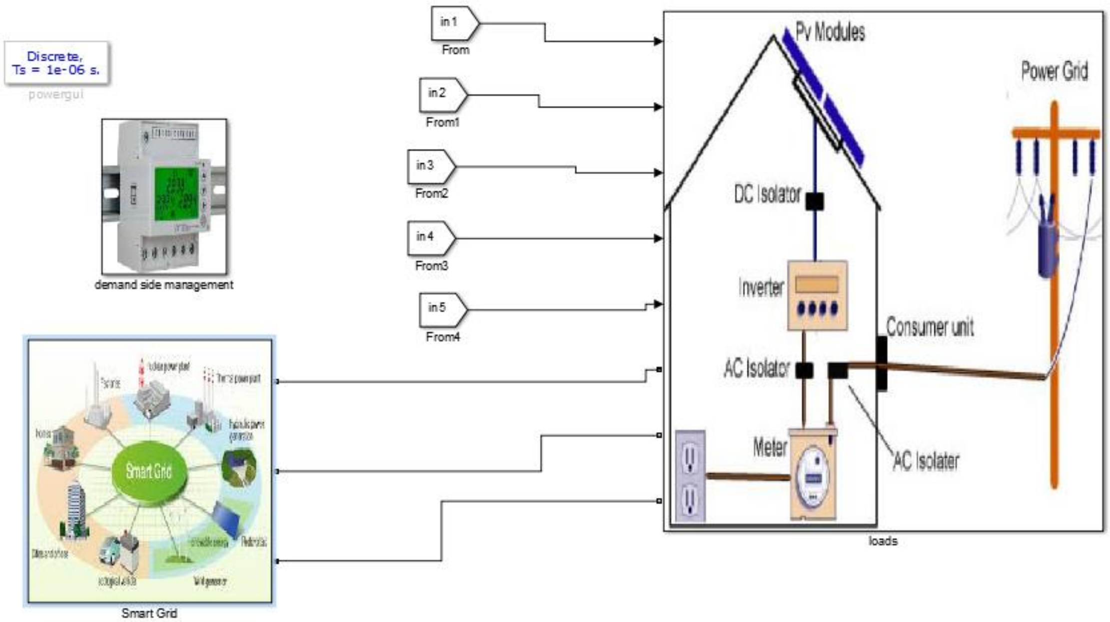

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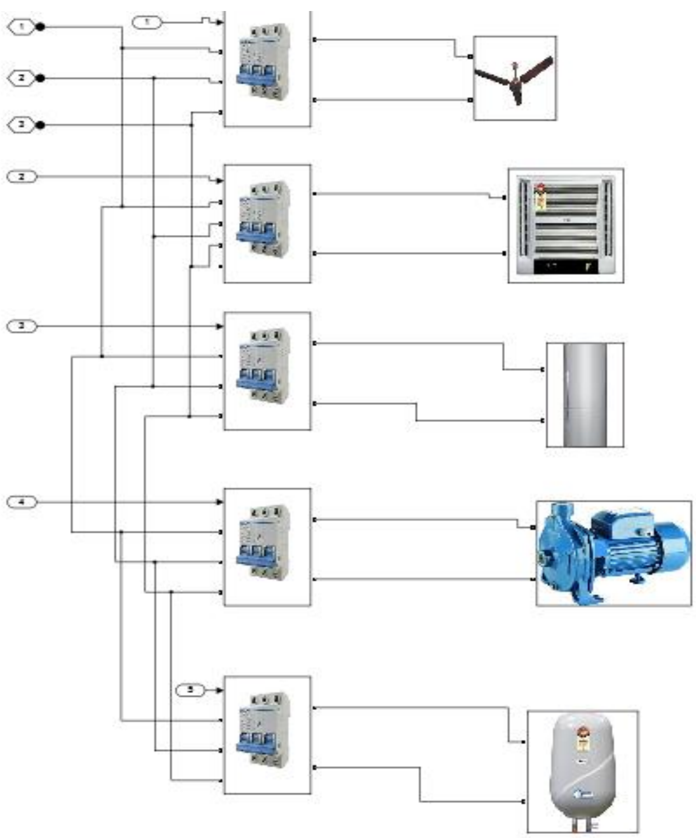

Here we connected the basic home loads

CONCLUSIONS

This paper presented the formulation and its solution to both generation scheduling and ED for CHP and heat only unit in the on-grid mode of a microgrid. The ED problem was investigated intensively by the Lagrange function and its complete solution procedure was provided in this paper.Also the proposed model can be analysed that how microgrid EMS is helpful in reducing the power consumption by the means of smart home monitoring control.

REFERNCES

[1] N. Hatziargyriou, H. Asano, R. Iravani and C. Marnay, "Microgrids," *IEEE Power Energy Mag.*, 2007, vol. 5, no. 4, pp. 78-94, Jul. 2007.
[2] C. A. Hernandez-Aramburo, T. C. Green and N. Mugniot, "Fuel consumption minimization of a microgrid," *IEEE Trans. Ind. Appl*., vol. 41, no. 3, pp. 673-681, May. 2005.
[3] A. K. Basu, A. Bhattacharya, S. Chowdhury, S. P. Chowdhury, "Planned scheduling for economic power sharing in a CHP-based microgrid," *IEEE Trans. Power Syst*., vol. 27, no. 1, pp. 30-38, Feb. 2012.
[4] T. Kerr. (2009) Cogeneration and district energy. International Energy Agency, Paris, France.
[5] M. T. Hagan and S. M. Behr, "The time series approach to short term load forecasting," *IEEE Trans. Power Syst*., vol. 2, no. 3, pp. 785-791, Aug. 1987.
[6] G. Gross and F. D. Galiana, "Short-term load forecasting," *Proc. IEEE*, vol. 75, no. 12, pp. 1558-1573, Dec. 1987.
[7] D. Sáez, F. Ávila, D. Olivares, C. Cañizares and L. Marín, "Fuzzy prediction interval models for forecasting renewable resources and loads in microgrids," *IEEE Trans. Smart Grid*, vol. 6, no. 2, pp. 548-556, Mar. 2015.
[8] A. Khotanzad, E. Zhou and H. Elragal, "A neuro-fuzzy approach to Short-term load forecasting in a price-sensitive environment," *IEEE Trans. Power Syst*., vol. 17, no. 4, pp. 1273-1282, Nov. 2002.
[9] L. Hernandez, C. Baladron, J. M. Aguiar, B. Carro, A. J. Sanchez-Esguevillas, J. Lloret and J. Massana, "A survey on electric power demand forecasting: future trends in smart grids, microgrids and smart buildings," *Commun. Surveys Tuts*., vol. 16, no. 3, pp. 1460-1495, Sep. 2014.
[10] A. Likas, N. Vlassis and J. J. Verbeek, "The global *k*-means clustering algorithm," *Pattern Recognition*, vol. 36, no. 2, pp. 451-461, Feb. 2003.
[11] R. Xu and D. Wunsch, "Survery of clustering algorithm," *IEEE Trans. Neural Netw*., vol. 16, no. 3, pp. 645-678, May. 2005.
[12] Y. Fu, M. Shahidehpour and Z. Li, "Security-constrained unit commitment with AC constraints," *IEEE Trans Power Syst*., vol. 20, no. 2, pp .1538-1550, May. 2005.
[13] N. Zendelhdel, A. Karimpour, M. Oloomi, "Optimal unit commitment using equivalent linear minimum up and down time constraints," presented at IEEE 2nd International Power and Energy Conference (PECON), Johor Bahru, Malaysia, Dec. 1-3, 2008.
[14] D. E. Olivares, C. Cañizares and M. Kazerani, "A centralized energy management system for isolated microgrids," *IEEE Trans. Smart Grid*, vol. 5, no. 4, pp. 1864-1875, July. 2014.
[15] M. Marzband, N. Parhizi and J. Adabi, "Optimal energy management for stand-alone microgrids based on multi-period imperialist competition algorithm considering uncertainties: Experimental validation," *Int. Trans. Electr. Energ. Syst*., Oct. 2015.
[16] S. Y. Derakhshandeh, M. A. S. Masoum and M. E. H. Golshan, "Unit commitment in industrial microgrids with plug-in electric vehicles and photovoltaic generation," *Int. Trans. Electr. Energy. Syst*., vol. 25, 2015.
[17] T. Guo, M. I. Henwood and M. Van Ooijen, "An algorithm for combined heat and power economic dispatch," *IEEE Trans Power Syst*., 1996, vol. 11, no. 4, pp. 1778-1784, Nov. 1996.
[18] Y. C. Wu, M. J. Chen, J. Y. Lin, W. S. Shen and W. I. Huang, "Corrective economic dispatch in a microgrid," *Int. J. Numer. Model*, vol. 26, no. 2, pp. 140-150, Mar. 2013.
[19] W. Shi, X. Xie, C. C. Chu and R. Gadh, "Distributed optimal energy management in microgrids," *IEEE Trans. Smart Grid*, vol. 6, no. 3, pp. 1137-1146, May. 2015.

NOMENCLATURE

Delec, Electrical load during period *t*

Dheat, Heat load during period *t*

URi Ramp-up and start-up rate limit of DER *i*

DRi Ramp-down and shut-down rate limit of DER *i*

Pit Electrical Power output of DER *i* at period *t*

Hit Heat output of DER *i* at period *t*

Costi,t Linearized fuel cost in block *b* of DER *i* at period *t*

Costit Fuel cost of DER *i* at period *t*

UCi Startup cost of DER *i* at period