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Optimal Participation of the Renewable Energy in Microgrids with Load Management Strategy

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***Abstract* – In this paper, bi-level optimization model is proposed for optimal energy trading between microgrids (MGs) and distribution companies (Discos) with consideration of the renewable energies. The first level modelling is maximizing MGs' profit and the second level is related to maximization of the Discos profit. In proposed system, power trading between MGs and Discos is considered. As well, renewable energies and demand management strategy are modelled in system for optimal energy consumption. The optimization modelling is solved by Particle Swarm Optimization (PSO), and results of the two case studies show optimal solution of prosed strategy in energy optimization.**

***Keywords* – Bi-level; demand management strategy; energy consumption; energy optimization; renewable energies.**

Nomenclature		
j	Microgrid index	–
k	Distributed Generations (DGs) index	–
i	Demand index	–
C^j_{DG}	Expense of the DGs generation	\$/kW
C^j_{IL}	Cost of Curtailable demand	\$/kW
E	Elasticity Matrix	%
P_D	Demand power	kW
P_{DG}	Power generation by DG	kW
P_{Buy}, P_{Sell}	Bought and sold power from energy market	kW

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ρ^{m}	Energy price in market	\$/kW
P^{T}	Power exchange between distribution companies and microgrids	kW
P^{wind}	Power generated by wind power	kW
P_{IL}	Amount of curtailed load	kW
η^{D^B}	Percent of load committed in DR	%
ρ_D^j	Power price for DISCO and MG	\$/kW

1. INTRODUCTION

The legacy distribution systems are being evolved as smart systems by incorporating innovative technologies, products, services and functionality. One of the important cost effective technologies under the provision of smart grid is demand response (DR) [1]–[3]. The distributed generations (DGs) and DR strategies focus on changing the consumption pattern of customers to reduce the stress on utility assets [4]. In conventional grid, power transfer takes place through unidirectional power lines and real-time communication is missing between the utility system and the customers. Decrease in fossil fuels, rapidly changing weather condition, power outage and increase in demand of energy are some re straining issues of conventional grids [5].

With the growing energy demand, by introducing new generation units, the total installed capacity can be increased. But DR works not only to increase the energy to be supplied; rather it controls the load consumption by the customers or shifts energy uses from peak-demand hours to peak hours [6]. Thus, DR helps to improve efficiency of utility and to reduce the bill of electricity consumption of the customers [7]. In order to introduce DR program in a system, a clear knowledge of the daily load consumption pattern is required. In smart grid environment, installation of smart meters and smart appliances makes it easy to get that information, which is impossible to get through the use of electromechanical meters used in conventional grid [8].

A rapidly increase in population leads to increase in power generation. The increase in power generation emits pollution emission which is dangerous for environment [9]. To minimize the pollution emission generates during the power generation and distribution side, DR is introduced in the presence of renewable energy sources [10]. The main focus is on renewable generations in order to reduce operating cost and pollution emission, wind energy produces low emissions as compare to other renewable energy sources [11]. Renewable energy sources provide cheap and clean energy is compare to non-renewable energy sources [12]. In order to get balance power at user end, the coordination between demand and supply is necessary, smart grid provides bi-directional communication between supply and demand while implementing DR programs. The DR by consumers is used via changing in consumption pattern which leads to reduce operational cost [13]. The smart grid integrates renewable and non-renewable energy sources and provides demand on optimal conditions, which minimize the power purchased from the utility grid, loss of power, and maximize reliability, these terms leads to minimize economic costs [14]–[18].

The studies are done on energy problems of microgrids (MGs) in approaches of economic modelling. The power generation cost reduction considering renewable energy sources and energy storage systems using artificial swarm intelligence technique is presented in [19]. The smart grid day ahead optimized scheduling in terms of loads uncertainty, electric vehicles (EVs) and RGs is studied to minimize cost of operation using bender decomposition

algorithms [20]. The smart grids optimization problem is considered as single objective function to reduce operating cost and pollution emission without using the concept of DR [21]. The optimal energy generation by distribution companies (Discos) based on day ahead scheduling problem is studied in [22] to optimize operational cost, in which concept of load shifting and clipping used. A multi objective genetic algorithm in [23] is proposed for multi objective optimization in MG considering demand response programs. Operating cost and pollution emission is minimized using renewable energy sources [24].

In this paper proposed, optimal operation of MG in distribution system containing MGs, DGs and DR program. The innovations of the paper based on literature reviews can be listed as follows:

1. In this paper bi-level optimization is modelled for optimal operation of the MG in a distribution electrical network to maximization of MGs and Disco profits;
2. The DR is proposed for consumers for covering uncertainty of power generation by renewable energies;
3. The Particle Swarm Optimization (PSO) algorithm is used for solving bi-level optimization modeling;
4. The DR leads to reduce generation costs by DGs and Disco and maximizing power generation by renewable energy.

2. SYSTEM MODELLING

In Fig. 1, system modelling of the proposed approach is shown. In this figure, as mentioned before, bi-level optimization is modelled based on maximization profit of Disco and MGs owner [25], [26]. The modelling bi-level optimization is as follow in Fig. 1.

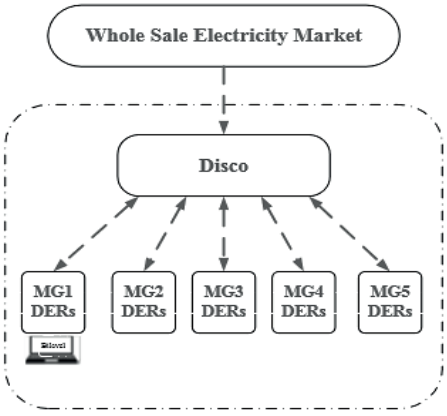


Fig. 1. schematic of proposed system.

2.1. First Level Optimization

First level optimization is maximizing MG profit. The first level modelling is as follow:

$$\text{Maximize} \sum_{t=1}^{Nt} (\rho_t^{\text{sell}} P_t^{\text{sell}} - \rho_t^{\text{buy}} P_t^{\text{buy}} - \sum_{i=1}^{N_{\text{DG}}} C_{\text{DG}}^{i} P_{\text{DG}}^{i.t} - \sum_{k=1}^{N_{\text{Load}}} C_{\text{IL}}^{k.t} P_{\text{IL}}^{k.t} - \sum_{k=1}^{N_{\text{Load}}} VOLL^{k.t} P_{\text{LS}}^{k.t}, \quad (1)$$

subject to:

$$P_t^{\text{sell}} \le P_{\max}^{\text{sell}}; P_t^{\text{buy}} \le P_{\max}^{\text{buy}}, \tag{2}$$

$$P_{\text{DG}\min}^{i} \le P_{\text{DG}}^{i} \le P_{\text{DG}\max}^{i}, \tag{3}$$

$$0 \le P_{\text{IL}}^{k} \le P_{\text{IL}\max}^{k}, \tag{4}$$

$$P_{\text{IL}}^{k.t} + P_{\text{LS}}^{k.t} \le P_{\text{d}}^{k.t}, \tag{5}$$

$$\sum_{k=1}^{N_{\text{Load}}} (P_{\text{d}}^{k.t} - P_{\text{IL}}^{k.t} - P_{\text{LS}}^{k.t}) = P_{\text{D}}^{t}, \tag{6}$$

$$\sum_{i=1}^{N_{\text{DG}}} P_{\text{DG}}^{\text{i.t}} + \sum_{k=1}^{N_{\text{Load}}} (P_{\text{IL}}^{k.t} + P_{\text{LS}}^{k.t}) + P_t^{\text{buy}} + P_t^{\text{wind}} = P_{\text{D}}^{t} + P_t^{\text{sell}}, \tag{7}$$

where Eq. (1) and (2) are objective function in first level optimization and power trading between Disco and MG, respectively. Eq. (3) and (4) are limit of the DGs powers and curtailed load bound, respectively. Eq. (5) shows that curtailed load and load shedding are less than demand. Eq. (6) and (7) are limit of the power flow in MGs and power balance in MGs [27]–[30], respectively.

2.2. Second Level Optimization

The maximizing profit for Disco is second level optimization. The objective function of the second level is as follow [31]–[34], Eq. (8):

$$\text{Maximize} \sum_{t=1}^{Nt} \left(\sum_j \rho_t^{\text{buy}.j} P_t^{\text{buy}.j} - \rho_t^{\text{sell}.j} P_t^{\text{sell}.j} - \rho^{\text{M}.t} P^{\text{M}.t} \right), \tag{8}$$

subject to:

$$0 \le \rho_D^{\text{sell}.j} \le \rho_{\max}^{\text{sell}}; 0 \le \rho_{\text{D}}^{\text{buy}.j} \le \rho_{\max}^{\text{buy}} \forall j, \tag{9}$$

$$| P^{\text{M}.t} | \le P_{\max}^{\text{T}_{up}}, \tag{10}$$

$$\sum_j P_t^{\text{sell}.j} - P_t^{\text{buy}.j} = P^{\text{M}.t}, \tag{11}$$

where Eq. (9) and (10) are limit of the power bought and sold to MGs and limit of the power exchange between Disco and MGs, respectively, and Eq. (11) is the limit of the wholesale market power.

3. DR MODELLING

DR programs are divided to two major sectors as incentive based DR (IBDR) and Time Based DR (TBDR) [35]. From technical point of view, IBDR are suitable to cover wind uncertainty while time based programs are well suited for wind variability. In other word when actual wind speed is less than forecasted, load curtailment guarantees load balance, and to adapt wind variability with load variability, time based programs can be applied to manage shift able load. The main part of this coordination is to allocate enough load curtailment

contracts to avoid high cost load management. Also time based programs has very low cost as the load follows the applied prices. Finally, price design for TBDR has been done based on wind variability, and load curtailment amount has been determined by uncertainty level. TBDR can be constructed based on forecasted wind speed and in the hours with high forecasted wind speed in which low TBDR needed, more IBDR contracts should be provided because of high wind speed uncertainty. Note that IBDR modeled has been included in Eq. (1), and TBDR has been modeled by elasticity model as [3], [35]–[37], Eq. (12).

$$D_{\mathrm{DR}}^{\mathrm{B}}(t)=\eta^{\mathrm{D}}\left\{1+E(t,t)\cdot\ln\left(\frac{\rho_{\mathrm{DR}}^{j}-\rho_{\mathrm{D}}^{j}}{\rho_{\mathrm{D}}^{j}}\right)+\sum_{\substack{j=1\\ j\neq t}}^{24}E(t,j)\cdot\ln\left(\frac{\rho_{\mathrm{DR}}^{j}-\rho_{\mathrm{D}}^{j}}{\rho_{\mathrm{D}}^{\mathrm{j}}}\right)\right\} \tag{12}$$

4. WIND TURBINE MODELLING

The power generation by wind turbine is deepened on wind speed, height, nominal power, cut-in, and cut-out of wind speed. The wind turbine modelling is as follow [38], [39], Eq. (13).

$$P_{\mathrm{WT}}^{t}=\begin{cases}0 & V_{\mathrm{W}}^{t}\le V_{\mathrm{c}}\\ p_{\mathrm{r}}\left(\dfrac{V_{\mathrm{W}}^{t}-V_{\mathrm{c}}}{V_{\mathrm{r}}-V_{\mathrm{c}}}\right) & V_{\mathrm{c}}\le V_{\mathrm{W}}^{t}\le V_{\mathrm{r}}\\ p_{\mathrm{r}} & V_{\mathrm{r}}\le V_{\mathrm{W}}^{t}\le V_{\mathrm{c0}}\\ 0 & V_{\mathrm{W}}^{t}\ge V_{\mathrm{c0}}\end{cases} \tag{13}$$

5. OPTIMIZATION SOLUTION

There are many process for solving the bi-level problems [40]. In bi-level optimization, the first level decision variables are parameters in the second level. Hence, proposed bi-level modelling can be solved by heuristics methods subject to system constraints. In this paper, proposed approach is solved by PSO based on each iteration and decision variables. The PSO modelling is described in [5], [41]–[45].

6. RESULTS AND DISCUSSION

The proposed problem is studied on a studied distribution system consists of 4 MGs. The data of DGs units are shown in Table 1 [46]–[50].

Ten percent of each demand point is considered as curtailable. The upper bound of price for the power trade between each MGs and DISCO is 50 $/MWh. The numerical simulation is done in day-ahead by *MATLAB* software in PC desktop with CPU 3.33 GHz Intel™ and 6 GB RAM.

The three case studies are considered for validation of the proposed approach:

- Case 1: Optimization of the energy without power exchange between Disco and MGs.
- Case 2: Optimization of the energy with power exchange between Disco and MGs.
- Case 3: Optimization of the energy with power exchange between Disco and MGs with covering wind energy uncertainty by DR.

TABLE 1. LOCATION, MINIMUM, MAXIMUM AND GENERATION COST OF CONSIDERED DG UNITS

MG, j	$P^j_{DG,min}$, MW	$P^j_{DG,max}$, MW	C^j_{DG}, \$/MWh
1	0	4	37
2	0	5	40
3	0	5.5	35
4	0	7	45

Wind units in each MGs generation pattern are as Fig. 2, and hourly load is presented in Fig. 3 for each MGs [51]–[54]. It should be mentioned that, wind speed is simulated by Monte Carlo method for power generation by wind turbine [4], [55]–[58]. The MG1 and MG2 are residential, MG3 and MG4 are commercial and industrial grid with more load demand.

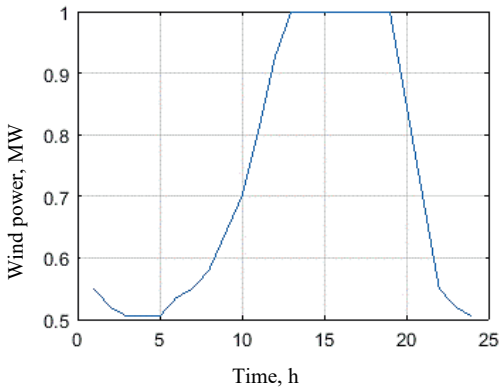


Fig. 2. Power generation by wind turbine.

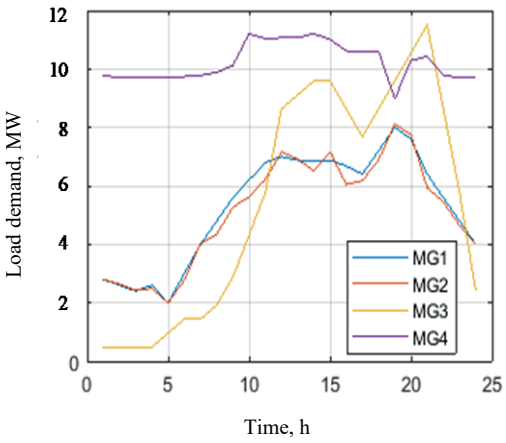


Fig. 3. Load demand in MGs.

Case 1. In this case power exchange between Disco and MGs are not considered. Also, MGs and Disco have not any role in buying and selling than each other. In this case power generation by wind turbine is not considered and power shortage from wind in each MG should be generated by Disco to meet demand in each MG. The off-peak demand price in

wholesale market is 30 $/MW for hours 1, 2, 3, 4, 5, 6, 24 and peak demand price is 40 $/MW for hours 7, 8, 9, 10, 11, 12, 13, 14, 22 and 23.

In Table 2, results of the Case 1 are listed. As shown, due to lack of power exchange between Disco and MGs, profit of them in low energy price are increased. Also, MG 4 due to high demand in this MG than other MGs have maximum profit. On the other hand, Disco in low price has maximum profit than other price in wholesale market. As shown, increasing demand has direct effect on cost of consumers in peak hours.

TABLE 2. PROFIT OF DISCO AND COST OF EACH MG IN CASE 1

Market price, $/MWh	Disco Profit, $	MG1 Cost, $	MG2 Cost, $	MG3 Cost, $	MG4 Cost, $
34	72	189	201	214	222.0
35	60	189	201	214	222.0
36	48	189	200.5	214	221.5
37	38.8	191.7	199.8	214.8	246.2
38	33.95	191.7	199.8	214.8	246.2
40	24.25	191.7	199.8	214.8	246.2
41	19.4	191.7	199.8	214.8	246.2
44	4.85	191.7	199.8	214.8	246.2
45	0	191.7	199.8	214.8	246.2
46	0	191.7	199.8	214.8	246.2

Case 2. In this case exchanging powers between MGs and Disco are considered. It's visible, profit of the MGs should be reduced, due to meet demand by Disco in low energy price. Also, power generation by Disco at low energy price is reduced. The results of the Case 2 are presented in Table 3.

TABLE 3. PROFIT OF DISCO AND COST OF EACH MG IN CASE 2

Market Price, $/MWh	DISCO Profit, $	MG1 Cost, $	MG2 Cost, $	MG3 Cost, $	MG4 Cost, $
34	62	188	200	212.5	222.0
35	55	188	200	212.5	220.0
36	45	188	200	212.5	220.0
37	34.4	191	198	212.6	246.3
38	39.55	191	198	212.6	246.3
40	20.85	191	198	212.6	245.3
41	18	191	198	212.6	245.3
44	0.45	191	198	212.6	245.3
45	0	191	198	212.6	245.3
46	0	191	198	212.6	245.3

The results in Table 3 show, profit of Disco is less than in Case 1, due to exchanging power and energy transactions between MGs. In this case, extra power in MGs in low energy price

is transferred to MGs with shortage power. Hence, this strategy leads to reduce costs in energy system.

Case 3. In this case, DR is used for covering uncertainty of the wind energy. As expected, power generation by wind turbine leads to reduced energy generation by Disco and DERs in MG, due to low energy price of wind energy. Also, DR has provided optimal level of the demand side for generation in MG, to meet demand with low energy cost. The results of the Case 3 are presented in Table 4.

TABLE 4. PROFIT OF DISCO AND COST OF EACH MG IN CASE 3

Market Price, $/MWh	DISCO Profit, $	MG1 Cost, $	MG2 Cost, $	MG3 Cost, $	MG4 Cost, $
34	62	188	200	212.5	220.0
35	55	188	200	212.5	220.0
36	45	188	200	212.5	220.0
37	34.4	191	198	212.6	245.3
38	29.55	191	198	212.6	245.3
40	19.85	191	198	212.6	245.3
41	15	191	198	212.6	245.3
44	0.45	191	198	212.6	245.3
45	0	191	198	212.6	245.3
46	0	191	198	212.6	245.3

7. CONCLUSION

In this paper bi-level optimization problem is used to modelling optimal operation of MGs to optimal energy exchanging and trading between Disco and MGs. The DR and renewable energies are used to meet demand in MGs with low operation cost and high reliability. The PSO method is employed to energy optimization for proposed modelling. The DR is used for covering wind power uncertainty and demand control in MGs. The three case studies are considered for validation of the proposed approach. The simulation results demonstrate that the current approach optimally allocates load and generation pattern for a day and significantly reduces peak load demand, costs, as a result, the electricity cost of generation reduces. The cost of electricity generation, further reduces in presence of wind energy source. The results also highlight that better optimized load profile can be extracted at higher participation level of DR. At the same time, all the participants of a day ahead electricity market draw economic profit due to optimized pattern of load and generation.

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