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Optimal Bidding Strategy of Microgrid with Uncertainty of RES in Day Ahead Electricity Market

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Abstract*: Microgrid is the most efficient way of integrating renewable generating sources in the low voltage network. This paper proposes a mathematical model for bidding power in low voltage grid connected microgrid system in an electricity market having pump storage plant. The optimization problem has been modeled and simulated using the CONOPT solver in GAMS environment interfaced with MATLAB. The storage units have been used to counter the impact due to uncertainty of the solar power and the load demand. The optimal bidding prices have been obtained for various renewable generating units in case of over and under production situations. Penalty factors have been imposed to manage the power imbalance which also helps in overall reduction of the operational cost. Pumped storage unit has been taken to obtain optimal bidding and minimized operational cost of the system.

***Keywords* : Microgrid, day-ahead electricity market, bidding, uncertain renewable energy sources.**

I. INTRODUCTION

Increasing power demand globally initiates the radical changes in the power system to satisfy the energy balance. The increase of power generation from conventional generators globally raised environmental issues. In modern power system the microgrid concept is introduced to overcome the various issues with the conventional power systems and their limited availability. The microgrid is consisting of small scale generating units distributed generators (DGs) located within a particular boundary close to the consumers. It helps in reducing the transmission losses and the network congestion problem associated with transmission system due to limited power carrying capacity. The intermittent and uncertain power output of the renewable energy sources present in the system can adversely affect the quality and reliability of power available, if operated without forecast schedules and proper backups/storages [1]. These issues become more prominent with the increased penetration of DGs in modern power systems and need to be addressed. The intermittent nature of renewable energy sources can be improved using storage devices. Microgrids (MGs) can be operated as single controllable small scale power system with ability bidirectional power exchange from the grid to microgrid or vice- versa, whenever there is shortage and surplus of power respectively. They can also provide the heat power (thermal) optionally depending upon the use of combined heat power generators.

MGs have huge application to supply power to low voltage level loads which includes schools, college campuses, offices, hospitals, hotels, sports complexes, commercial and residential complexes and remote areas etc. depending upon their limited capacity [2]. Increasing use of environment friendly DGs can improve the carbon emissions problem and concerns of power quality, reliability, congestion at optimal operating cost [3].

Despite of many benefits of the microgrid system the integration of microgrid with conventional distribution system practically has many challenging issues like optimal energy management, coordination strategy, design, protection, congestion and many more which have to be investigated in detail. The system operator of the microgrid system plays an important role in deciding the components, design and the operating rules for the microgrid and manages the dynamic demands of the consumers of its local grid.

Microgrid comprises of many renewable energy sources which provide variable or uncertain power output, reliability and the market prices are not considered to a large extent. These uncertainties in the renewable energy sources are the main hindrance in the penetration of these systems into the conventional system. The probabilistic energy management strategies were proposed under uncertainty environment in [4-7]. The uncertainty nature of the RES must not be neglected because it must affect the profitability of the microgrid system under the modern electricity market. The study of the microgrid system considering the uncertainty in the various renewable energy sources by many researchers.

Numbers of investigations have been done in the field of power coordination strategy of distributed generation sources [8-11], optimal energy management strategy [12-14], protection design [15-17], stability assessment [18-20], optimal sizing and placement [21-22] and many more.

Out of these issues interaction between utility grid and the microgrid is of prime concern, to increase the penetration of the distributed energy sources or microgrid in near future which are need of the hour.

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Number of studies has been carried out to find the role, contribution of the MGs into the deregulated electricity market for cost minimization, reliable optimal operation of the grid connected microgrid system and the impact of MGs to minimize the operating cost by many researchers and discussed widely in literature [3, 23-25].

These all researches and practically implemented system improve the effectiveness of microgrid operation with the utility grid at the optimal cost of operation.

In this present work a pump storage plant has been considered in addition to other generating sources to reduce the variability and maximizing the profit of the microgrid in the day-ahead market. The CONOPT solver in GAMS has been used to solve the optimization problem the interfacing with MATLAB.

The main contributions are as follows:

1. Mathematical modeling for the bidding strategy of grid connected microgrid containing solar, boiler, diesel combined heat and power, pump storage plants in day-ahead electricity market for dynamic load demand and uncertain renewable power of solar and wind power plants.
2. The effect of pump storage plant on the reduction of operational cost of the microgrid in the electricity market scenario.
3. Economic dispatch of the microgrid imposing penalties on combined solar and wind renewable power producers for combined power imbalances (over production and under production) refer to forecasted power.

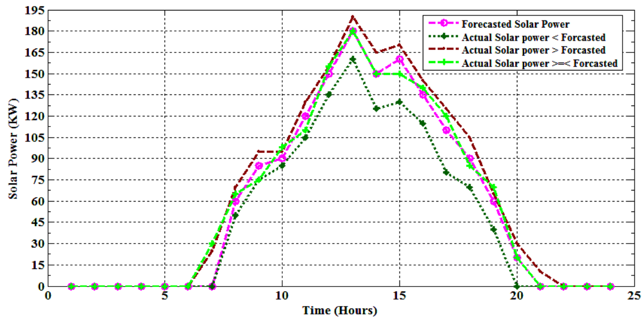
In the present work mathematical model for deciding optimal bidding is developed for microgrid working under uncertainty of the solar and wind power plants in a day-ahead energy market. The main focus is on the dynamic economic dispatch of the microgrid system under observation which includes conventional (diesel), combined heat and power, boiler unit, solar, wind and pump storage power plants. Thermal and electrical loads are considered dynamic in this present work. The dynamic thermal load demand of the microgrid is fully satisfied from thermal power produced by combined heat and power generators and the independent boiler. The dynamic electrical load is satisfied by the generation from the conventional diesel, combined heat and power, solar, wind, pump storage power and power exchange from the grid respectively. Surplus or deficit power if any can be sold or purchased to or from grid respectively to maintain the power balance.

The solar unit (RES) produces uncertain power and plays an important role in profit making. Profit/ loss can be maximize/ minimize through the reliable predictions for combined solar and wind power bids.

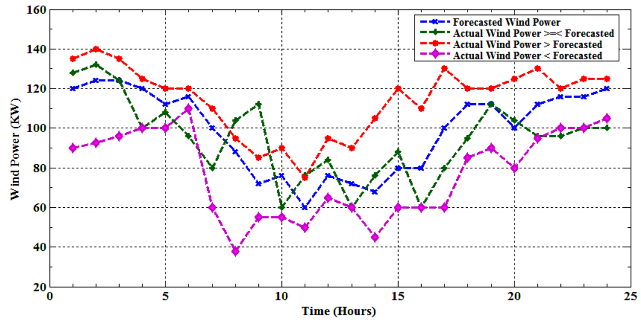
The effect of predictions on the profit is analyzed by considering three different cases (i) when solar power generation is always more than the forecasted power (ii) when solar power generation is always less than the forecasted power (iii) when solar power generation is equal, more and less than the forecasted power. The expected variations of solar power generations are as shown in Fig. 1.

In the problem we assume that system operator of MG formulate optimal bidding strategy on hourly bases one day prior to actual scheduling day from known minimum and maximum energy prices, solar forecasted power and load demand profiles for a day- ahead electricity market. The power exchange limits between microgrid and utility grid are also set by the system operator. Each electricity market has its own rules of operation. Based on the existing rules of the energy market and bid offers by power producers the relationship between the price and the quantity are as shown in Fig. 2 [26]. For higher power demands price of unit power is lower as compared to the lower power demand to encourage microgrid system to operate in such a way that it always tries to purchase and a sell power to operate economically to maximize the microgrid profit and minimize cost of operation.

The paper is organized as: section II explains the modeling of the microgrid system having conventional, combined heat and power, Boiler, solar, pump storage plant for stabilize the uncertainty of solar renewable energy resource including power trading between the grid and microgrid. Section III elaborates the methodological procedure applied for the simulations. Section IV presents the data, results and discussions. At last conclusions are presented in section V.



(a) Solar Power variations



(b) Wind Power variations

Fig. 1. Forecasted and Actual power variations of renewable power sources for three cases.

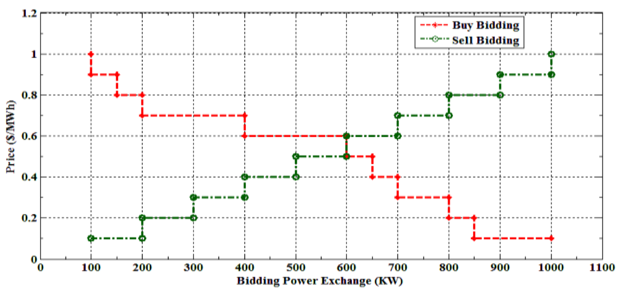


Fig. 2. Price bidding strategy of microgrid for buying (red) and selling electricity (green).

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II. SYSTEM DESCRIPTION

In modern power system the renewable energy resources are being promoted globally to meet the increased load demand and to reduce the carbon emission through sustainable eco-friendly solutions. The renewable energy sources perform better when operated in conjunction with any other DGs as it helps in alleviating their problem of uncertainty. Microgrid operating in electricity market needs to sell and purchase power according to the demand supply function of the market. Microgrid can play an important role in providing ancillary support to the power system through technological enhancements in protection, design and control system. It is also capable of providing the necessary support to the existing power system whenever main grid is under stress.

A. Modeling of microgrid system for bidding strategy in Day- ahead electricity market

Microgrid system in the paper consists of conventional (Diesel) plant, solar plant, wind plant, combined heat and power plant (CHP), boiler plant and pump storage plant. The solar and wind RESs are intermittent in nature as their outputs cannot be controlled and predicted accurately due to their dependency on environmental conditions. The power outputs of the solar and wind plants depend upon some factors which are given by (1) and (2) respectively.

$$P_{st} = \eta_{st} A_{Cst} I_{Rst} \qquad (1)$$

Where, η_{st}, P_{st}, A_{Cst} and I_{Rst} are the efficiency of the solar arrays, hourly solar power output, area of the solar arrays and solar hourly irradiations (WH/m^2) respectively.

$$P_{wd} = 0.5\, \eta_{wd} \rho_{ad} C_{wt} A_s V_s^3 \qquad (2)$$

Where, η_{wd}, P_{wd}, C_{wt}, ρ_{ad}, A_s and V_s are the efficiency of the wind generator, hourly wind power output, power coefficient of the wind turbine, air density, swept area of the wind rotor and wind speed respectively [27].

Two diesel generators are operated in combination with four combined heat power generators, one boiler unit, one pump storage plant, solar and wind plants. The fuel cost function for power generation from diesel generator for i^{th} generator at t^{th} time interval can be modeled as the quadratic function of the power generate by i^{th}generator at t^{th} time interval and is expressed as given by (3).

$$C_{Pgd}(i,t) = a_i\, P_{gd}^2(i,t) + b_i\, P_{gd}(i,t) + c_i \qquad (3)$$

Where, $C_{Pgd}(i,t)$ is the fuel cost of i^{th} generator at t^{th} time interval, a_i, b_i, c_i are the fuel coefficients for i^{th} diesel generator and $P_{gd}(i,t)$ is the power output for i^{th} diesel generator at t^{th} time interval.

The fuel cost function for power generation from combined heat and power for j^{th} generator at t^{th} time interval can be modeled as the quadratic function of the power generated in j^{th}generator at t^{th} time interval from the CHP generator which is expressed in (4).

$$C_{Pgc}(j,t) = a_j\, P_{gc}^2(j,t) + b_j\, P_{gc}(j,t) + c_j \qquad (4)$$

Where, $C_{Pgc}(j,t)$ is the fuel cost of j^{th} CHP generator at t^{th} time interval, a_j , b_j, c_j are the fuel coefficients of j^{th} CHP generator and $P_{gc}(j,t)$ is the power output of j^{th} CHP generator at t^{th} time interval.

The fuel cost function for thermal power generation from boiler for k^{th} boiler unit at t^{th} time interval can be modeled as function of the power generated in k^{th} boiler unit at t^{th} time interval from the boiler unit is expressed in (5).

$$C_{Pgb}(k,t) = b_k\, P_{gb}(k,t) \qquad (5)$$

Where, $C_{Pgb}(k, t)$ is the fuel cost of k^{th} boiler unit at t^{th} time interval, b_k fuel coefficient for k^{th} boiler unit and $P_{gb}(k,t)$ is the power output for k^{th} boiler unit at t^{th} time interval.

B. Pump storage modeling

Pump storage plant can be used in the microgrid system to overcome the intermittent nature of renewable energy source solar plant. When microgrid power generated is higher than the microgrid total load demand, it uses the power for pumping the water into the reservoir for its usage when there is power deficit. It stores different energy at different time intervals. The stored energy at any time t depends upon its previous state and power requirement of the system can be expressed/ modeled as:

$$E_{PS}(t)=E_{PS}(t\text{-}1)+E_{PSpumping}(t)\text{-}E_{PSgeneration}(t) \qquad (6)$$

$E_{PSpumping}(t)$ and $E_{PSgeneration}(t)$ are the energy stored in pump storage plant by pumping additional water to the reservoir and is the energy released / generated by pump storage plant generators during time interval 't' respectively. The energy can be calculated as given by (7) and (8).

$$E_{PSpumping}(t)=\eta_{pm}\ E_{CP}(t) \qquad (7)$$

$$E_{PSgeneration}(t)=\eta_{gn}\ E_{RG}(t) \qquad (8)$$

Where, η_{pm} is the efficiency of the pumping motor, η_{pm} is the efficiency of the pump storage generators. $E_{CP}(t)$ is the energy consumed by the pumped motor and $E_{RG}(t)$ is the energy generated by the pump storage generators during any time 't'. The minimum and maximum capacity of energy generation depends upon the water tank capacity. The minimum and maximum level for discharging and filling are limited. $E_{CP}(t)$ and $E_{RG}(t)$ are bounded in minimum and maximum limits [28-29].

C. Power exchange modeling

Microgrids generally have different generating plants out of them some are fully controllable and some are not controllable fully. The power generation from the diesel generators is fully controllable whereas solar and wind power are not predictable and fully controllable. To meet out the dynamic demand of the consumers at minimum operating cost microgrid operators must sell/buy the surplus/deficit power to/from the utility grid. These variations are there due to the dynamic and intermittent nature of the load and RESs (solar and wind) power respectively. The costs of power generations are different for different types of generation units. To optimal utilization of the sources to minimize the operating cost, power exchange between the grid and microgrid become the most important part of the modern power system as it mitigate some important issues.

Normally, during peak and off peak hours of grid connected microgrid system power exchange between grid and microgrid and vice- versa takes respectively. Whenever electrical power demand rises beyond the generation capacity of the microgrid then the deficit power is purchased by the microgrid operator from the utility grid which increases the operating cost of microgrid system. Surplus power sold to grid reduces the operating cost of the microgrid. Power exchange is denoted by $P_{exchange}$. Gamma is the trading price for trading between the grid and microgrid. The cost of power exchange through trading between grid and microgrid mathematically modeled as given below:

$$C_{Pexchange}(t) = P_{r\ down} * gamma(t) * P_{exchange}(t)$$
$$= 0$$
$$= - P_{r\ up} * \text{gamma}(t) * P_{exchange} \tag{9}$$

Where, $gamma$, $P_{exchange}$, $P_{r\ up}$ and $P_{r\ down}$ are the cost ($/MWh) of power exchange, power exchange between grid and microgrid, price penalties for selling and buying power respectively for the microgrid [30-32].

D. Power imbalance modeling

Intermittent RESs solar and wind plants used in the Microgrid system are the actual source of power variation in the total power generation. These variations in power may lead to the mismatch and thereby affect the power bidding of the microgrid in the electricity market and may result in changes in the net operating cost of the system.

Many countries impose penalties for over production and under production of renewable. These penalties can be modeled as a function of the difference in the forecasted and actual power production. Higher penalties are forced for under production as compared to the over production. This extra operating cost encourages the bidders to bid more accurately to avoid the financial loss. The cost of power imbalance is mathematically modeled as defined in (10).

$$C_{Pimbalance}(t) = P_{penality}(t) * gamma(t) * P_{imbalance}(t) \tag{10}$$

The penalties enforced under power imbalances are as given below:

$$P_{penality}(t) = P_{down} * P_{imbalance}(t)$$
$$= 0$$
$$= P_{up} * P_{imbalance}(t) \tag{11}$$

Where, P_{pdown} and P_{pup} are assumed to be the function of power imbalance.

III. PROBLEM FORMULATION

The operation of the microgrid consists of the coordination between various stake holders such as conventional as well as renewable generating sources, load and participation of consumers in load balancing with storage systems. The mathematical modeling of grid connected microgrid done here consists of conventional diesel, combined heat and power, pump storage, boiler, wind and solar power generating plants along with the uncertainty of power generation from renewable power plants. Power exchange between the utility grid and microgrid has been modeled. The dynamic dispatch problem with optimal bidding strategy has been formulated. The mathematical formulation of total cost of operation can be represented by (12):

$$\min Tcost = \sum_t^T \left(\sum_i^I C_{Pgd}(i,t) + \sum_j^J C_{Pgc}(j,t) + kKCPgbk,t+CPexchange\ t+CPimbalancet \right. \tag{12}$$

Constraints

A. Electrical power balance constraints

The total electrical power generation from the different power plants of the microgrid must fulfill the internal power demand of the microgrid.

$$\sum_i^I P_{gd}(i,t) + \sum_j^J P_{gc}(j,t) + P_{exchange}(t) + P_{st}(t) + P_{wd}(t) + P_{gp}(t) = P_d^{electrical}(t) + P_{dp}(t) \tag{13}$$

Where, P_{gd} (i,t), P_{gc} (j,t), $P_{exchange}$ (t), P_{st} (t), P_{wd} (t), P_{gp} (t), $P_d^{electrical}$ (t) and P_{dp} (t) are the Power from i^{th} diesel generator, power generation from j^{th} combined heat and power generator, power exchange, power from solar unit, power from wind unit, power from pump storage unit, electrical power demand and power demand of pump storage unit at t^{th} time interval.

B. Thermal power balance constraints

$$\sum_j^J \frac{P_{gc}(j,t)}{\eta_j} + \sum_k^K P_{gb}(k,t) = P_d^{thermal}(t) \tag{14}$$

Where, $P_{gc}(j,t)$, $P_{gb}(k,t)$, $P_d^{thermal}(t)$ and η_j are the generations from j^{th} combined heat power plant at t^{th} time interval, generation from k^{th} boiler unit at t^{th} time interval, thermal load at t^{th} time interval and efficiency of the CHP unit respectively.

C. Real power generation inequality constraints

For the stable operation of the microgrid system generations from different plants must be within their specified generation and grid power exchange limit bounds which are as follows:

$$P_{gp}^{min}(t) \le P_{gp}(t) \le P_{gp}^{max}(t) \tag{15}$$
$$P_{gd}^{min}(i,t) \le P_{gd}(i,t) \le P_{gd}^{max}(i,t) \tag{16}$$
$$P_{gb}^{min}(k,t) \le P_{gb}(k,t) \le P_{gb}^{max}(k,t) \tag{17}$$
$$P_{gc}^{min}(j,t) \le P_{gc}(j,t) \le P_{gc}^{max}(j,t) \tag{18}$$
$$0 \le P_{st}(t) \le P_{st}^{max}(t) \tag{19}$$
$$0 \le P_{wd}(t) \le P_{wd}^{max}(t) \tag{20}$$
$$-P_{exchange}^{max}(t) \le P_{exchange}(t) \le P_{exchanged}^{max}(t) \tag{21}$$

D. Real power demand inequality constraints

For feasible operation of the microgrid system electrical as well as thermal load must be within the specified limit bounds as defined in (22)-(27) below:

$$P_d^{electrical\ min}(t) \le P_d^{electrical}(t) \le P_d^{electrical\ max}(t) \tag{22}$$
$$P_d^{thermal\ min}(t) \le P_d^{thermal}(t) \le P_d^{thermal\ max}(t) \tag{23}$$
$$E_{CP}^{min}(t) \le E_{CP}(t) \le E_{CP}^{max}(t) \tag{24}$$
$$E_{RG}^{min}(t) \le E_{RG}(t) \le E_{RG}^{max}(t) \tag{25}$$
$$E_{PSpumping}(t) = \eta_{pm}\ E_{CP}(t) \tag{26}$$
$$E_{PSgeneration}(t) = \eta_{gn}\ E_{RG}(t) \tag{27}$$

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The variables to be evaluated from the model developed are as follows:

$P_{exchange}(t)$, $C_{Pexchange}(t)$, $C_{Pimbalance}(t)$, $P_{st}(t)$, $P_{wd}(t)$, $P_{gd}(t)$, $P_{gc}(t)$, $P_{gb}(t)$, $P_{dp}(t)$, $P_{gp}(t)$, $C_{Pgd}(t)$ and $C_{gb}(t)$.

IV. RESULTS AND DISCUSSIONS

The grid connected microgrid system model is tested on test data of a sunny summer day as shown in Table I. The total electrical load of the system is aggregated load of sport complex, a hospital, a manufacturing plant, a super market, a hotel and several offices [24]. The minimum and maximum spot price variations for the system under investigation are taken from the historical real market price data (Italian market) for 24 hours of a day over a complete year.

These spot prices are the important inputs to the proposed simulation model as they are used to decide the bidding strategy for optimal power dispatch. The second important input under consideration is the forecasted renewable power from the solar plant for deciding the penalty to be imposed for over and under production. Three cases of renewable power generations deviating from the forecasted renewable power are considered for the system as shown in the Fig. 3.These variations in solar and wind powers are computed using Monte Carlo simulations. The penalty factors for over productions, under productions and mixed productions depend upon the total difference in the power forecasted and actual production. No penalty is imposed if power production is exactly matched with the power forecasted.

High penalty charges are imposed for under production as compared over production for the simulation because underproduction violates the contract. These penalties can be calculated as supply demand functions.

For successful operation of the microgrid system different types of generation sources are integrated out of which some are controllable and some cannot be controlled. The system under test have two conventional (diesel) generators, four (Cogeneration) combined heat and power generators, a solar plant, a wind plant, an independent boiler exclusively for the thermal power and the pump storage generator to control the extra power demand (positive or negative). The fuel coefficients and the limits of the each type of the generators are reported in the Table II.

Table- I: Average electrical thermal load demand and range of spot prices for a 24 hours period

Time	Load Demand (MW)	Gamma (Min) ($/MWh)	Gamma (Max) ($/MWh)	Thermal Demand (MW)
1	0.440	30.7	102.6	0.34
2	0.440	25.7	96.6	0.33
3	0.440	21.4	92.0	0.31
4	0.440	17.3	87.0	0.44
5	0.440	14.9	85.7	0.44
6	0.740	16.6	86.8	0.50
7	1.200	16.1	85.5	0.50
8	1.905	16.6	145.1	0.90
9	2.345	26.4	188.8	1.20
10	2.405	32.7	207.0	1.20
11	2.420	32.2	207.1	1.20
12	2.440	29.5	206.5	1.20
13	2.470	27.2	143.9	1.20
14	2.465	15.2	121.9	1.15
15	2.450	12.1	144.5	1.15
16	2.395	12.8	163.7	1.05
17	2.360	20.2	186.6	1.05
18	2.335	36.5	196.6	0.90
19	1.695	56.9	222.3	0.45
20	1.425	69.9	211.9	0.45
21	1.295	64.1	324.2	0.35
22	0.955	60.0	156.3	0.35
23	0.530	52.0	144.4	0.34
24	0.425	39.1	101.7	0.34

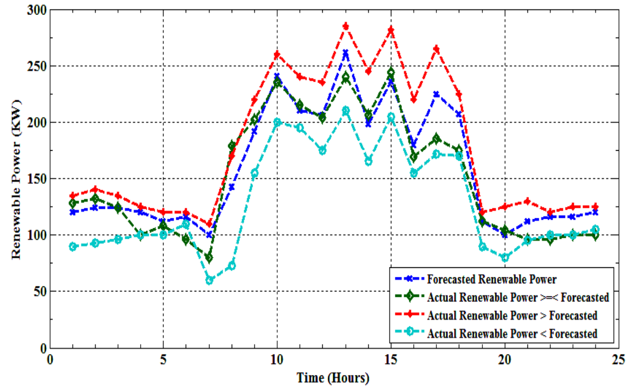

Fig. 3. Variations in forecasted and actual renewable power produced.

Fig. 4(a) and (b) show the power variations of power exchange, solar and wind power as renewable power, power from CHPs, and diesel power for the load profile with and without pump storage plant. The variations show that the pump storage generator has major control on the power exchange, and it takes place between the grid and the microgrid for optimal operation of the system based on the variations in the prices over the operating period.

Fig. 5 shows the variations in generated powers in different generators with respect to price when the system is operating with and without the pump storage unit. For investigation purpose operation of the system at 8th hour has been considered. It is found that the generators generate maximum power when bidding prices are higher or vice-versa. Surplus power after fulfilling the load demand is sold to the utility to get higher revenue. Microgrid, purchase power from the grid during generation deficit intervals to fulfill the load demands. It is also found that when pump storage is included in the system the prices are further reduced below the prices offered to generate minimum and maximum power by the generators. This helps in reducing the operating cost of operation of the system.

Simulation studies have been carried out to obtain the optimal bidding prices for the operating units under three different conditions viz. over production, under production and random power production from combined renewable power plants over forecasted power. Fig. 6 shows the optimal prices offered for bidding strategies for three power exchanges cases with and without pump storage unit. It is found that the bidding prices are reduced handsomely with the pump storage plant. Penalties are imposed on combined renewable power generations whenever there is a mismatch in the powers. The higher penalty is imposed when combined renewable power is less than the bid forecasted power.

Fig. 7 shows that variation in overall cost of microgrid system when it operates with and without pump storage plant. It is found that the cost of operation with pump storage is less than the cost of operation without pump storage. At 11th and 17th hour of operation the cost of operation without pump storage is less than the pump storage plant because during those periods water level is lower and more power is used to pump water to the reservoir.

In Fig. 8 the variations in bidding prices for the microgrid with pump and without pump storage plant for optimal power dispatch problem are shown. It is found that prices are different at different time intervals for optimal dispatch. In the initial intervals as the PS unit pumps the water hence the cost of operation is higher than the cost without PS unit. The net cost is also decided by the PS operation in pumping and generation modes besides the power exchange taking place during different intervals. Fig. 9 shows the periods when PS unit works in pump and generation modes along with power being exchanged during those operating intervals.

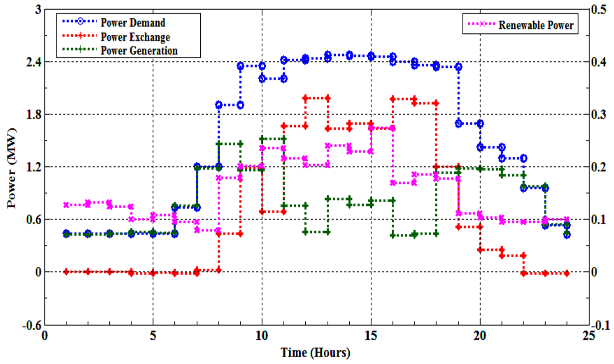

Fig. 4a. Power variations from different sources without pump storage (WPS) plant.

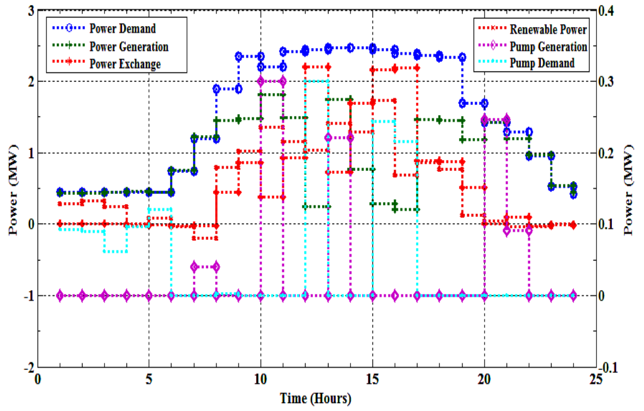

Fig. 4b. Power variations from different sources with pump storage (PS) plant.

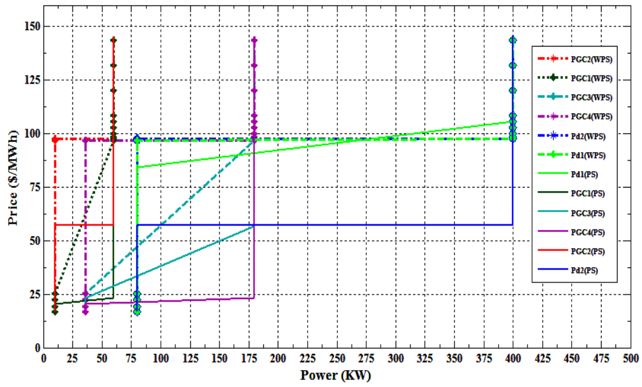

Fig. 5. Variations in powers from different generators with (PS) and without pump storage plant.

Table- II: Generator Data

Power Plant		Cost Coefficients			Power Generation		Efficiency	Pond Level	
		a_i ($/MW^{2}h)	b_i ($/MWh)	c_i ($/h)	P_{gmax} (MW)	P_{gmin} (MW)	η	P_{ondmin}	P_{ondmax}
Conventional	Gen1	0.0005	21.63	1.054	0.400	0.080	-	-	-
(Diesel)	Gen2	0.0025	09.87	1.054	0.400	0.080	-	-	-
Cogeneration	Gen1	0.2222	45.81	0.800	0.060	0.010	0.6	-	-
(CHP)	Gen2	0.1000	51.60	0.461	0.060	0.010	0.6	-	-
	Gen3	0.0021	34.40	0.892	0.180	0.036	0.6	-	-
	Gen4	0.0420	25.78	0.892	0.180	0.036	0.6	-	-
Boiler		-	63.0	-	3.0	0	-	-	-
Solar		-	-	-	0.200	0	-	-	-
Wind		-	-	-	0.160	0	-	-	-
Pump storage	Gen	-	-	-	0	0.040	0.8447	0	0.04
	Pump	-	-	-	0	0.035	0.871	0	0.04

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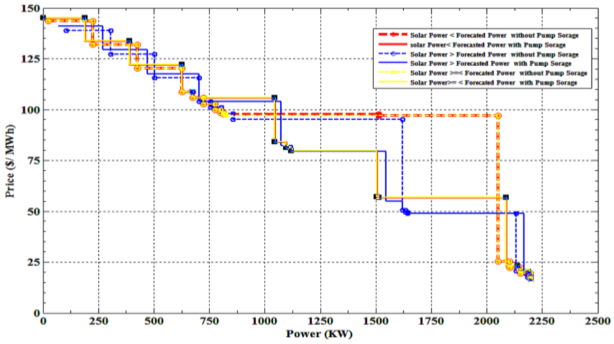

Fig. 6. Price variations with power exchange for over power, under power and random power with pump storage (PS) and without pump storage (WPS) plant.

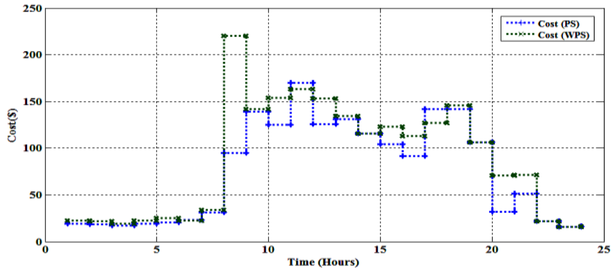

Fig. 7. Cost variations for system with pump storage (PS) and without pump storage (WPS) plant.

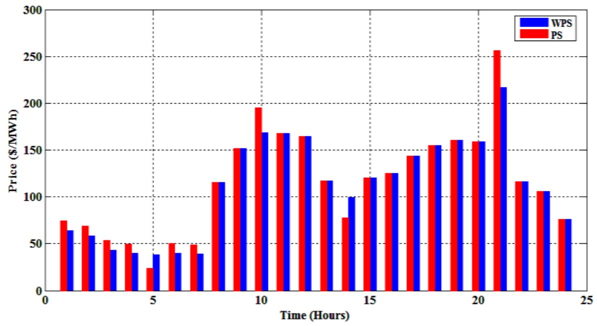

Fig. 8. Price variations with time for microgrid with pump storage (PS) and without pump storage (WPS) plant.

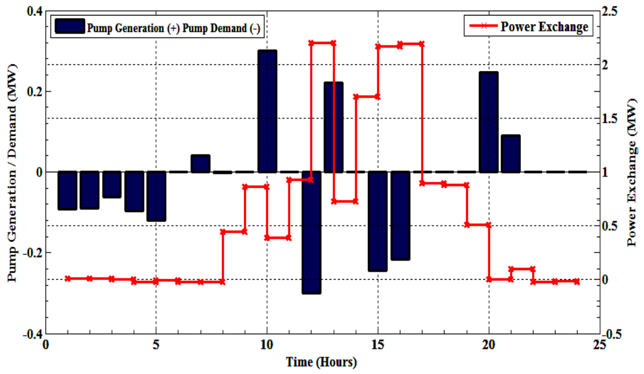

Fig. 9. Pumping and generation of pump storage plant with time of microgrid for the power exchange.

V. CONCLUSIONS

In this paper bidding strategy of grid connected residential microgrid system is proposed for economic scheduling operation in a day-ahead electricity market while considering the variations in electrical, thermal load and renewable power generation. Microgrid system is assumed to consist of various power generating units with power exchange capabilities and itis managed and controlled by the system operator. Power bidding for the system to operate optimally while participating in the electricity market is to be determined. Various results show that the uncertainty of the power production from the solar unit has an impact on the bidding outcome. Incorporating the pump storage plant into the system improves the bidding prices to operate at reduced operating cost. The proposed methodology provide higher improvements during the hours of high pricing and at that time microgrid can take risks by bidding more power due to availability of multiple sources. The pump storage plant helps in reducing the uncertainty of the solar renewable unit to operate more effectively in energy market scenario. If the electrical demand of the microgrid is less than the maximum capacity of the microgrid system then the surplus power can be used for ancillary services market to help the stressed utility grid in future studies.

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REFERENCES

1. W. Pei, Y. Du, W. Deng, K. Sheng, H. Xiao, and H. Qu, "Optimal Bidding Strategy and Intramarket Mechanism of Microgrid Aggregator in Real-Time Balancing Market," *IEEE Trans. Ind. INFORMATICS*, vol. 12, no. 2, pp. 587–596, 2016.
2. P. Kriett, and M. Salani, "Optimal control of a residential microgrid," *Energy*, vol. 42, no. 1, pp. 321-330.
3. L. Shi, Y. Luo, and G. Y. Tu, "Bidding strategy of microgrid with consideration of uncertainty for participating in power market," *Electr. Power Energy Syst.*, vol. 59, pp. 1–13, 2014.
4. T. Niknam, F. Golestaneh, and M. Shafiei," Probabilistic energy management of a renewable microgrid with hydrogen storage using self-adaptive charge search algorithm," *Energy*, vol. 49, pp. 252-267, 2013.
5. A. Mirakyan, and G.R. De, "Modelling and uncertainties in integrated energy planning," *Renewable and Sustainable Energy Reviews*, vol. 46, pp. 62-69, 2015.
6. K. Akbari, M.M. Nasiri, F. Jolai, and J. S.F. Ghader, "Optimal investment and unit sizing of distributed energy systems under uncertainty: A robust optimization approach," *Energy and Buildings*, vol. 85, pp. 275-286, 2014.
7. S. Mohammadi, B. Mozafari, S. Solimani, and T. Niknam, " An Adaptive Modified Firefly Optimisation Algorithm based on Hong's Point Estimate Method to optimal operation management in a microgrid with consideration of uncertainties," *Energy*, vol. 51, pp. 339-348, 2013.
8. P.G. Arul, V.K. Ramachandaramurthy, and R.K. Rajkumar, "Control strategies for a hybrid renewable energy system: A review," *Renewable and Sustainable Energy Reviews*, vol. 42, pp.597-608, 2015.
9. T. Morstyn, B. Hredzak, and V.G. Agelidis, "Control Strategies for Microgrids with Distributed Energy Storage Systems: An Overview," *IEEE Transactions on Smart Grid*, vol. 9, no. 4, pp. 3652-3666, 2018.
10. C. Dou, Z. Zhang, D. Yue, and Y. Zheng, "MAS-Based Hierarchical Distributed Coordinate Control Strategy of Virtual Power Source Voltage in Low-Voltage Microgrid," *IEEE Access*, vol. 5, pp.11381-11390, 2017.
11. Y. Xia, Y. Peng, P. Yang, M. Yu, and W. Wei, "Distributed Coordination Control for Multiple Bidirectional Power Converters in a Hybrid AC/DC Microgrid," *IEEE Transactions on Power Electronics*, vol. 32, no. 6, pp. 4949-4959, 2017.

12. M. Petrollese, L. Valverde, D. Cocco, G. Cau, and J. Guerra, " Real-time integration of optimal generation scheduling with MPC for the energy management of a renewable hydrogen-based microgrid," *Applied Energy*, vol. 166, pp. 96-106, 2016.
13. S. Sukumar, H. Mokhlis, S. Mekhilef, K. Naidu, and M. Karimi, "Mix-mode energy management strategy and battery sizing for economic operation of grid-tied microgrid," *Energy*, vol. 118, pp. 1322-1333, 2017.
14. L. Meng, E.R. Sanseverino, A. Luna, T. Dragicevic, J.C. Vasquez, and J.M. Guerrero, "Microgrid supervisory controllers and energy management systems: A literature review," *Renewable and Sustainable Energy Reviews*, vol. 60, pp. 1263-1273, 2016.
15. J. Kennedy, P. Ciufo, and A. Agalgaonkar, "A review of protection systems for distribution networks embedded with renewable generation," *Renewable and Sustainable Energy Reviews*, vol. 58, pp. 1308-1317, 2016.
16. H. Laaksonen, D. Ishchenko, and A. Oudalov, "Adaptive protection and microgrid control design for Hailuoto Island," *IEEE Transactions on Smart Grid*, vol. 5, no. 3, pp. 1486-1493, 2014.
17. A. Meghwani, S.C. Srivastava, S. Chakrabarti, "A non-unit protection scheme for DC microgrid based on local measurements," *IEEE Transactions on Power Delivery*, vol. 32, no. 1, pp. 172-181, 2017.
18. R. Majumder, "Some aspects of stability in microgrids," *IEEE Transactions on power systems*, vol. 28, no. 3, pp.3243-3252, 2013.
19. J. Alipoor, Y. Miura, and T. Ise, "Stability Assessment and Optimization Methods for Microgrid with Multiple VSG Units," *IEEE Transactions on Smart Grid*, vol. 9, no. 2, pp.1462-1471, 2018.
20. J. Jung, and M. Villaran, " Optimal planning and design of hybrid renewable energy systems for microgrids," *Renewable and Sustainable Energy Reviews*, vol. 75, pp. 180-191, 2017.
21. H. Nazaripouya, Y. Wang, P. Chu, H.R. Pota, and R. Gadh, "Optimal sizing and placement of battery energy storage in distribution system based on solar size for voltage regulation," *2015 IEEE Power & Energy Society General Meeting*, Denver, CO, 2015, pp. 1-5.
22. M.L. Di Silvestre, G. Graditi, and E.R. Sanseverino, "A generalized framework for optimal sizing of distributed energy resources in micro-grids using an indicator-based swarm approach," *IEEE Transactions on Industrial Informatics*, vol. 10, no. 1, pp. 152-162, 2014.
23. D.T. Nguyen, and L.B. Le, "Optimal bidding strategy for microgrids considering renewable energy and building thermal dynamics," *IEEE Transactions on Smart Grid*, vol. 5, no. 4, pp. 1608-1620, 2014.
24. G. Ferruzzi, G. Cervone, L. DelleMonache, G. Graditi, and F. Jacobone, "Optimal bidding in a Day-Ahead energy market for Micro Grid under uncertainty in renewable energy production," *Energy*, vol. 106, pp. 194-202, 2016.
25. A. Rabiee, M. Sadeghi, J. Aghaeic, and A. Heidari, "Optimal operation of microgrids through simultaneous scheduling of electrical vehicles and responsive loads considering wind and PV units uncertainties," *Renewable and Sustainable Energy Reviews*, vol. 57, pp. 721-739, 2016.
26. I. Maity, and S. Rao, "Simulation and Pricing Mechanism Analysis of a Solar-Powerwd Electrical Microgrid," *IEEE Syst. J.*, vol. 4, no. 3, pp. 275–284, 2010.
27. H. Tazvinga, B. Zhu, and X. Xia, "Energy dispatch strategy for a photovoltaic – wind – diesel – battery hybrid power system," *Sol. Energy*, vol. 108, pp. 412–420, 2014.
28. Y. P. Verma, and A. Kumar, "Economic-emission unit commitment solution for wind integrated hybrid system," *Int. J. Energy Sect. Manag.*, vol. 5, no. 2, pp. 287–306, 2011.
29. S. Braun, and R. Hoffmann, "Intraday Optimization of Pumped Hydro Power Plants in the German Electricity Market," *Energy Procedia*, vol. 87, pp. 45–52, 2016.
30. N. I. Nwulu, and X. Xia, "Optimal dispatch for a microgrid incorporating renewables and demand response," *Renew. Energy*, vol. 101, pp. 16–28, 2017.
31. D. Kumar, Y.P. Verma, and R. Khanna, "Demand response-based dynamic dispatch of microgrid system in hybrid electricity market," *International Journal of Energy Sector Management*,vol. 13, no. 2, pp. 318-340, 2019.
32. D. Kumar, Y. P. Verma, and R. Khanna, "Consumer Participation Based Scheduling of Microgrid System in Electricity Market," *2018 IEEE 8th Power India International Conference (PIICON)*, Kurukshetra, India, 2018, pp. 1-5.

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