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JWEET

Reliability Constrained Energy and Reserve Scheduling of Microgrids Including High Penetration of Renewable Resources

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***Abstract** – Due to environmentally and economically advantages, high deployment of renewable energy sources (RES) such as wind or photovoltaic (PV) units in Microgrids (MG) has been increasing in recent decades. On the other hand, random and uncertain nature of the RES poses a challenge to Microgrid operators (MGO) for energy and reserve scheduling considering reliability constraints. To address this problem, a novel probabilistic energy and reserve scheduling method is proposed in this paper. The proposed method maximizes the Microgrid net benefit and reliability so that the optimal requirement reserve is determined by a tradeoff between reliability and economics.*

***Keywords**: Microgrids, renewable energy sources (RES), energy and reserve scheduling, expected energy not supplied (EENS).*

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INTRODUCTION

Increasing deployment of renewable energy sources in Microgrids implies that MGOs will need to handle the random and uncertain nature of RESs like wind and PV in order to continuously preserve the supply-demand balance [1]. Microgrid, as a low voltage small distribution network illustrated in Fig. 1, integrating renewable and conventional energy sources, energy storage and loads in order to local production of electricity as well selling power back to the upstream network [2]. Energy and reserve scheduling of a MG has substantial differences from the large power system due to the flexibility and usability of MGs depend on their composition [4]. The MGs energy scheduling, including renewable generation in a MG, have been studied in many works [5-7].

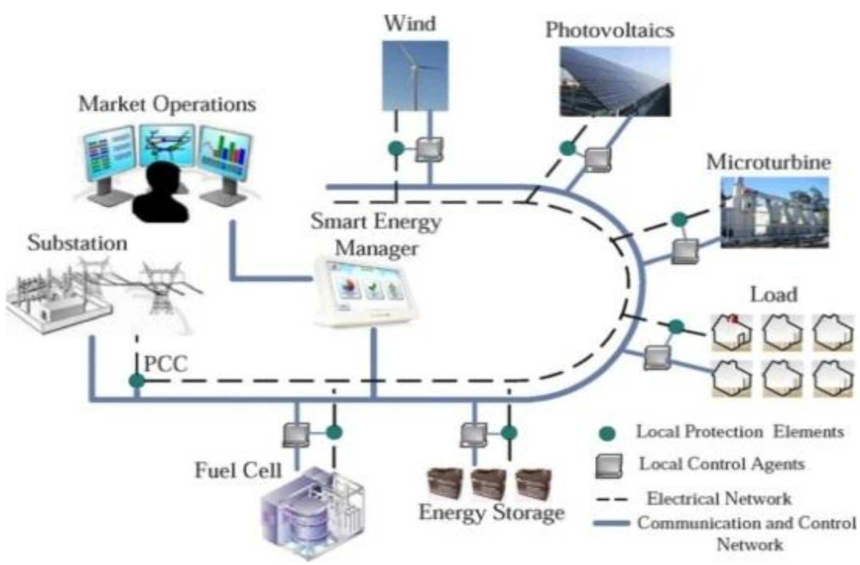

Figure 1. Microgrids [3]

In study of Foo Eddy et al. [5], a multi-agent based system for coordination of MG is proposed. Although the developed multi-agent system ensures proper operation scheduling of MG but uncertainties of renewable energy sources is ignored. In study of Xiong Wu et al. [6], a hierarchical framework for MGs energy scheduling is

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proposed. The upper level the MG operation cost is minimize while the lower level combines scheduling of renewable energy sources and energy storage unit in order to minimize uncertainties of power generation of RESs. However, reliability constraints are not investigated by authors. In study of Duong Nguyen et al. [7], an optimal stochastic day-ahead energy scheduling framework of MGs has been proposed incorporating the uncertainties of renewable energy sources. However, procurement reserve for satisfying wind and PV power uncertainties has not been taken into account within the proposed stochastic day-ahead MG scheduling.

The study of Khodaei [8], explores resiliency-oriented MGs optimal scheduling problem. The proposed model minimizes the load shedding by optimally MG scheduling when supply of power from the upstream network is disconnected for a specific period of time. However, uncertainties of renewable energy sources are not included in the proposed model. In study of Cecati at al. [9], a combined operation of renewable energy sources and responsive loads is optimized in the MGs. By combining supply and demand scheduling, it permits a better use of renewable energy sources and a decrease in the payment cost of responsive loads. Islanded MGs scheduling model including renewable energy sources and battery storage unit is proposed in [10]. In this regard, the MG operation cost including battery life loss cost, operation and maintenance cost, fuel cost, and environmental cost is minimized. In study of Duong Nguyen [11], an optimal bidding strategy for MGs is presented. The proposed method enables MGO to determine optimal day-ahead hourly bids that maximize the MG profit by a risk constrained stochastic programming approach.

To the best of our knowledge, no probabilistic energy and reserve scheduling method in Microgrids with high deployment of renewable sources considering reliability constraints has been reported in the papers. Accordingly, this paper address this issue by proposing a probabilistic approach for energy and reserve scheduling of Microgrids in which reliability constraints are taken into account.

The remaining paper is organized as follows. The uncertainties of wind, PV and Microgrid demand are described in section 'Uncertainties modeling'. The proposed method is introduced in section 'energy and reserve scheduling '. A case study is examined in section 'simulation results'. Conclusion section is explained in section 'Conclusion'.

MATERIAL AND METHODS

UNCERTAINTIES MODELING

The random output power of renewable energy sources such as wind and PV units is caused a significant uncertainty into MG scheduling. As well, the load forecasting uncertainty at the MG level is high [12]. In this section, the uncertainty of wind power, PV power and load is modeled.

A. Load Demand

The MG load demand forecasting uncertainty can be obtained from historical data set. According to power system, a normal distribution probability as shown in Fig. 2 with a large standard deviation is used [7].

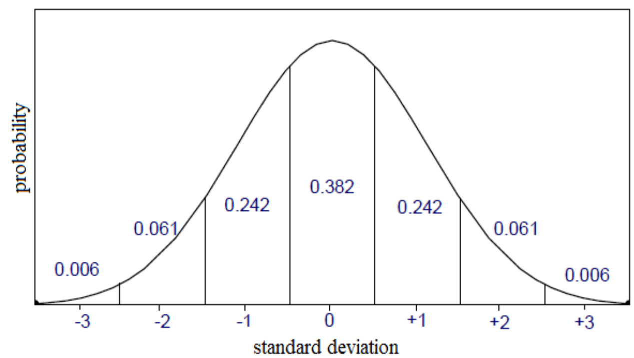

Fig. 2 – Probabilistic Load Model

B. Wind Power

The probability density function of wind speed which is modeled by the Weibull distribution [2] is shown in Fig. 3 and given by:

$$f(v) = (k/c)(v/c)^{(k-1)} e^{-(v/c)^k}, \qquad 0 < v < \infty \tag{1}$$

Where, v, k and c represent wind speed, shape and scale factor respectively.

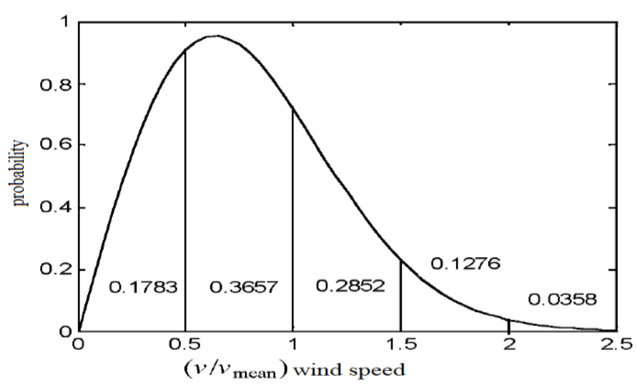

Fig. 3 – Wind speed probability Model

The power generation of the wind unit can be calculated by:

$$w = \begin{cases} 0 & \text{for } v < v_i \text{ and } v > v_o \\ w_r (v - v_i)/(v_r - v_i) & \text{for } v_i \le v \le v_r \\ w_r & \text{for } v_r \le v \le v_o \end{cases} \tag{2}$$

Where, v_i, v_o and v_r are cut-in, cut-out and rated speed of wind turbine, respectively. Also, w_r is rated power of wind turbine.

C. PV Power

The probability density function of solar irradiance which is modeled by the bimodal distribution [11] is shown in Fig. 4 and given by:

$$f(g) = \omega (k_1 / c_1)\left(g / c_1\right)^{(k_1 - 1)} e^{-(g/c_1)^{k_1}} + (1-\omega)(k_2 / c_2)\left(g / c_2\right)^{(k_2 - 1)} e^{-(g/c_2)^{k_2}}, \quad 0 < g < \infty \tag{3}$$

Where, g and ω are solar irradiation and weight factor, respectively, k_1 and k_2 are shape factors, c_1 and c_2 are scale factors.

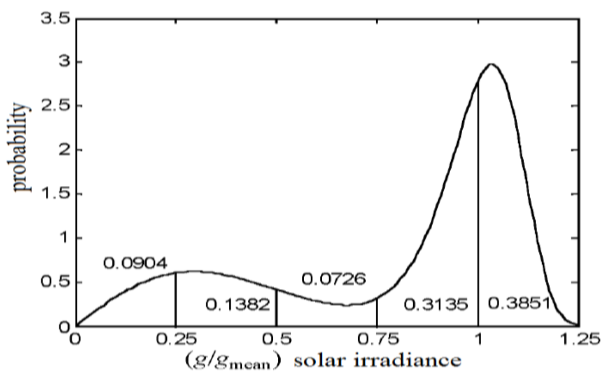

Fig. 4 – Solar irradiance probability Model

The power generation of the PV unit can be calculated by:

$$p = \eta^{PV} S^{PV} g \tag{4}$$

Where, p is PV power generation, S^{PV} and η are PV total area and efficacy, respectively.

D. Scenario Generation

Monte Carlo sampling method [11] is used to sample day-ahead load demand, wind speed and solar irradiance according to their aforementioned probability distributions. Then wind and PV power generation can be calculated using equations (2) and (4), respectively.

ENERGY AND RESERVE SCHEDULING

In this section, the mathematical formulation of the proposed method is described.

A. Objective function and constraints

The objective of proposed method is to maximize the total benefit of the MG:

$$\max \left\{ \sum_{t=1}^{T} \sum_{i=1}^{I} MP(t) \times P_{i,t} - \sum_{t=1}^{T} \sum_{i=1}^{I} \left[a_i . U_{i,t} + b_i . P_{i,t} + SC_i \times K_{i,t} \right] - \sum_{t=1}^{T} \sum_{i=1}^{I} q_{i,t} \times R_{i,t} - EENS \times VOLL \right\} \tag{5}$$

Where, $MP(t)$ is wholesale market price, $P_{i,t}$ and $U_{i,t}$ are power generation and status of unit i during period t, respectively. a_i, b_i and SC_i are cost coefficients and start-up cost of unit i, respectively. $q_{i,t}$ and $R_{i,t}$ are reserve cost and its value related to unit i, respectively. Reliability cost is equal to expected energy not supplied (EENS) caused by load demand, wind and PV power uncertainties and value of loss of load (VOLL) is taken into account.

The constraints of proposed model are depicted as follow:

- Load balance constraint

$$\sum_{i=1}^{I} P_{i,t} = P_t^D \quad \forall\ t = 1,...,T \tag{6}$$

Where, P_t^D is forecasted MG load demand during period t.

- Reliability constraint

$$LOLP_t \le LOLP_t^{\max} \tag{7}$$

Where, LOLP is probability of loss of load caused by load demand, wind and PV power uncertainties.

- Reserve constraint

$$\begin{cases} R_{i,t} \le P_i^{\max} U_{i,t} - P_{i,t} \\ R_{i,t} \le U_{i,t} . R_{i,t}^{up} \end{cases} \tag{8}$$

Where, $R_{i,t}^{up}$ is ramp up rate of unit i during period t. In addition, each unit is subject to its own operating limits, which consist of the maximum and minimum unit limits, minimum up and down time limits and ramp up and ramp down limits [9].

B. Reliability formulations

The mathematical formulation of LOLP and EENS are presented as bellow:

$$\begin{aligned} EENS = & \sum_{t=1}^{T} \sum_{n=1}^{N} p_t^0 p_{n,t} b_{n,t}^0 (\Delta P_{n,t} - R_t) \\ & + \sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{n=1}^{N} p_{i,t}^1 p_{n,t} b_{i,n,t}^1 (P_{i,t} + R_{i,t} + \Delta P_{n,t} - R_t) \\ & + \sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{j>i}^{I} \sum_{n=1}^{N} p_{i,j,t}^2 p_{n,t} b_{i,j,n,t}^2 (P_{i,t} + R_{i,t} + P_{j,t} + R_{j,t} + \Delta P_{n,t} - R_t) \end{aligned} \tag{9}$$

$$LOLP_t = \sum_{n=1}^{N} p_t^0 p_{n,t} b_{n,t}^0 + \sum_{i=1}^{I} \sum_{n=1}^{N} p_{i,t}^1 p_{n,t} b_{i,n,t}^1 + \sum_{i=1}^{I} \sum_{j>i}^{I} \sum_{n=1}^{N} p_{i,j,t}^2 p_{n,t} b_{i,j,n,t}^2 \tag{10}$$

Where, k, m and l are numbers of load demand, wind speed and solar irradiance generated scenarios in Monte Carlo method, respectively.

$$\Delta P_{k,t}^{WT} = \sum_{i=1}^{nWT} \left[f_i^{WT}\left(v_{i,t}^{fcst}\right) - f_i^{WT}\left(v_{i,t}^{scen}\right) \right] \tag{11}$$

$$\Delta P_{m,t}^{PV} = \sum_{i=1}^{nPV} \left[f_i^{PV}\left(g_{i,t}^{fcst}\right) - f_i^{PV}\left(g_{i,t}^{scen}\right) \right] \tag{12}$$

$$\Delta P_{l,t}^{D} = P_t^D - P_{l,t}^D \tag{13}$$

Where, load demand, wind speed and solar irradiance scenarios are $P_{l,t}^D$, $v_{i,t}^{scen}$ and $g_{i,t}^{scen}$, respectively.

$$b_{k,l,m,t}^0 = \begin{cases} 1 & if \quad \Delta P_{k,t}^{WT} + \Delta P_{m,t}^{PV} + \Delta P_{l,t}^{D} - R_t > 0 \\ 0 & \text{otherwise.} \end{cases} \tag{14}$$

The p_t^0, $p_{i,t}^1$ and $p_{i,j,t}^2$ are forced outage probabilities [13] of zeros, one and two units, respectively.

$$p_t^0 = \prod_{i=1}^{I} \left(1 - u_i U_{i,t}\right) \tag{15}$$

$$p_{i,t}^1 = u_i U_{i,t} \prod_{j=1, j\neq i}^{I} \left(1 - u_j U_{j,t}\right) \tag{16}$$

$$p_{i,j,t}^2 = u_i u_j U_{i,t} U_{j,t} \prod_{k=1, k\neq i,j}^{I} \left(1 - u_k U_{k,t}\right) \tag{17}$$

Where, u_i is forced outage rate (FOR) of unit i.

RESULTS

In this section, the proposed model is implemented on the MG as illustrated in Fig. 5. Hourly load, wind speed as well wind turbine, solar irradiation as well PV array and price data are drive from [2].

Technical and economic data of units was taken from works of Chen at al. [3]. Reserve cost and FOR let fix and equal to 0.04 $/kWh and 0.006, respectively, while VOLL is set to be 1000 $/kWh.

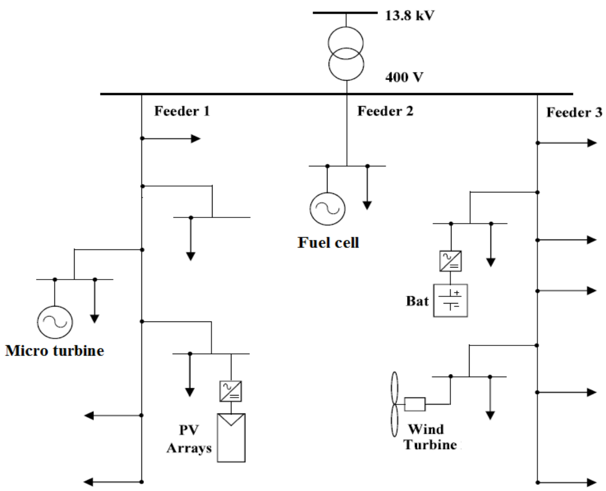

Figure 5. Test Microgrid

Energy scheduling of MG units is shown in Fig. 6. As shown in Fig. 6, in the hours with high wholesale price MGO using local units' energy production and sell back extra energy to upstream grid. The profit of MGO is 189 $ in this case.

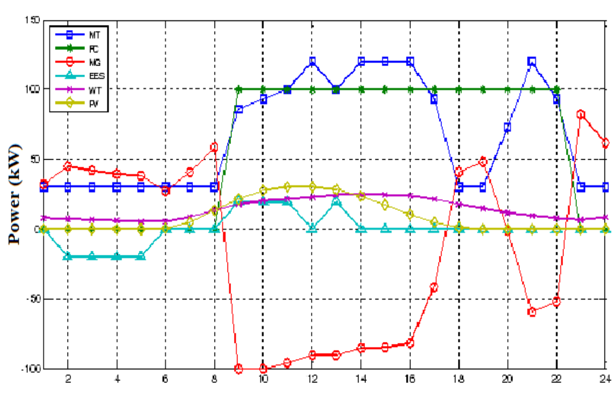

Figure 6. Energy scheduling of MG units

Reserve scheduling and available reserve of MG is illustrated in Fig. 7. As shown, with increasing energy production of RESs and load demand of MG, requirement reserve of MG is grown while available reserve of MG is reduced.

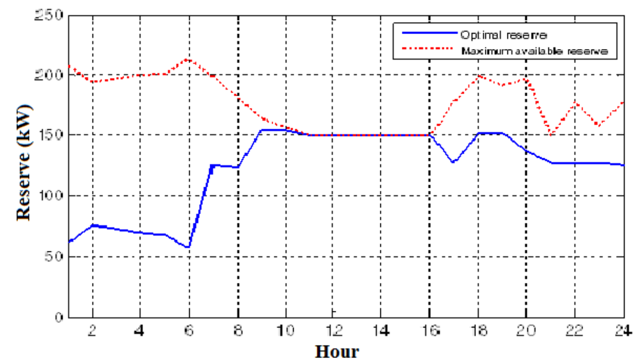

Figure 7. Reserve scheduling and available reserve of MG

Loss of load probability is presented in Fig. 8. As depicted, with increasing energy production of RESs and load demand of MG, uncertainty is grown. In this case study $LOLP^{max}$ is set to be 0.005.

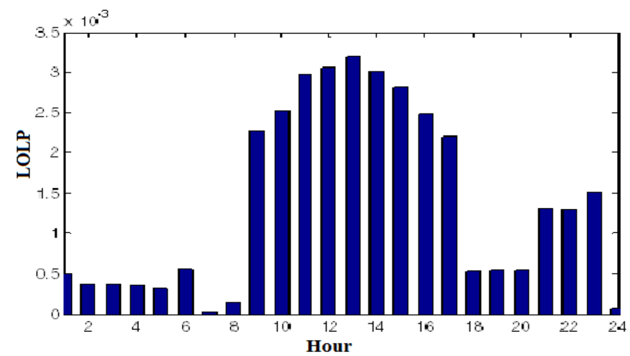

Figure 8. Loss of load probability

Reserve scheduling of MG with different FOR is shown in Fig. 9. As shown, with increasing of FOR, forced outage rate of units is grown and as a result requirement reserve of MGO is exceeded.

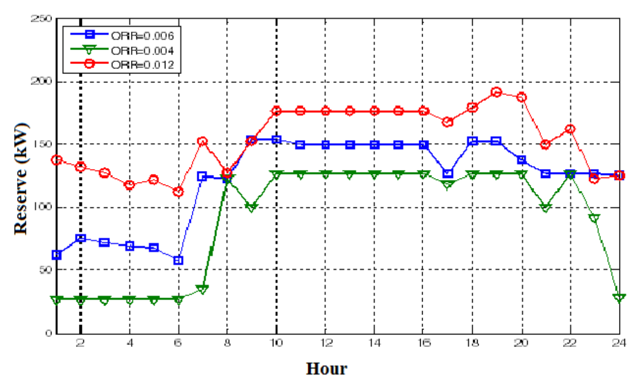

Figure 9. Reserve scheduling for different FOR

Reserve scheduling of MG with different wind penetration is shown in Fig. 10. As illustrated, with increasing energy production of wind unit, uncertainty is grown and as a result requirement reserve of MGO is exceeded.

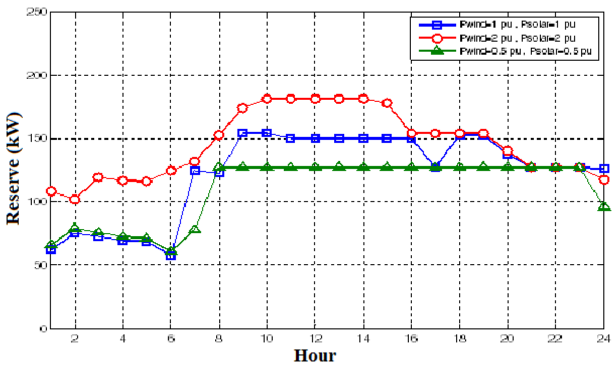

Figure 10. Reserve scheduling for different wind penetration

Reserve scheduling of MG with different VOLL is shown in Fig. 11. As shown, with increasing VOLL, cost of MGO caused by load shedding is grown and as a result requirement reserve of MGO is exceeded.

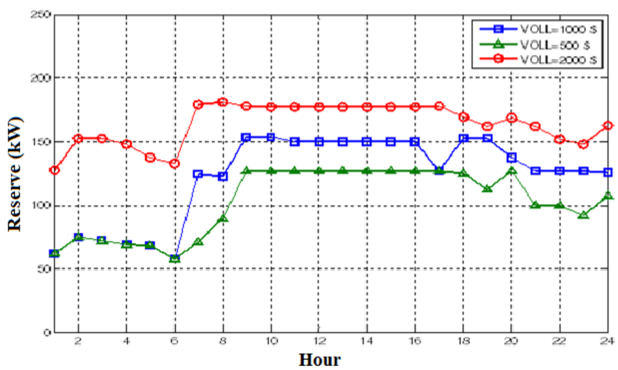

Figure 11. Reserve scheduling for different VOLL

DISCUSSION

Microgrids provide various benefits for consumers in terms of reliability and economy. However, the economic benefits of MG should be studied to justify high penetration of renewable resources while considering reliability constraints in the scheduling process. Specific features of proposed energy and reserve scheduling of MG are listed as follows:

1- Considering reliability constraints in energy and reserve scheduling of MG.

2- Proposed a unified and mixed integer linear mathematical formulation for modeling the problem.

3- A comprehensive uncertainty modeling using Monte Carlo simulation technic.

4- Doing a sensitivity analysis for evaluating reliability parameters.

CONCLUSION

In this paper, a probabilistic method for energy and reserve scheduling of MG is proposed. Effeteness of the proposed method is demonstrated by implemented on the MG and simulation results are analyzed. The results show that the MG profit is maximized while reliability constraints are met.

REFERENCES

[1] M.A. Matos, Bessa, R.J., "Setting the Operating Reserve Using Probabilistic Wind Power Forecasts," Power Systems, IEEE Transactions on , vol.26, no.2, pp.594,603, May 2011.

[2] A.G. Tsikalakis, Hatziargyriou, N.D., "Centralized Control for Optimizing Microgrids Operation," Energy Conversion, IEEE Transactions on , vol.23, no.1, pp.241,248, March 2008.

[3] S.X. Chen, Gooi, H.B., Wang, M.Q., "Sizing of Energy Storage for Microgrids," Smart Grid, IEEE Transactions on, vol.3, no.1, pp.142,151, March 2012.

[4] M.Q. Wang, Gooi, H.B., "Spinning Reserve Estimation in Microgrids," Power Systems, IEEE Transactions on, vol.26, no.3, pp.1164,1174, Aug. 2011.

[5] Y.S. Foo Eddy, Gooi, H.B.; Chen, S.X., "Multi-Agent System for Distributed Management of Microgrids," Power Systems, IEEE Transactions on , vol.30, no.1, pp.24,34, Jan. 2015.

[6] Wu Xiong Xiuli Wang; Chong Qu, "A Hierarchical Framework for Generation Scheduling of Microgrids," Power Delivery, IEEE Transactions on , vol.29, no.6, pp.2448,2457, Dec. 2014.

[7] D.T. Nguyen; Bao Le L., "Optimal Bidding Strategy for Microgrids Considering Renewable Energy and Building Thermal Dynamics," Smart Grid, IEEE Transactions on , vol.5, no.4, pp.1608,1620, July 2014.

[8] A. Khodaei, "Resiliency-Oriented Microgrid Optimal Scheduling," Smart Grid, IEEE Transactions on , vol.5, no.4, pp.1584,1591, July 2014.

[9] C. Cecati, Citro, C.; Siano, P., "Combined Operations of Renewable Energy Systems and Responsive Demand in a Smart Grid," Sustainable Energy, IEEE Transactions on , vol.2, no.4, pp.468,476, Oct. 2011.

[10] B. Zhao; Zhang X, Chen J., Wang C., Guo L, "Operation Optimization of Standalone Microgrids

Considering Lifetime Characteristics of Battery Energy Storage System," Sustainable Energy, IEEE Transactions on , vol.4, no.4, pp.934,943, Oct. 2013.

[11] D.T. Nguyen, Bao Le L., "Risk-Constrained Profit Maximization for Microgrid Aggregators With Demand Response," Smart Grid, IEEE Transactions on , vol.6, no.1, pp.135,146, Jan. 2015.

[12] N. Amjady, Keynia, F., Zareipour, H., "Short-Term Load Forecast of Microgrids by a New Bilevel Prediction Strategy," Smart Grid, IEEE Transactions on , vol.1, no.3, pp.286,294, Dec. 2010.

[13] M.A. Ortega-Vazquez, Kirschen, D.S., "Optimizing the Spinning Reserve Requirements Using a Cost/Benefit Analysis," Power Systems, IEEE Transactions on , vol.22, no.1, pp.24,33, Feb. 2007