Scheduling of Battery Energy Storage & Demand Response Resource in Balancing Ancillary Service

Meysam Khojasteh, Pedro Faria, Zita Vale
Polytechnic Porto, Porto, Portugal
meysa@isep.ipp.pt, pnf@isep.ipp.pt, zav@isep.ipp.pt

***Abstract*—Nowadays, benefits and advantages of renewable energies are clear for everyone. Lower cost of these resources (in compare with non-renewable resources), global demanding for the clean energy, limitations of fossil fuel resources, and so on, increase the popularity of renewable energies in power systems. However, the main problem is that the wind and solar power as two cheapest and biggest resources of renewable energy are variable, un-dispatchable, uncontrollable. Every change in the forecasted values of these resources could disturb the balance of generation and consumption in the electricity power network, which can lead to the instability of grid. Therefore, the flexibility of network shall be increased to neutralize the fluctuations of renewable resource. The Battery Energy Storage (BES) as the trusted and reliable energy resource can play a crucial role to maintain the flexibility of grid by instantaneous response to supply and demand variations. However, some constraints of BES such as minimum charge and discharge times, capacity, rate of charge and discharge could limit the generation/consumption of this resource in the real-time balancing. This paper provides a model for scheduling of BES and shifting demand response (SDR) in balancing ancillary service to improve the flexibility of grid. SDR program is proposed as the backup resource to cover the limitations of BES and improve the flexibility of grid. The objective function of proposed model is minimizing the real-time energy supply cost. The proposed model is formulated based on mixed integer linear programming (MILP) methodology. Moreover, the performance and advantages of the proposed model are investigated via a case study.**

Keywords—ancillary service, balancing market, battery energy storage, demand response.

I. INTRODUCTION

Increasing the penetration level of renewable energy resources such as wind farms and photovoltaic panels could decrease the flexibility of distribution network. Fluctuations of output power of renewable energy resources are inevitable and can put at risk the stability of power system. Therefore, the distribution system operator (DSO) shall use more flexible and controllable resources to improve the maneuverability of network. The unique characteristics of BES and SDR, such as controllability and flexibility increase their penetration level in power systems. BES can provide both supply (in charging mode) and demand (in discharging mode) roles for the power network. In the other words, the surplus/shortage of renewable resources power can be absorbed/generated by BES. However, the operation of BES has some operational limitations such as capacity, charging and discharging times, ramp rates, etc. Demand response programs are another effective alternative that can be used to improve flexibility of power system. It shall be noted that the ramp rate constraint of generating units imposes a time delay in increasing or decreasing of power in real time. Therefore, a very fast response generating units such as gas turbine shall be used for the regulation service. Usually, the marginal cost of fast response units is higher than the average value of power system that could increase the real time market-clearing price and increase the operational cost of system, consequently. Demand response programs enable power system planners to reduce or shift the consumption of end-users during the unplanned events or peak periods to maintain the security and reliability of grid in the acceptable range. Moreover, the smart controlling devices give the chance to market operator the control of consumption in real-time

It shall be noted that participation of DR and BES in balancing ancillary service has been presented in various technical references. In [1] the impact of DR on the flexibility of grid in the substation level is analyzed. The strategy of DR participation in frequency reserve service is represented in [2]. In [3], a probabilistic approach is proposed for coordinating of DR and pumped hydro storage in order to compensate the fluctuation of wind power uncertainties. The presented model in [4] provides a coordinated strategy for BES and wind power for participating in frequency ancillary service. In [5], two reliability indices are defined to evaluate the effect of BES on spinning reserve and frequency regulations. The proposed model in [6] enables the market operator to manage the industrial loads for participating in the regulation and load following ancillary service. To increase the BES potential for providing the primary reserve control, two operating control schemes, which entitles as droop-control and energy arbitrage is provided in [7]. In [8], the robust optimization methodology is applied for modeling wholesale price uncertainty in scheduling of BES in joint energy and ancillary service market. In [10-11], the effect of demand elasticity on the energy procurement strategy of electricity providers is evaluated, and a deterministic model is proposed to manage the uncertainty of wholesale price and the financial risk.

As seen in the technical literature, the less attention has been paid to the simultaneous scheduling of BES and DR. In this paper, a cost-effective model is presented for the coordinate scheduling of BES and DR in the distribution network to compensate the fluctuations of renewable energy resources. In the proposed model, the shifting demand response is used to cover the operational limits of BES. It shall be noted that unbalancing of demand and supply is detected in real-time or near to real-time. Therefore, only forward shifting of load is considered in the presented model. In this work, it is supposed that the wind power fluctuations could disrupt the balance of generation and consumption in real-time. However, other uncertainty resources such as demand fluctuations can be considered, which is neglected in the work. As the scope of this work is not forecasting, the wind power uncertainty is modeled by different scenarios. Additionally, the model is formulated based on MILP methodology. The contributions of this work can be summarized as follow:

- Modeling the operational limitation of resource in the balancing ancillary service.
- Simultaneous scheduling of BES and SDR in balancing ancillary service.

The rest of paper is organized as follow: In section 2, the proposed model is represented. Section 3 demonstrates the

This work received funding from FEDER Funds through COMPETE program and from National Funds through FCT under the project UID/EEA/00760/2019.

performance of the model via a case study. The conclusions and remarks are provided in section 4.

II. MODEL OF SCHEDULING BES AND SDR

This section introduces the proposed model for scheduling of BES and SDR in the balancing ancillary service in order to compensate the fluctuations of wind power resources. The objective function is formulated based on the cost minimization. Moreover, the scenario generation approach is used to model the uncertainty of wind power.

Within period *t*, the balancing power (P_B^t) is the difference between actual (P_A^t) and forecasted power within the previous period (P_F^{t-1}), which is represented in Eq. (1). It shall be noted that in various markets such as California electricity market, the period of estimation for future demand and generation in regulation ancillary service is usually 5-min interval [9].

$$P_B^t = P_A^t - P_F^{t-1};\ \forall t \in T \qquad (1)$$

The values of P_F^{t-1} are specified in day-ahead market or previous time interval. To determine P_A^t, the market operator uses different methodology such as stochastic programming approach. As the scope of this paper is the regulation ancillary service, it is supposed that P_F^{t-1} is available at the time of decision-making. Additionally, the uncertainty of P_A^t is modeled by the scenario generation method, which will be described in continue.

As mentioned before, in this paper, the balancing ancillary service is provided by BES and SDR. To compensate the positive values of P_B^t, BES shall be operated in charging mode or demand of consumers shall be increased, and vice versa. Moreover, $P_{BES}^{t,\text{Reg}}$ and $P_{DRS}^{t,\text{Reg}}$ are the part of BES and SDR capacities that can participate in the regulation service.

$$P_B^t = P_{BES}^{t,\text{Reg}} + P_{DRS}^{t,\text{Reg}};\ \forall t \in T \qquad (2)$$

The state of charge (*SOC*) or the energy of battery energy storage *k*th in each time interval is:

$$SOC_k^t = SOC_k^{t-1} + \left(\nu_k P_{Ch,k}^t \eta_{Ch,k} - (1-\nu_k) \frac{P_{Dch,k}^t}{\eta_{Dch,k}} \right) \Delta t; \quad \forall t \in T \,\&\, \forall k \in K \qquad (3)$$

where, ν_k is the decision binary variable (1 for charging, 0 for discharging), and η_{Ch} are η_{Dch} efficiencies of BES in charging and discharging modes, respectively.

Moreover, the variation rate of BES charging and discharging powers (P_{Ch}^t and P_{Dch}^t) powers is limited by the technology of battery, as follows:

$$P_{Ch,k}^t - P_{Ch,k}^{t-1} \le R_{BES,k}^{Ch};\ \forall t \in T \,\&\, \forall k \in K \qquad (4)$$

$$P_{Dch,k}^{t-1} - P_{Dch,k}^t \le R_{BES,k}^{Dch};\ \forall t \in T \,\&\, \forall k \in K \qquad (5)$$

where, $R_{BES,k}^{Ch}$ and $R_{BES,k}^{Dch}$ are ramp-rates of BES *k*th, charging and discharging modes, respectively. In charging and discharging modes, BES can consume P_{Ch}^t and generate P_{Dch}^t, respectively. Therefore, $P_{BES}^{t,\text{Reg}}$ can be rewritten as follow:

$$P_{BES}^{t,\text{Reg}} = \sum_{k \in K} \left[\nu_k P_{Ch,k}^t - (1-\nu_k) P_{Dch,k}^t \right];\ \forall t \in T \qquad (6)$$

The capacity limitation of BES can be formulated as follows:

$$0 \le SOC_k^t \le SOC_k^{\max};\ \forall t \in T \,\&\, \forall k \in K \qquad (7)$$

As mentioned before, SDR is another resource of balancing in the regulation ancillary service. In this work, it is supposed that the hourly load includes three parts, which are called as "fixed load" (D_t^{FIX}), "shift-able load" that can be shifted from operational time *t*th to *r*th ($D_{t,r}^{SDR}$), and a part of load which is shifted to operational period *t*th from the previous time intervals ($D_{s,t}^{SDR}; s = 0,1,...,t-1$). The part of hourly load that can participate in regulation ancillary service is shift able load or SDR. Therefore:

$$D_t = D_t^{FIX} + \sum_{r=t}^{T} D_{t,r}^{SDR} + \sum_{s=0}^{t-1} D_{s,t}^{SDR};\ \forall t \in T \qquad (8)$$

$$D_{t,r}^{SDR} = (1-\alpha_{t,r}) \overline{SDR_t};\ \forall t \in T, r = t+1,...T \qquad (9)$$

$$0 \le \sum_{r=t+1}^{T} \alpha_{t,r} \le 1;\ \forall t \in T \qquad (10)$$

$$0 \le \alpha_{t,r} \le 1;\ \forall t \in T, r = t+1,...T \qquad (11)$$

In Eq. (9), $\alpha_{t,r}$ is the percentage of hourly SDR that can be shifted from time interval *t*th to *r*th, and it is specified by the market operator based on the minimum cost. Additionally, the maximum capacity of hourly load for participation in the regulation ancillary service is represented by $\overline{SDR_t}$, that is declared by the load service entity in the day-ahead market. Another constraint of consumption is the maximum demand (D_t^{MAX}) that is limited by the characteristics of metering devices and facilities. It shall be noted that in this work, the minimum consumption is the fixed part of consumption that cannot be shifted to other time intervals.

$$D_t^{FIX} \le D_t \le D_t^{MAX};\ \forall t \in T \qquad (12)$$

As the time scope of this work is short-term planning that includes regulation service for the next time intervals, it is supposed that values of $D_{s,t}^{SDR}$ are available at the start of each operational time. Therefore, $P_{SDR}^{t,\text{Reg}}$ is represented as follow:

$$P_{SDR}^{t,\text{Reg}} = \sum_{r=t+1}^{T} (1-\alpha_{t,r}) \overline{SDR_t};\ \forall t \in T \qquad (13)$$

BES and SDR shall be scheduled in a way that compensates the fluctuations of wind generation. The wind power or P_A^t can be formulated based on the wind speed (V_w^t) as follow:

$$P_A^t = \begin{cases} 0 & V_w^t < V_{ci} \\ \overline{P} \times \left(\dfrac{V_w^t - V_{ci}}{V_r - V_{ci}} \right) & V_{ci} < V_w^t < V_r \\ \overline{P} & V_r < V_w^t < V_{co} \\ 0 & V_{co} < V_w^t \end{cases};\ \forall t \in T \qquad (14)$$

In Eq. (14), $\overline{P}$, V_{ci} , V_{co} , and V_r are the nominal power of wind turbine, cut-in, cut-out and rated speed of wind-turbines, respectively. Evidently, the main uncertainty source of wind power generation is the wind speed. In this paper, fluctuations of wind speed are modeled by the normal probability function. Therefore, in each time interval, wind speed is approximated by seven scenarios as follow:

$$V_w^t = \begin{Bmatrix} \mu_w^t - 3\sigma_w^t, \mu_w^t - 2\sigma_w^t, \mu_w^t - \sigma_w^t, \mu_w^t, \\ \mu_w^t + \sigma_w^t, \mu_w^t + 2\sigma_w^t, \mu_w^t + 3\sigma_w^t \end{Bmatrix} \quad (15)$$

Where, σ_w^t and μ_w^t are the standard deviation and average value of wind speed in each period. The probability of scenarios is calculated by cumulative distribution function. Therefore, in each period, the uncertainty of wind speed is modeled by seven scenarios, and the total number of scenarios is 7^T, where T is the number of time intervals. To reduce the number of scenarios, the Kantorovich distance methodology can be used.

The objective function of regulation service is formulated based on the cost minimization. In the regulation market two type payments are available for the load service entities. The first one is capacity that is paid for the participation in the regulation service. The second one is the actual payment that is paid for the actual load reduction. Therefore, the regulation cost of SDR ($C_{SDR}^{t,\text{Reg}}$) is formulated as follow:

$$C_{SDR}^{t,\text{Reg}} = \overline{SDR}_t \times \pi_t^{cap} + \left(\sum_{r=t+1}^{T} (1-\alpha_{t,r}) \overline{SDR}_t \right) \times \pi_t^{act}; \ \forall t \in T \quad (16)$$

where, π^{cap} and π^{act} are capacity price for participation in balancing service, and actual price for load reduction service, respectively.

To encourage BES resources for participating in balancing service, in the charging mode, they pay the charging cost (π^{Ch}), which is less than the regulation price (π^{Reg}). In discharging mode, the generated power of BES will be purchased based real-time pricing scheme.

$$C_{BES}^{t,\text{Reg}} = \sum_{\forall k \in K} \left[(1-\nu_k) P_{Dch,k}^t \pi_t^{\text{Reg}} - \nu_k P_{Ch,k}^t \pi_t^{Ch} \right]; \ \forall t \in T \quad (17)$$

Therefore, the objective function of scheduling BES and SDR for participation in the balancing service is formulated as follows:

$$OF: \min C_T^{t,\text{Reg}} = \sum_{\forall k \in K} \left[(1-\nu_k) P_{Dch,k}^t \pi_t^{\text{Reg}} - \nu_k P_{Ch,k}^t \pi_t^{Ch} \right] + \overline{SDR}_t \times \pi_t^{cap} + \left(\sum_{r=t+1}^{T} (1-\alpha_{t,r}) \overline{SDR}_t \right) \times \pi_t^{act}; \ \forall t \in T \quad (18)$$

In the next section, the performance of the proposed model is evaluated via a case study.

III. NUMERICAL RESULTS

In this section, the proposed model is simulated on a case study. The expected values of wind speed (μ_w^t) and wind-turbine generation (P_F^t) within 3 hours period (5-min time step) are represented in Fig. 1. Therefore, the total number of time steps is 36. Moreover, the standard deviation of wind speed (σ_w^t) for different time steps are shown in Fig. 2.

It shall be noted that the rated power, cut-in, cut-out, and rated speeds of wind-turbine are 12kW, 1, 6, 8 m/s, respectively. The efficiencies of battery energy storages (in charging and discharging modes) are 90%. Moreover, it is supposed that 10 BESs are available, and their characteristics are as follows:

- *Type A*: Five BESs: total ramp-rate= 100W/min and maximum charging capacity 1500 W, and the initial state is fully charged.
- *Type B*: Five BESs: total ramp-rate= 90W/min and maximum charging capacity 800 W, and the initial state is fully charged.

The maximum SDR and regulation price are demonstrated in Fig. 3. Moreover, the values of π_t^{cap} , π_t^{act} , and π_t^{Ch} are 5%, 30% and 70% of regulation price, respectively. It shall be noted that in this work, the demand side resources are considered as a real-time and controllable alternative to compensate the wind fluctuations. Therefore, the ramp rate of consumption is not considered.

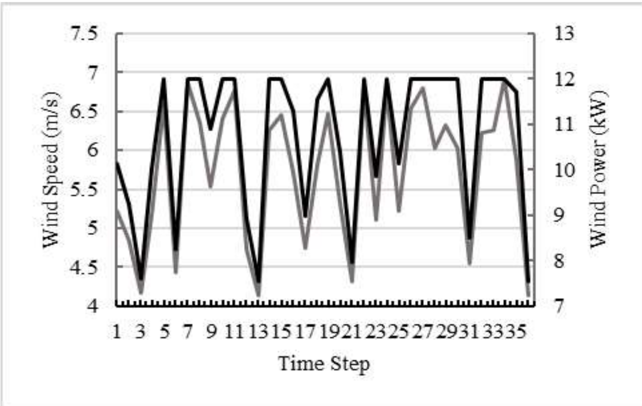

Fig. 1. Expected values of wind speed (Gray) & wind power (Black).

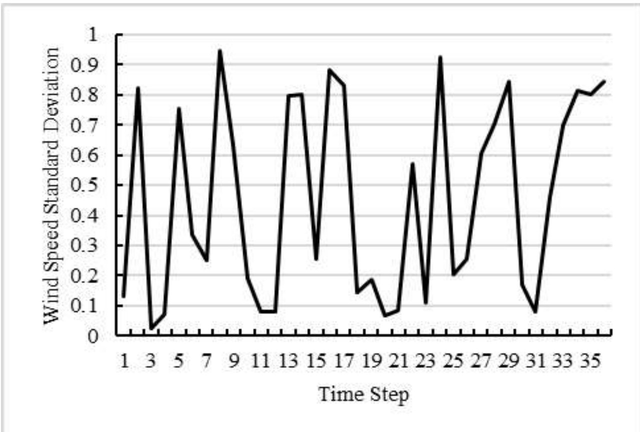

Fig. 2. Standard deviation of wind speed (m/s).

To evaluate the performance of the proposed model, in the first case study it is supposed that both forward and backward load shifting programs are possible in SDR as the scheme, which is used in [12]. Table I tabulates the amount of shifted load to different time intervals. It shall be noted that scheduling of BES is not presented in this table.

Additionally, the load shifting for other time intervals is zero. As the objective function of the proposed model is cost minimization, Table I demonstrates that the market operator tries to shift the load from high-price period to low-price period. For example, within the operation period 1*th* that the price energy price is high (28 C/kW), the market operator prefers to shift 133.88 kW to period 27*th* and 93.68 kW to period 4*th*, which have lower prices (energy prices in period 4*th* and 27*th* is 20 C/kW). According to Fig. 3, the minimum energy prices would happen in periods 10*th*, 16*th*, and 34*th*, which are 16 C/kW. Therefore, these periods are in the priority for load shifting from the peak periods (e.g. period 2*th* and 14*th*). It shall be noted that the cost of compensating the power shortage by generating units is higher than the shifting load. Therefore, the market operator prefers to do not use BES during high-price periods. However, this strategy is not always applicable. Multiple increasing/decreasing the power of generating units could decrease the lifetime of generating units.

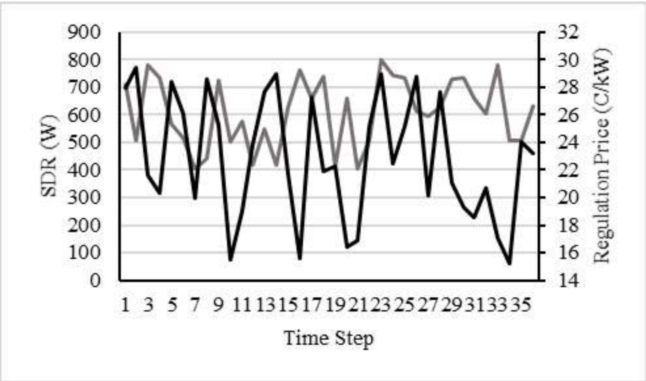

Fig. 3. Maximum SDR (Gray line) and regulation price (Black line).

TABLE I. SCHEDULING OF SDR IN REGULATION SERVICE WITH CONSIDERING FORWARD AND BACKWARD LOAD SHIFTING OPTIONS (W).

From	To	Amount	To	Amount	To	Amount	To	Amount
1	27	133.88	4	93.68				
2	34	254.11	10	251.14	16	275.88		
5	11	219.75	30	366.50	7	201.86	27	164.39
6	24	20.09						
8	33	285.37	31	331.10	11	68.29		
9	24	162.54						
13	3	331.48	15	312.97	18	9.84		
14	16	105.00	20	329.03	21	143.72		
17	18	359.72	19	207.49	24	46.20		
22	24	144.03	36	254.08	12	161.33		
23	21	58.79	33	71.77				
25	12	48.91	35	254.08				
26	33	32.85						
28	4	273.46	32	303.26	29	364.41	3	60.21

As mentioned before, the backward load shifting is not possible in real-time operation (the highlighted cells in Table I). Within the short period before to the target-time (5-mins), the market operator has more accurate and reliable information about the expected power of renewable energy resources. In this work, it is supposed that the uncertainty of wind power for the next 5 mins (P_A^t) is modeled by the Eq. (15). Therefore, within this short period, the market operator shall decide to use BES or SDR. The main difference of BES and SDR is that usually in real-time, increasing the consumption is not possible. Therefore, SDR cannot be used in over-generation condition. However, the power of BES can be increased or decreased via charging and discharging capabilities.

Table II shows scheduling of SDR without considering the backward option. It shall be noted that the capacity payment for both case studies are equal. However, the actual load shifting payments (within 3 Hours period) in the first and second case are 1397.7 Cent and 1340.5 Cent, respectively. Moreover, the amounts of shifted load in first and second case studies are 1675.3 Wh and 1599.55 Wh, respectively. Evidently, the value of SDR in the second case study is lower than the first one. The main reason is that the backward load shifting is not allowed in the second case study.

TABLE II. SCHEDULING OF SDR IN REGULATION SERVICE WITHOUT BACKWARD LOAD SHIFTING OPTION (W).

From	To	Amount	To	Amount	To	Amount	To	Amount
1	27	133.88	4	93.68				
2	34	254.11	10	251.14	16	275.88		
5	11	219.75	30	366.50	7	201.86	27	164.39
6	12	20.09						
8	21	58.79	33	226.58	31	331.104	11	68.28
9	12	162.54						
13	15	312.97	18	341.32				
14	16	105.00	20	329.03	21	143.72		
17	18	28.24	19	207.49	24	372.86	35	4.82
22	35	249.29	25	310.15				
23	33	130.56						
26	33	32.85						
28	32	303.26	29	364.41	36	315.52	35	18.15

It shall be noted that in Tables I and II, the maximum load that can be shifted to each time interval is equal to 50 % of SDR. In other words, if SDR of time interval *i*th will be 200 W, the maximum load that can be shifted to this time interval is 100 W.

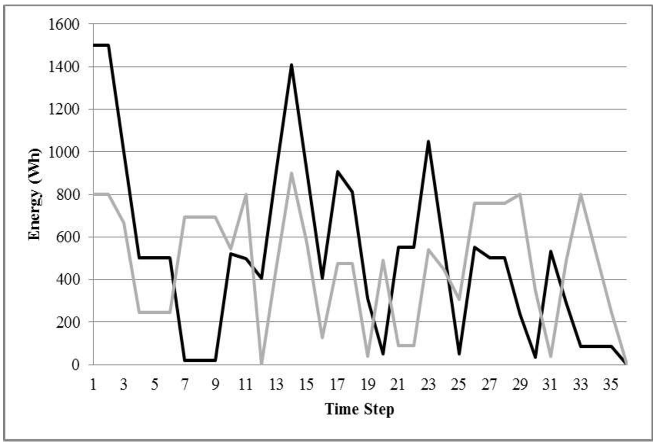

Fig. 4. Energy Levels of BES 1 (Black line) and BES 2 (Gray Line).

Fig. 4 represents the energy level of BES 1 and BES 2 in the regulation ancillary service. It shall be noted that the optimal charging and discharging power of battery energy storages are presented for the second case study. As seen in this figure, the energy levels of BESs are fixed when the regulation price is high (Fig. 3). By decreasing the regulation price, the operator tries to use BES in discharging mode to compensate the renewable power shortage and maintain the energy balance. However, in some high-price periods, BESs must be charged to neutralize the over-generation of wind-turbines. Usually, the market operator tries to use faster batteries to maintain the balance of generation and consumption. In this work, the ramp-rate of BES 1 is higher than BES 2. However, in some periods (such as 33, 34), the operator must use the BES 2. The main reason of this issue is the capacity limitation of BES 1. In case of modeling the distribution network, which is neglected in this work, the scheduling of BESs can be affected by the energy losses. In other words, the scheduling of BESs depends on the economic dispatch equations.

Fig. 5 shows the charging and discharging power of BESs, and amount of SDR, which is shifted to other operational periods.

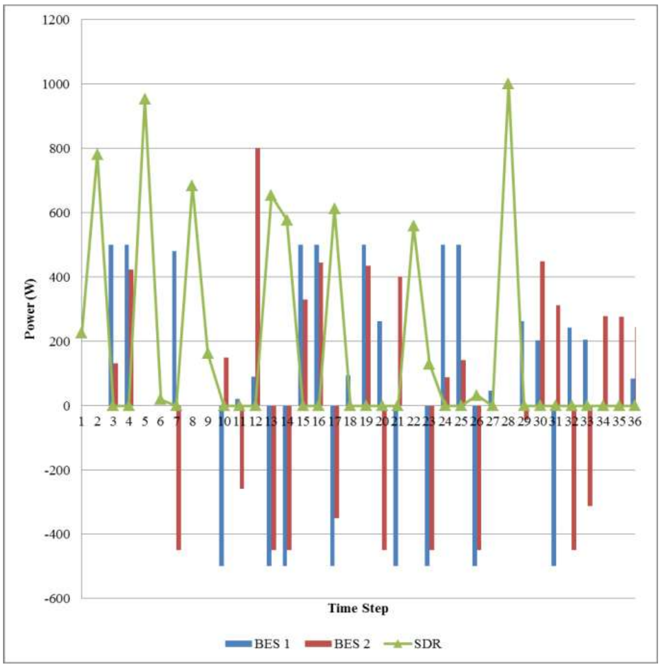

Fig. 5. Charging/discharging of BES and amount of SDR (W).

It shall be noted in this figure, the positive and negative values of BES power represent discharging and charging modes, respectively. According to Fig. 5, in mid-price periods (e.g. 3*th* and 4*th*), the operator uses the BESs to compensate the energy shortage, and prefers to commit SDR in high-price periods. Additionally, in this case study and within 3 hours period, the costs of participation BES1, BES 2, SDR (with considering capacity cost), are as follow:

TABLE III. OPERATIONAL COST OF BES AND SDR FOR PARTICIPATION IN REGULATION SERVICE.

Resource	**Cost (Cent)**
BES 1	11663.89
BES 2	6944.00
SDR	7570.5
Total	26178.39

According to the simulation results, without considering SDR, the operational cost of power system would increase to 30122.41 Cent.

IV. CONCLUSIONS

In this paper, a model for scheduling BES and SDR programs in the regulation ancillary service is presented. Fluctuations of renewable resource generating power are inevitable. Therefore, the main objective of the proposed model is the minimization of the regulation cost. Simulation results demonstrate that using SDR can cover the technical constraints of BES. The capacity and ramp-rate limitations of BES can limit its operation in regulation ancillary service and using SDR could improve the flexibility of network and reduce operational cost. The price of generating power by the energy resources is higher than load shifting. In other words, within peak-price period, the operator could shift part of load to low-price period instead of discharging BES. Therefore, the operator could provide the regulation service within mid-price and low-price periods by discharging BES, which reduces the operational cost. Evidently, some constraint of load such as maximum shifting, capacity, and maximum load are inevitable, and operator cannot provide all the required power for the regulation service by BES.

As the future work, the authors are going to model the frequency of grid, the dissatisfaction cost of consumer, which is resulted by the load shifting, and depth of charge of BES that is the important factor on lifetime of batteries.

REFERENCES

[1] Tulabing, R., Yin, R., DeForest, N., Li, Y., Wang, K., Yong, T., & Stadler, M. (2016). Modeling study on flexible load's demand response potentials for providing ancillary services at the substation level. *Electric Power Systems Research*, *140*, 240-252.

[2] Motalleb, M., Thornton, M., Reihani, E., & Ghorbani, R. (2016). Providing frequency regulation reserve services using demand response scheduling. *Energy Conversion and Management*, *124*, 439-452.

[3] Kiran, B. D. H., & Kumari, M. S. (2016). Demand response and pumped hydro storage scheduling for balancing wind power uncertainties: A probabilistic unit commitment approach. *International Journal of Electrical Power & Energy Systems*, *81*, 114-122.

[4] Tan, J., & Zhang, Y. (2017). Coordinated control strategy of a battery energy storage system to support a wind power plant providing multi-timescale frequency ancillary services. *IEEE Transactions on Sustainable Energy*, *8*(3), 1140-1153.

[5] Kim, W. W., Shin, J. S., & Kim, J. O. (2017). Operation strategy of multi-energy storage system for ancillary services. *IEEE Transactions on Power Systems*, *32*(6), 4409-4417.

[6] Zhang, X., Hug, G., Kolter, J. Z., & Harjunkoski, I. (2017). Demand response of ancillary service from industrial loads coordinated with energy storage. *IEEE Transactions on Power Systems*, *33*(1), 951-961.

[7] Brivio, C., Mandelli, S., & Merlo, M. (2016). Battery energy storage system for primary control reserve and energy arbitrage. *Sustainable Energy, Grids and Networks*, *6*, 152-165.

[8] Kazemi, M., Zareipour, H., Amjady, N., Rosehart, W. D., & Ehsan, M. (2017). Operation scheduling of battery storage systems in joint energy and ancillary services markets. *IEEE Transactions on Sustainable Energy*, *8*(4), 1726-1735.

[9] Godoy-González, D., Gil, E., & Gutiérrez-Alcaraz, G. (2020). Ramping ancillary service for cost-based electricity markets with high penetration of variable renewable energy. *Energy Economics*, *85*, 104556.

[10] Khojasteh, M., & Jadid, S. (2015). Decision-making framework for supplying electricity from distributed generation-owning retailers to price-sensitive customers. *Utilities Policy*, *37*, 1-12.

[11] Khojasteh, M., & Jadid, S. (2015). A two- stage robust model to determine the optimal selling price for a distributed generation owning retailer. *International Transactions on electrical energy Systems*, *25*(12), 3753-3771.

[12] Faria, P., & Vale, Z. (2019). A Demand Response Approach to Scheduling Constrained Load Shifting. *Energies*, *12*(9), 1752.