Coordinated Storage and Flexible Loads as a Network Service Provider: a Resilience-Oriented Paradigm

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***Abstract*—A resilience-oriented operation multi-time scale scheduling is proposed in this paper that deploys a coordinated storage and flexible loads (CSFLs) structure to act as a network service provider (NSP). The proposed proactive operation strategy can deal not only with intermittent wind generations in hourly operation but also with load supplying resilience for the sub-hourly variations. The energy storage systems (ESSs) can retain the state of charge (SoC) during the sub-hourly fine-tuning periods to supply critical loads for predefined time intervals. In this regard, by integrating the so-called NSPs into a stochastic unit commitment model, the advent-ages of ESSs and flexible loads (FLs) are taken to enrich the short-term scheduling for the different time resolutions. The proposed model is tested by the IEEE RTS-24 standard network. The results show that NSPs can successfully participate in providing coordinated ancillary services in different time-scales, and concurrently by support of FLs, the ESSs proactive role is also retained. The usage of CSFLs reduces the curtailment of wind energy, while they provide a large portion of reserves for the possible fluctuations.**

***Keywords*—Network Service provider, Multi-time scale scheduling, coordinated ESSs and flexible loads, Resilience, wind energy fluctuations, stochastic unit commitment.**

NUMENCLATURE

Indices and Sets

i, d, l	Indices of buses, demands, and lines.
c, w, v	Indices of ESS, wind, and CSFL units.
Ch / Dis	Indices of charging/discharging status.
g, k	Indices of generators and inside blocks.
$\max/\min$	Indices of maximum/minimum values.
n, s, t	Indices of intra-hour time-steps, scenarios (s_0=base case), and time (t_0=initial state).
$+/-$	Indices of up/down directions of re-dispatches.
$\phi, \Lambda, \sigma, \xi, \beta$	Sets of connected lines, demands, generators, wind farms, CSFLs to bus i.
κ, λ	Sets of connected flexible loads, and ESSs to CSFL v.

Variables

A	Available energy of ESSs.
$I, J1, J2$	Binary status of generators, and ESSs.
$L_{d,t}^{s,n}$	Demand after issuing control actions.
P	Power generation of units.
$P1_{c,t}^{s}, P2_{c,t}^{s}$	ESS charge/discharge.
r	Re-dispatch of generators in scenarios.
R	Deployed reserve from generators.
$R1, R2$	ESS reserves in charging/discharging modes during the retaining period.
$RL1, RL2$	Demand increase/decrease as FLs' reserves during the retaining period.
T	Set of switching time periods (on/off).
$X1, X2$	Auxiliary variables of energy backup for ESSs.
θ	Voltage buses' angle.

Constants

Fl, X	Power flow and reactance of lines.
Ru, Rd	Ramp rates in upward/downward.
S_{base}	Base power.
W	Available wind energy during the different scenarios.
π	Probability of scenarios.
η	Efficiency of ESS in charging/discharging.

I. INTRODUCTION

The integration of renewable energy resources (RESs) is attractive worldwide, however intermittent nature limits their expansion [1]. Because of this intermittency, a number of R&D and industrial activities have been carried, and the inteGRIDy is one of them [2]. The integrated smart GRID cross-functional solutions for optimized synergetic energy distribution, utilization storage technologies (inteGRIDy) project, a H2020 project funded by European commission, aims to integrate cutting-edge technologies, solutions, and mechanisms in a scalable cross-functional modular platform (CMP) [2].

The reserve provided by conventional generators is used to overcome the intermittent character of renewables [3], but the resulting pollutions from these generators cause environmental issues [4, 5]. Furthermore, using only the classical generators to overcome the intermittency of wind is not sufficient because of the dynamic response difference between the wind and classical generators [6]. This problem can be overcome by using the energy storage systems (ESSs), which have fast response dynamics and for this reason the authors of this papers were keen to use the ESSs to provide ancillary services. However, the usage of ESSs may lead to infeasible solutions in real-time operation. On the other hand, the use of flexibility of some loads is our second choice to address the uncertainty in the network [7]. The flexible loads (FLs) can provide reserve energy when they are entirely controlled by the operators. Also, the multi-time scale models open up new opportunities for the optimal use of existing equipment [8]. To sum up, the main idea of this paper is to take advantages of both ESSs and FLs to introduce a new framework for their active participation in the ancillary services market.

As a response to the demand for reliability, improving the quality of supply is an objective in the electricity markets. For this purpose, the authors of [9] investigated a resilience-oriented model to address lines outages, variation of loads. and variable generation. Also, the security evaluation of microgrids for estimating consumers' participation in reliability improvement is investigated in [10]. The optimal switching of lines is presented in [11] to address the uncertainties of wind energy and component outages. Reference [12] presents a review of the solutions used to deal with the intermittent character of wind in considering the potential reserves of wind energy at different countries and locations. A robust model for uncertainties of electric vehicles, loads, and prices is presented in [13].

In previous studies, the ESS performance to deal with uncertain operational conditions is considered in two categories: real-time and forward-contract based models. In real-time based models, the operators act based on the available information of wind power and the system frequency. In this way, wind integrated pumped hydro storage system is used to reach high penetration of wind power in an island in [14]. Reference [15] addresses the uncertainties with the hybrid ESS and wind power by using filter-based method. The ultra-capacitors and lithium-ion batteries are used for the fluctuations of wind power. In [16], renewables and load fluctuations are captured by ESSs with energy management based on frequency approach and polynomial controllers. In [10], the regulation provided by operator's request are used to keep frequency in a pre-defined range in real-time. In forward-contracts like the model of day-ahead markets, operators should make decisions based on the information of forecasted values of uncertain quantities. A robust unit commitment with considering storage devices and uncertain quantities is implemented in [17] to address the correlation of wind and solar power. In [18], the heat storage units and the combined heat and power, used for supply the heating demand, are used to deal with the wind energy variations. A convex perspective optimization is presented in [19] for a microgrid with storage and renewable generations. Reference [20] considers the uncertainties resulting from the penetration of plug-in vehicles (EVs), renewables, and load in a set of scenarios, where the EVs are considered as storages. An interval optimization is presented in [21] to deploy enough flexibility of pumped hydro storages to consider the renewable energy fluctuations. The model assumes the forecasted conditions as the base values for each time-step, and it checks the linking energy levels in different scenarios.

In forward-contract models, the operators cannot make accurate decisions as they do not have the exact information about the future behavior of demanded reserves. The authors in [22] claimed that the previous works did not consider the energy management of the storage under uncertainties. The authors presented a stochastic model with a limited horizon of the look-ahead performance of storage to capture wind variations, but the proposed method cannot deal with the unforeseen sequence of scenarios. Also, a stochastic model for contingencies and wind variations in the presence of ESSs and FLs is presented in [23], while it estimates a range for the feasible storage compensation.

Other studies consider also the demand response and flexibility of loads as an ancillary services provider. In [24], the operational cost of residential loads is reduced using the demand response. A real-time method for pricing the demand response is suggested in [25]. Reference [26] presents a model with demand response and maximizing the social welfare for unit commitment. The regulation of controlled devices and load shifting have been seen as a source of regulation and storage capacity in [27]. Reference [7] introduces the fast response of adjustable loads to address the variations in the system. The major challenge in the deployment of FLs for ancillary services is that they should be managed directly by operators in real-time and they may be interrupted without any previous permissions or alerts. This problem may reduce the willingness of consumers to offer such services. In this way, the self-dispatch of units is an option in models with aggregation of distributed units [28].

The solution obtained from the multi-resolution models gives higher reliability as they consider the uncertainties in details. A multi-resolution robust unit commitment is presented for load and wind uncertainties in [29], while the model optimizes the solution for the predicted scenarios and considers enough ramp capabilities without corresponding costs. The authors of [30] studied a coordinated multi-time scale model with storages and under high penetration of RESs.

In this paper, a multi-time scale stochastic unit commitment (SUC) is presented to capture the fluctuation of wind power in a joint energy and reserve market model. In the proposed model, the coordinated storages and FLs (CSFLs) have participation in service provision to the network at different time-scales. The ESSs will immediately compensate the sub-hourly fluctuations, while the FLs have a time-gap to recover the state of charge (SoC) level of ESS. In other words, the model takes advantages of the fast response of ESSs and the increasing share of FLs. By applying this approach, the issue of shortage in ESS energy and the obligation of the immediate interruption of FLs are solved. The main contributions of this paper are summarized as follow:

- To provide CSFLs as a proactive network service provider (NSP) entity;
- To solve the issue of deficiency of the SoC level of ESSs because of their participation in uncertainties;
- To solve the issue of sudden interruptions of flexible loads in fully control obligations;
- Preparing sub-hourly ancillary services to address RESs' intermittencies with higher resolution, and therefore enhancing the network reliability.

The rest of the paper is organized as follows. The problem formulation including scenarios of wind power, models of ESSs and FLs are described in section II. Section III shows and discusses the results, and section IV gives the conclusion.

II. The Network Service Providers Model

This section is describing the proposed model for multi-resolution scheduling of CSLFs as a network services provider. First, the scenario generation for wind fluctuations is illustrated in the following subsection. The SUC model in joint energy and reserve market will be presented under the day-ahead time horizon. Also, the models of ESSs and FLs for active participation in wind power variations in the different time-scales are formulated in the corresponding subsection.

A. Scenarios of Wind Power

The scenarios of wind power are considered in two levels of time-scale. The hourly base scenarios of wind are generated based on Weibull distribution function around the mean value of predicted wind speed. An increasing standard diversion is considered during the operation period. Then, four scenarios with the diversion less than 10% is generated around each scenario using the normal function. Then, the scenario reduction is performed based on probability distance method. The expected value of four intra-hour samples is considered as the correspond-ding scenario of wind speed. The wind power is obtained based on the power function of wind turbines.

B. Model of Energy Storage Systems

As stated before, in this work the model of coordinated ESSs and FLs is considered to compensate the wind power variations. The cooperation mechanism between ESSs and FLs is such that the ESS will immediately respond to the wind power variation. In the next time-step, the FLs are adjusted their consumption to back-up the ESS variations of energy level in the previous step. The ESS model is presented in (1)-(12).

$$P1_{c}^{\min}\cdot J1_{c,t}^{s_0,n}\le P1_{c,t}^{s_0}\le P1_{c}^{\max}\cdot J1_{c,t}^{s_0,n} \tag{1}$$

$$P2_{c}^{\min}\cdot J2_{c,t}^{s_0,n}\le P2_{c,t}^{s_0}\le P2_{c}^{\max}\cdot J2_{c,t}^{s_0,n} \tag{2}$$

$$P1_{c}^{\min}\le P1_{c,t}^{s_0}+R1_{c,t}^{s,n}\le P1_{c}^{\max} \tag{3}$$

$$P2_{c}^{\min}\le P2_{c,t}^{s_0}+R2_{c,t}^{s,n}\le P2_{c}^{\max} \tag{4}$$

$$R1_{c}^{\min}\cdot J1_{c,t}^{s_0,n}\le R1_{c,t}^{s,n}\le R1_{c}^{\max}\cdot J1_{c,t}^{s_0,n} \tag{5}$$

$$R2_{c}^{\min}\cdot J2_{c,t}^{s_0,n}\le R2_{c,t}^{s,n}\le R2_{c}^{\max}\cdot J2_{c,t}^{s_0,n} \tag{6}$$

$$P_{c,t}^{s,n}=P1_{c,t}^{s_0}-P2_{c,t}^{s_0}+R1_{c,t}^{s,n}-R2_{c,t}^{s,n}+X1_{c,t}^{s,n}-X2_{c,t}^{s,n} \tag{7}$$

$$A_{c,t}^{s,n}=A_{c,t}^{s_0}+(R1_{c,t}^{s,n}+X1_{c,t}^{s,n})\cdot\eta^{Ch}-(R2_{c,t}^{s,n}+X2_{c,t}^{s,n})/\eta^{Dis} \tag{8}$$

$$A_{c,t}^{s_0}=A_{c,(t-1)}^{s_0}+(P2_{c,t}^{s_0})\cdot\eta^{Ch}-(P1_{c,t}^{s_0})/\eta^{Dis} \tag{9}$$

$$A_{c,t_0}^{s_0}=A_{c,t_{24}}^{s_0} \tag{10}$$

$$A_{c}^{\min}\le A_{c,t}^{s,n}\le A_{c}^{\max} \tag{11}$$

$$J1_{c,t}^{s,n}+J2_{c,t}^{s,n}\le 1. \tag{12}$$

The dispatch limits of the base schedule and in compensation mode are presented in (1)-(6). The overall dispatch of ESS is obtained by (7), and the relations between energy and dispatches are presented in (8) and (9). Energy limits are checked in (10) and (11). Eq. (12) checks ESSs' status in different modes.

C. Model of Flexible Loads

In new market designs, private suppliers can participate in day-ahead and ancillary service markets. In this respect, the industrial or coordinated commercial loads can offer their services for balancing the real-time mismatches. The variation in output of uncertain resources is unknown before the real-time. As the sudden interruptions of loads are not attractive to consumers, the proposed model offered a duration of gap-time for preparation. The model takes advantages of fast response of ESSs without any conflict to their primary schedule. By considering the aggregation of ESSs and FLs, a flexible source of ancillary service will become feasible for system operators. This strategy will provide a time-gap for the decision of aggregators to select the desired FLs. Also, the readiness of consumers to participate in the ancillary services will be increased with being aware of the control orders during the next time periods. The model of flexible loads is presented in (13)-(21).

$$RL1_{d,t}^{s,n}\le RL1_{d,t}^{\max} \tag{13}$$

$$RL2_{d,t}^{s,n}\le RL2_{d,t}^{\max} \tag{14}$$

$$\sum_{c\in\lambda(v)} R1_{c,t}^{s,(n+1)}=\sum_{d\in\kappa(v)} RL2_{d,t}^{s,n} \tag{15}$$

$$\sum_{c\in\lambda(v)} R1_{c,(t+1)}^{s,n_1}=\sum_{d\in\kappa(v)} RL2_{d,t}^{s,n_4} \tag{16}$$

$$\sum_{c\in\lambda(v)} R2_{c,t}^{s,(n+1)}=\sum_{d\in\kappa(v)} RL1_{d,t}^{s,n} \tag{17}$$

$$\sum_{c\in\lambda(v)} R2_{c,(t+1)}^{s,n_1}=\sum_{d\in\kappa(v)} RL1_{d,t}^{s,n_4} \tag{18}$$

$$\sum_{c\in\lambda(v)} X1_{c,t}^{s,n}=\sum_{d\in\kappa(v)} RL2_{d,t}^{s,n} \tag{19}$$

$$\sum_{c\in\lambda(v)} X2_{c,t}^{s,n}=\sum_{d\in\kappa(v)} RL1_{d,t}^{s,n} \tag{20}$$

$$L_{d,t}^{s,n}=L_{d,t}^{s_0}+RL1_{d,t}^{s,n}-RL2_{d,t}^{s,n}. \tag{21}$$

The maximum increase and decrease in loads are presented in (13) and (14), respectively. The ESS variation from the base schedule will be compensated by coordinated loads in the next time-steps based on (15)-(18). The auxiliary variables "X" in (19) and (20) is defined to avoid the simultaneous operation of ESS in compensation and backup modes. The base load and FLs accumulate as the total load in the variable "$L_{d,t}^{s,n}$" in (21).

D. Multi-time Scale SUC Model

The objective function of intended SUC is presented in (22), and the corresponding constraints are (1)-(21), and (23)-(41). The function "f" is used to present various cost. The objective consists of the cost of energy and reserves. The fixed cost includes the start-up, shut-down, and no-load costs. Variable costs include the upward and downward reserves, the expected generation of different scenarios, and the generation cost of ESS in the base schedule and the compensation modes. The cost of FLs is not considered in the objective function. Loads will compensate the same dispatches with a duration gap. So, the compensation cost will share based on their contracts.

$$\min \sum_{t}\left(\begin{array}{l}\sum_{g}\left(\begin{array}{l} f(st_{g,t},sd_{g,t},I_{g,t})+f(R_{g,t}^{+})+\\ f(R_{g,t}^{-})+\sum_{s\ge 1}\pi_s\cdot\left(\sum_{k} f(P_{g,t}^{k,s})\right)\end{array}\right)+\\ \sum_{c}\left(f(P1_{c,t}^{s_0})+\sum_{s\ge 1}\pi_s\cdot\left(\sum_{n} f(R1_{c,t}^{s,n})\right)\right)\end{array}\right) \tag{22}$$

S.t. (1)-(21) and :

$$st_{g,t}-sd_{g,t}=I_{g,t}-I_{g,(t-1)} \tag{23}$$

$$st_{g,t}+sd_{g,t}\le 1 \tag{24}$$

$$[T_{g,(t-1)}^{\text{on}}-T_{g}^{\text{on,min}}]\cdot[I_{g,(t-1)}-I_{g,t}]\ge 0 \tag{25}$$

$$[T_{g,(t-1)}^{\text{off}}-T_{g}^{\text{off,max}}]\cdot[I_{g,t}-I_{g,(t-1)}]\ge 0 \tag{26}$$

$$P_{g,t}^{k,s}\le P_{g}^{k,\max}\cdot I_{g,t} \tag{27}$$

$$P_{g,t}^{s_0}\ge P_{g}^{\min}\cdot I_{g,t} \tag{28}$$

$$P_{g,t}^{s}\ge P_{g}^{\min}\cdot I_{g,t} \tag{29}$$

$$P^{s_0}_{g,(t+1)} - P^{s_0}_{g,t} \leq Ru_g \quad (30)$$

$$P^{s_0}_{g,t} - P^{s_0}_{g,(t+1)} \leq Rd_g \quad (31)$$

$$P^{s}_{g,t} = \sum_k P^{k,s}_{g,t} \quad (32)$$

$$P^{s}_{g,t} = P^{s_0}_{g,t} + r^{+,s}_{g,t} - r^{-,s}_{g,t} \quad (33)$$

$$R^{+}_{g,t} \geq r^{+,s}_{g,t} \quad (34)$$

$$R^{-}_{g,t} \geq r^{-,s}_{g,t} \quad (35)$$

$$r^{+,s}_{g,t} \leq Ru_g \cdot I_{g,t} \quad (36)$$

$$r^{-,s}_{g,t} \leq Rd_g \cdot I_{g,t} \quad (37)$$

$$P^{s}_{w,t} \leq W^{s}_{w,t} \quad (38)$$

$$\left| Fl^{s,n}_{l,t} = S_{\text{base}} \cdot (\theta^{s,n}_{\text{from}(l),t} - \theta^{s,n}_{\text{to}(l),t}) / X_l \right| \leq Fl^{\max}_l \quad (39)$$

$$-\pi/2 \leq \theta^{s,n}_{i,t} \leq \pi/2 \quad ; \quad \theta^{s,n}_{i_{\text{slack}},t} = 0 \quad (40)$$

$$\sum_{l\in\phi(i)} Fl^{s,n}_{t,l} + \sum_{d\in\Lambda(i)} L^{s,n}_{d,t} = \sum_{g\in\sigma(i)} P^{s}_{g,t} + \sum_{w\in\xi(i)} P^{s,n}_{w,t} + \sum_{c\in\beta(i)} P^{s,n}_{c,t}. \quad (41)$$

The start-up/shut-down and on/off binary variable relations are presented in (23) and (24). Minimum up/down time limits are considered in (25) and (26). The minimum and maximum generation constraints are presented as (27)-(29). Ramp rate limits are defined as (30) and (31). The constraints of generation in different scenarios are checked in (32)-(37). Maximum wind production in each scenario is limited in (38). The load flow and voltage angle constraints are considered as (39) and (40). The load balance equation is presented as (41) for each bus.

III. Simulation Results

The numerical results of the proposed model are evaluated in this section. The RTS-24 test system is used as the study case based on data in [31]. Three 300 MW wind farms and 12 ESSs with hourly dispatch capacity of 50 are distributed in buses number 4, 14, and 17. The efficiency of ESSs is 95%. The results are analyzed in different aspects and at different time-scale. The model was performed using CPLEX, on a laptop with Intel i7-core 2.4 GHz and 8 GB of RAM.

A. SUC Dispatches on Base Schedule

The dispatch of the units during the operation period is obtained in Fig. 1. The ESSs are filling the valley of load curve, while they re-generate at peak load. The ESSs and wind farms reduce the peak load of the system. Fig. 2 is comparing the detailed dispatch of ESSs in the base schedule in two cases. By using the ESS in compensation of wind power uncertainties, it can be seen that the base schedule will be changed.

B. Reserves for Wind Power Fluctuations

In the joint energy and reserve markets, the spinning reserves are the regular source of operators to address the variation of wind power. As shown in Fig. 3, the optimally deployed reserves for covering the wind uncertainties is supplied from generators with and without the participation of CSFL units. It can be seen that with considering the participation of CSFLs, a large part of the upward reserve will be provided by the CSFLs. The downward reserves are mainly provided by the regular units

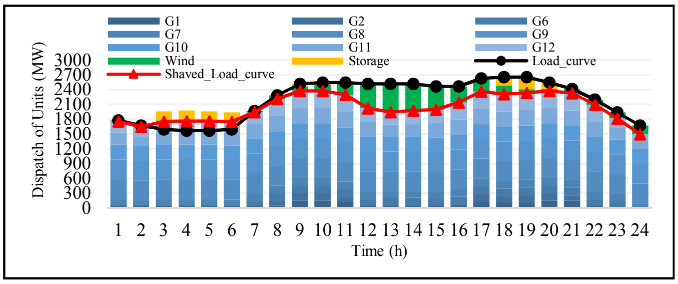

Fig. 1. SUC result for dispatches of units

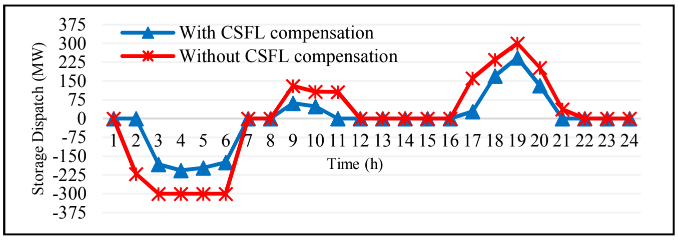

Fig. 2. ESSs base schedule in charge/discharge modes

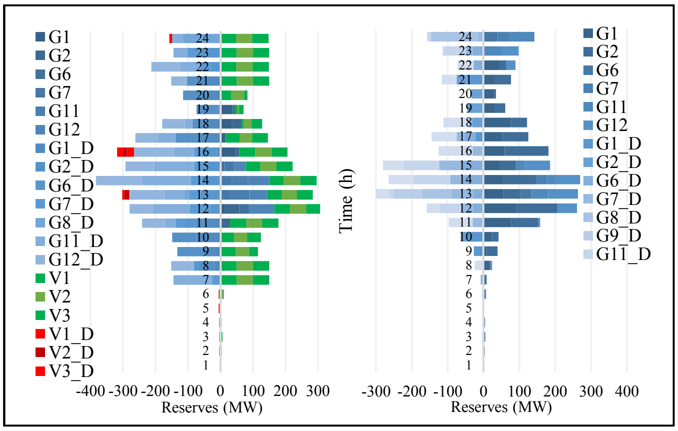

Fig. 3. Reserves with (left) and without (right) CSFLs participation

because this reduction will save a higher value of total cost. Also, the reserve deployments in both directions are increased because the participation of CSFLs changes the operation point.

C. Wind Penetration and Curtailment

The policy of increasing wind penetration is accompanied by the readiness of operators for reducing the curtailment of wind power. The wind penetration is the share of hourly load sup-lied by the wind generation. Fig. 4 shows the wind penetration in the operation period. Up to 20% of the penetration of wind power is achieved while using the CSFLs increases these values. The corresponding curtailment power is compared based on the participation modes of CSFL units in Fig. 5. With the CSFLs' participation, the wind curtailment is significantly reduced.

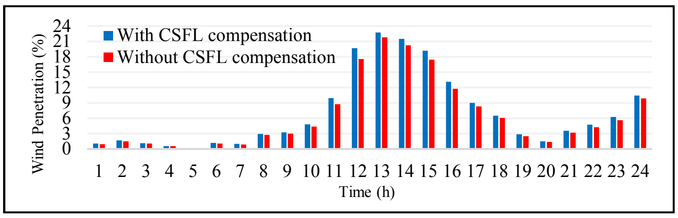

Fig. 4. Wind penetration over operation period

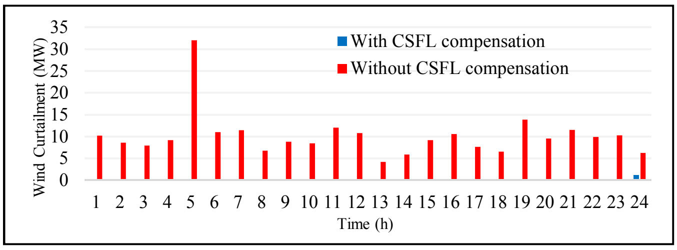

Fig. 5. Wind curtailment over the operation period

D. Cost Evaluation for the Proposed Model

The objective function of this study is regarded as the minimization of total cost. By considering a new ancillary service in two levels of hourly and intra-hour participations, new players will receive their profits. It is expected the operational cost increases, while the model takes into account the price of intra-hour balancing services. With the participation of CSFLs in covering the wind uncertainties, the total operational cost is reduced about \$13195.27 and falls to \$293723.85 for 24 hours.

E. Covering the Uncertainties on the Hourly Basis

To investigate the impact of the model, we first perform the conventional reserve deployment without considering the CSFL participation. The scenario realization for hour 13 is presented in Table I. It can be seen that the wind power variations are only absorbed by re-dispatch of the generators. Table II represents the realization of scenarios with the participation of CSFL in the proposed model. We can see the CSFLs successfully participate in the compensation of wind fluctuations in different scenarios.

TABLE I. EVALUATION IN SCENARIOS WITHOUT CSFL COMPENSATION

For t=13	Re-dispatches in different scenarios (MW)				
	S1	*S2*	*S3*	*S4*	*S5*
W1	322.35	212.799	265.234	113.089	159.175
W2	429.79	283.732	353.645	150.786	212.233
W3	101.38	39.465	72.048	21.961	24.213
ΔG1	0	0	0	55.74	0
ΔG2	0	0	0	45.6	0
ΔG6	-28.851	0	-26.252	31	31
ΔG7	-62	0	-62	0	0
ΔG8	-80	0	0	0	0
ΔG9	-80	0	0	0	0
ΔG11	-14.18	0	-14.179	47.821	47.821
ΔG12	-39.88	12.617	-39.883	82.617	74.1712
ΣPG^{S_0}	1969.36	1969.36	1969.36	1969.36	1969.36
Sum	2517.98	2517.98	2517.98	2517.98	2517.98
Load	2517.98	2517.98	2517.98	2517.98	2517.98

F. Covering the Uncertainties on the Intra-hour Basis

As mentioned, the CSFLs have an intra-hour compensation option that can damp the unbalances in every 15 minutes. Table III shows the intra-hour dispatches of CSFLs for scenario two and at hour 13. It can be seen that the sum of total generations is equal to the load. It should be noted that the base load is supplied in each scenario and in each time-steps. So, the load variation is used to restore the ESS energy based on its compensation action in the previous time-step. In other words, the load variations is an internal transaction that has an impact on the power flow of transmission lines. The highlighted average value of CSFL units is matched to the reserve value in Table II. This results proved that the proposed model is successfully deployed CSFLs in a coordinated hourly and sub-hourly application.

TABLE II. EVALUATION IN SCENARIOS WITH CSFL COMPENSATION

For t=13	Re-dispatches in different scenarios (MW)				
	S1	*S2*	*S3*	*S4*	*S5*
W1	322.35	212.799	265.234	113.089	159.175
W2	429.8	283.732	353.645	150.786	212.233
W3	122.91	72.225	98.428	29.087	45.43
V1	0	45.564	43.75	42.246	42.455
V2	-15.05	39.369	40.755	46.35	37.5
V3	-6.48	39.783	39.115	48.261	48.828
ΔG6	-62	-62	-62	0	0
ΔG7	-35.55	-4.554	-35.554	26.446	0
ΔG8	-12.59	0	0	0	0
ΔG11	-62	-28.797	-62	62	0
ΔG12	-108.57	-25.322	-108.574	54.535	27.178
ΣPG^{S_0}	1945.18	1945.18	1945.18	1945.18	1945.18
Sum	2517.98	2517.98	2517.98	2517.98	2517.98
Load	2517.98	2517.98	2517.98	2517.98	2517.98

TABLE III. EVALUATION OF INTRA-HOUR BALANCING PERFORMANCE

For t=13	Re-dispatches (MW)				
	n1	*n2*	*n3*	*n4*	*Ave*
ΣPW	586.217	568.472	535.99	584.34	584.339
ΣPG^{S_0}	1824.50	1824.50	1824.50	1824.50	1824.503
V1	32.255	50	50	50	45.564
V2	50	25	57.476	25	39.369
V3	25	50	50	34.132	39.783
Sum	2517.98	2517.98	2517.98	2517.98	-
Load	2517.98	2517.98	2517.98	2517.98	-

G. Resilience Oriented ESSs Energy Restoration

One of the motivations of using the ESSs to address real-time variations is the feasibility of the final solution. As it reviewed, ESS will violate the base schedule if it works in different scenarios. The proposed model takes advantages of ESSs' fast response without such issues. Table IV indicates the sub-hourly re-dispatches of ESS to the unbalances and the corresponding reaction of FLs in the next time-step. The results of this table are presented for the 2nd scenario at hour 13. It can be observed that the highlighted values are fully matched with the corresponding values in Table III. The reaction of FLs in the first step of hours depends on the last time-step of the previous hour. As it can be seen, by the proposed proactive sub-hourly fine-tuning, can retain the SoC of ESSs in an operator's defined levels in order that it can supply the critical loads for a predefined time intervals after the occurrence of an event and enhance systems resilience.

TABLE IV. EVALUATION OF MODEL IN ESS RESTORATION

For t=13	Re-dispatches at intra-hour time-steps (MW)				
	unit	*n1*	*n2*	*n3*	*n4*
S1	ESS	0	0	0	0
	FL	-50	0	0	0
S2	ESS	32.255	50	50	50
	FL	-9.068	-32.255	-50	-50
S3	ESS	0	75	25	75
	FL	-38.095	0	-75	-25
S4	ESS	50	25	68.983	25
	FL	-50	-50	-25	-68.983
S5	ESS	0	69.821	25	75
	FL	-73.977	0	-69.821	-25

IV. CONCLUSION

A coordinated storage and flexible loads structure as a network service provider is proposed in this paper. The model considers the participation of ESSs in compensation of wind fluctuations, while the FLs restore the energy level of ESSs in the following time-steps. The model prepares an option to self-dispatch between the coordinated units. Also, the flexible loads have a time-gap to be informed about the next time-steps offers. The results show that coordinated ESSs and FLs supply the main up-ward reserves, and coordinately address the sub-hour fluctuations. The proposed model of CSFLs simultaneously deploys the hourly and sub-hourly network services for DERs' (here wind power) variations without any conflict. Also, the wind power curtailment is significantly reduced, while the model decreases total operational cost. The results demonstrate the effectiveness of the proposed NSPs concept to maximize the benefits (reducing cost and enhancing systems resilience) of a system operator that deploy the proposed framework.

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