Optimal Scheduling Strategy in Insular Grids Considering Significant Share of Renewables

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***Abstract*—Due to the uncertainty and stochastic behavior of wind and photovoltaic production introduced in conventional power systems, the correct overall management considering all the technical and economic constraints is faced with more challenges. To address also the specificities of insular power systems, several strategies have been proposed in last years, including energy storage systems with the aim of increasing system flexibility. Accurate forecasting tools may also help to reduce overall uncertainty. Other scheduling tools based on probabilistic, heuristic and stochastic programming have also been considered. In this work, a new scheduling strategy is proposed considering the integration of wind production in an insular power system. To this end, some arbitrarily chosen scenarios from wind production are introduced in the scheduling process, and a comparative study is carried out, with and without renewable production, providing an acceptable computational time.**

Keywords—insular system; scheduling; uncertainty; wind.

I. Introduction

A. Motivation and Approach

In last years, the focus on insular power systems has significantly increased due to its natural features, sensitivities, and (in)capabilities that allow the development of new computational tools with scalability to mainland power systems, with computational tractability and acceptable time.

Insular systems have by nature high renewable potential, which brings more uncertainty in the daily production management, mainly when wind and photovoltaic power is integrated in power systems, incrementing the overall operational cost, the conventional and pollutant gases emissions, reducing the power reliability, robustness or service quality, even under the smart grid paradigm [1]. One of the ways to mitigate the aforementioned renewable impacts in insular power systems is by introducing energy storage systems, based on hydro reservoirs, or more recently with batteries, which improves the flexibility of power systems; however, such technologies are heavily dependent on insular features, cost of implementation, lifetime, and careful design of their integration to be profitable [2, 3].

In this work, a new scheduling strategy is proposed for the integration of wind production in an insular system.

To this end, some scenarios, arbitrarily chosen, from forecasted wind and load, are introduced in the scheduling process, and a comparison with the same system without renewable production will be carried out, trying to produce the desired results in an acceptable computational time, with a reduced uncertainty related with forecasted data, showing the benefits to increase the integration of renewables in the considered insular power system.

B. Literature Review

In the last years, efforts done by the scientific community to overcome the power system scheduling problems have been significant.

For instance, in [4] a robust optimization unit commitment (UC) approach was proposed considering wind uncertainty for scheduling the conventional generation in the daily market, minimizing the total cost under the worst wind power scenario.

In [5], an optimal UC decision tool was proposed for the reliability UC run by the Independent System Operator (ISO), with the goal of maximizing the total social welfare under the joint worst-case wind power and demand response (DR) scenarios, formulated as a multi-stage robust mixed-integer programming and Benders' decomposition.

In [6], the operation scheduling problem in renewable-powered microgrids was considered for the least-cost UC and dispatch, considering the load, environmental, and operational constraints. To this end, a probability approach was considered to analyze the microgrid capabilities to meet the local demand.

In [7], a review of the state-of-the-art was presented related with UC and scheduling research, i.e., from the deterministic resolution, to mixed integer programming, crossing to priority list, dynamic programming, Lagrangian relaxation and stochastic optimization, giving a perspective on how to model UC problems facing deregulated electricity markets, growing demand, and higher integration of renewables.

In [8], a multi-objective tool is described due to the combination of the economic and emission problems. In this sense, a weighted sum model was proposed to analyze the multi-objective problem as a single objective problem, by a linear combination of different purposes as weighted sum.

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An efficient hybrid algorithm was proposed to solve the UC problem considering a scenario generation/ reduction model for the high potential of wind power, priority list, for solving the spinning reserve and other constraints, improved with a genetic algorithm.

In [9], a method was proposed to determine an optimal solution for profit-based UC problem considering emission constraint, under a deregulated environment. To this end, an imperialist competitive algorithm in combination with a meta-heuristic constraint handling technique was proposed, using the operation features of profit-based UC and a penalty factor approach to solving the emission constraints in order to maximize the producers' profit. Then, the problem was formulated under a scheduling process for the daily market under a scalability perspective.

In [10], an economic dispatch model was presented considering the energy storage and renewable energy potential divided into two steps. The first one was formulated as stochastic UC approach with wind power forecast uncertainty and energy storage. In the second step, the solution from the stochastic UC was used to derive a flexible schedule for energy storage in economic dispatch.

In [11], a UC problem was proposed based on the cost-benefit analysis and here-and-now approach for optimal sizing of energy storage system based on batteries in a microgrid with wind power potential, where wind power uncertainty was considered as a constraint. Particle swarm optimization was used to minimize the total cost and maximize the total benefit, considering some scenarios with and without energy storage, to stand-alone and grid-connected options.

C. *Contributions*

The contributions of this study are:

- To provide an optimal scheduling tool considering a case study with and without wind production, maximizing the profits and reducing operational costs and pollutant emissions.
- To include some random scenarios of load and wind with a reduced uncertainty in the forecasts, showing the benefits of using the renewable potential in this conventional power system in a reduced computational time.

The remaining manuscript is structured as follows: Section II presents the proposed approach and case study; Section III describes the main results conducted in this work; and finally, main conclusions are presented in Section IV.

II. PROPOSED APPROACH

The proposed approach considered the UC and scheduling problem with conventional generation, together with a random scenario of wind and load considering a real case-study based on an islanded power system. As reported in most of the present state-of-the-art, the UC problem usually uses a quadratic formulation considering the fuel cost from the corresponding production and some constraints such as starting costs, among others.

In this work, the proposed UC and scheduling problem is solved by:

$$TC = \sum_{t=1}^{T} \sum_{g=1}^{G} \left(a_g S_g^t + b_g P_g^t S_g^t + c_g \left(P_g^t\right)^2 S_g^t \right) fuel + \\ + ST_g^t \left(1 - S_g^{t-1}\right) S_g^t \tag{1}$$

where TC is the total cost; a_g, b_g and c_g are parameters related with operational curve line of generator g; $fuel$is the cost of fuel in l/\$ P_g^t is the output power of generator g at time t; S_g^t is the binary status of unit g at time t (1 – On; 0 – Off) and ST_g^t are the starting cost (cold and hot starting-up cost) linearly approximated considering [12] and [13]. Moreover, the problem is subject to:

$$P_{min}^g S_g^t \leq P_g^t \leq P_{max}^g S_g^t \tag{2}$$

$$P_g^t - P_g^{t-1} \leq UR_g \tag{3}$$

$$P_g^{t-1} - P_g^t \leq DR_g \tag{4}$$

$$Reserve = \delta \times Load_f \tag{5}$$

$$\sum_{t=1}^{T} P_g^t S_g^t + W^t = Load_f \tag{6}$$

$$0 \leq W_f^t \leq W_{max} \tag{7}$$

where (2) is related with power generation constraint limits of unit g according with its minimum P_{min}^g or maximum P_{max}^g capacity, respectively and its status S_g^t; (3) and (4) are related with the ramping constraints between the actual and previous state. Moreover, (5) is related with the required spinning reserve determined by δ and the forecasted load $Load_f$, and (6) describes the power balance of the system. Finally, (7) describes the maximum wind power generation W_f^t.

The case study under analysis is briefly represented in Figure 1.

Moreover, Figure 2 shows the load and wind power forecast results for 24 hours ahead [14].

Table I shows the features of power system under analysis, in particular the conventional generation, considering the cold cc_g and hot cost hc_g, respectively.

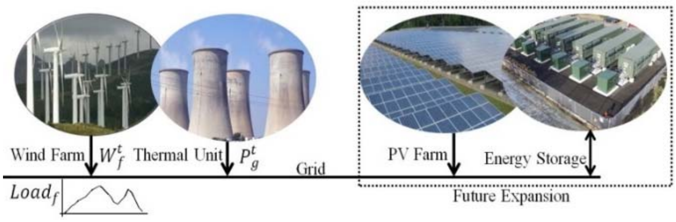

Fig. 1. Power system under analysis.

TABLE I
THERMAL GENERATION FEATURES

g	1	2	3	4	5	6	7	8	9	10
a_g ($/h)	1000	970	450	680	700	370	370	480	480	660
b_g($/MWh)	16.19	17.26	19.70	16.50	16.60	22.26	22.26	27.74	27.74	25.92
c_g ($/MW^{2}h) x10^{-4}	4.80	3.10	39.80	21.10	20.00	71.20	71.20	7.90	7.90	41.30
P_{min}^g (MW)	150	150	25	20	20	20	20	25	25	10
P_{max}^g (MW)	450	450	162	130	30	80	80	85	85	55
cc_g ($)	9000	10000	1800	1120	1100	340	340	520	520	60
hc_g ($)	4500	5000	900	560	550	170	170	260	260	30
UR_g (MW/h)	130	130	90	60	60	40	40	40	40	40
DR_g (MW/h)	130	130	90	60	60	40	40	40	40	40

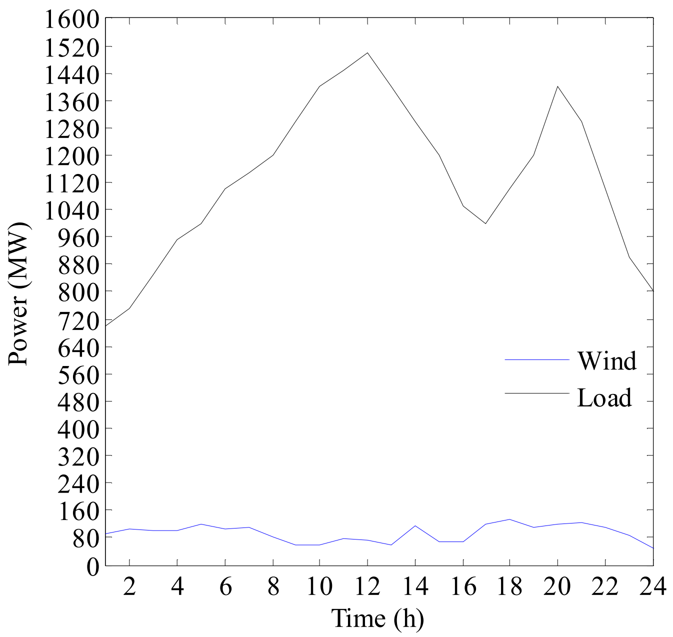

Fig. 2. Load and wind power day-ahead forecasted profiles.

For reserve requirements it was considered as $\delta = 10\%$ from the total capacity of conventional generation. The cost of fuel was considered as $fuel = 1.247\ \$/l$. The forecasted profiles from load and wind power were considered as the expected data with reduced error, i.e., less than 10%.

III. ANALYSIS OF RESULTS

The proposed UC and scheduling approach was performed using GAMS 24.0.2 [15] and considering the mixed integer quadratic programing (MIQP)/CPLEX solver.

Moreover, the hardware used was an Intel XEON X5690 with 3.46GHz and 48GB of RAM running with Windows 7.

Table II shows how the thermal generation units are scheduled for the next day without considering the wind generation.

It is possible to observe that generators 1 and 2 are working as base load and generators 3 till 10 are working according with the needs of the system. Moreover, it is possible to observe that some generators are scheduled momentarily like generator 10. In this sense, the total generation cost reached $532260.62.

Considering the wind generation and comparing the results obtained with those from ref. [14] it is possible to observe that, with the work developed in this paper, the costs decreased from $525220.60 to $517480.00, which is a considerable saving.

Moreover, while in [14] the computation time was about 1000ss, less than 30 seconds are now required, which is of major importance in real-time optimization.

Thus, avoiding the usage of a priority list, the results provided in this study are consistent with the original case study and close to the optimal point.

Table III shows how the thermal generation units are scheduled for the next day considering wind generation. It is possible to observe that generators 1 and 2 are working as base load and generators 3 to 10 are working according with the needs of system.

Moreover, it is possible to observe that generators 8 and 10 are not used for this day, but considering the analysis of generators 6 till 10, those generators are used as peak units.

TABLE II
SCHEDULING OF THERMAL GENERATION WITHOUT WIND POWER

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
g1	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455
g2	210	258	353	448	365	330	378	425	455	455	455	455	455	455	455	455	455	455	455	455	455	455	400	305
g3	0	0	0	0	0	0	0	0	0	160	162	162	160	65	100	88	40	135	100	160	65	135	0	0
g4	0	0	0	0	130	130	130	130	130	130	130	130	130	130	130	0	0	0	130	130	130	0	0	0
g5	0	0	0	0	0	130	130	130	130	130	130	130	130	130	0	0	0	0	0	130	130	0	0	0
g6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g7	0	0	0	0	0	0	0	0	65	0	46	80	0	0	0	0	0	0	0	0	0	0	0	0
g8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g10	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0

TABLE III
SCHEDULING OF THERMAL GENERATION WITH WIND POWER

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
g1	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455
g2	152	188	295	375	403	387	432	455	455	455	455	455	455	445	392	370	403	455	455	455	437	380	357	298
g3	0	0	0	0	25	25	25	60	50	128	137	162	130	25	25	25	25	55	50	89	25	25	0	0
g4	0	0	0	0	0	130	130	130	130	130	130	130	130	130	130	130	0	0	0	130	130	130	0	0
g5	0	0	0	0	0	0	0	0	130	130	130	130	130	130	130	0	0	0	130	130	130	0	0	0
g6	0	0	0	0	0	0	0	20	20	20	20	36	20	0	0	0	0	0	0	0	0	0	0	0
g7	0	0	0	20	0	0	0	0	0	0	20	36	20	0	0	0	0	0	0	20	0	0	0	0
g8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g9	0	0	0	0	0	0	0	0	0	25	25	25	0	0	0	0	0	0	0	0	0	0	0	0
g10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

IV. CONCLUSION

The work proposed in this paper provided a fast solution for the UC problem considering an islanded power system. The integration of wind power generation decreased the total operational cost and provided a reliable result in an acceptable computation time. The total operational cost was reduced from \$525220.60 to \$517480.00, considering previously published results, which is a considerable saving. As future wok, photovoltaic production can be included in the model to allow additional reductions in operating cost and pollutant emissions.

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