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An adaptive load dispatching and forecasting strategy for a virtual power plant including renewable energy conversion units

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HIGHLIGHTS

- Feasibility of virtual power plant concept for electricity market participation.
- An economic operation based adaptive load dispatching strategy.
- A new meteorological data forecasting algorithm.
- Long term scheduling of virtual power plant components.

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ABSTRACT

The increasing awareness on the risky state of conventional energy sources in terms of future energy supply security and health of environment has promoted the research activities on alternative energy systems. However, due to the fact that the power production of main alternative sources such as wind and solar is directly related with meteorological conditions, these sources should be combined with dispatchable energy sources in a hybrid combination in order to ensure security of demand supply. In this study, the evaluation of such a hybrid system consisting of wind, solar, hydrogen and thermal power systems in the concept of virtual power plant strategy is realized. An economic operation-based load dispatching strategy that can interactively adapt to the real measured wind and solar power production values is proposed. The adaptation of the load dispatching algorithm is provided by the update mechanism employed in the meteorological condition forecasting algorithms provided by the combination of Empirical Mode Decomposition, Cascade-Forward Neural Network and Linear Model through a fusion strategy. Thus, the effects of the stochastic nature of solar and wind energy systems are better overcome in order to participate in the electricity market with higher benefits.

1. Introduction

The recently growing concern on negative environmental impacts of conventional means of energy production leads the researchers to focus more on alternative sources of energy. Besides, depletion of fossil fuels and accordingly the increasing unit costs of fossil fuel-based energy production have also accelerated the mentioned research activities. Among the alternative sources, wind and solar energy conversion systems via wind turbines (WTs) and photovoltaic (PV) systems have found a remarkable area of use and there is an increasing trend for wider penetration of these systems due to the legal promotions of governments of the developed and developing countries [1]. However, the produced power from such sources is directly related to the meteorological conditions of the installation site and this stochastic nature provides a lower reliability and accordingly decreases the competition capability of the plant owner with conventional constant power producers in the electric market. Thus, there is a strong need for integrating these sources with dispatchable energy conversion systems in a proper hybrid combination to provide a reliable power supply [2].

This hybrid combination can be evaluated in two different scales. The first one is the small scale evaluation of such hybrid systems that supplies the demand of a specific place (a building, a group of buildings, an island, etc.) either in a stand-alone or grid parallel mode of operation. In this concept, the hybrid system components are physically in the same place and connected in a hybrid combination with suitable power conditioning units. The operation of such hybrid systems is evaluated in relevant literature studies given in Refs. [3–5]. A similar structure of hybrid combination can also be evaluated in large scale in the concept of recently investigated "Virtual Power Plant (VPP)" methodology.

VPP is a combination of different distributed generation (DG) units including renewable energy systems, conventional/non-conventional

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different types of generators and storage systems that can provide market actions as a single power plant supplying a pre-defined hourly power profile [6]. Thus, the strengths of some DGs can be utilized for preventing the weaknesses of other DGs (such as the dependence of WT and PV system-based power production on meteorological conditions). Hybrid system components of a VPP may be physically dislocated in different places of a country. There is an "aggregator" that makes contracts with each DG owner that contributes the VPP structure and provides a virtual hybrid system. Thus, the aggregator gains the chance of participating in the electricity market with a reliable constant supply of power. By this way, the owner of a non-dispatchable power plant can acquire the advantage of providing a higher economic value to the produced power of his unreliable power plant compared to the case of participating in the electricity market alone apart from being a part in a VPP structure. In general structure of electricity markets, aggregator acts in the market by bidding for electricity or offering electricity in day-ahead horizon. After the market clearing process, electricity market regulator determines a profile to be supplied by the relevant aggregator if reserves are neglected and the real electricity purchasing and selling amounts of the aggregator are considered in real-time market. It is to be noted that the proposed concept is only applicable for power markets where bilateral contracts are allowed due to the natural logic of the VPP structure. There must be contracts between the aggregator-plant owners and aggregator-customer as mentioned above and these contracts provide the basis of the VPP structure.

In the literature, Moghaddam et al. [7] presented a mixed integer linear programming (MILP) based optimum operation of a wind-hydro VPP considering the day-ahead scheduling of VPP components. The market energy prices and the deviations of wind power were considered with a risk aversion strategy on bidding prices in the mentioned study. A VPP structure including a wind power plant, PV power plant, conventional gas turbine power plant and pumped hydro storage system was evaluated by Pandzic et al. [8]. In Ref. [8], authors provided the modelling of the bilateral contract coordination and the day-ahead market bidding with a MILP-based optimization method. In a further study, a two-stage stochastic offering model for the day-ahead operation of a VPP consisting of a wind power plant, thermal conventional power plant and pumped hydro storage system was proposed by Pandzic et al. [9]. A MILP-based strategy that maximizes the VPP expected profit and a historical real-time measured data-based strategy to overcome the wind power uncertainty were employed in Ref. [9]. A heuristic game theory-based virtual power market model for security constrained unit commitment strategy was proposed in Ref. [10]. The wind power uncertainty was also considered as a part of the approach given in Ref. [10]. A probabilistic price-based unit commitment method allowing a VPP to provide unit commitment along distributed energy resources for day-ahead market sale/purchase bids was employed in Ref. [11]. The stochastic structure of market price and distributed power generation were also considered in Ref. [11], together with the possibility of exchanging energy with upstream network along different grid connection points. There are also many studies in the literature contributing the VPP operation evaluation from many different points of view.

In this study, the economic operation of a hybrid system in the VPP structure is evaluated to participate in the electricity market with high levels of reliable power production. Apart from the similar literature studies, the PV and WT systems are both considered with necessary forecasting actions of suitable meteorological data in the VPP concept. Besides, compared to the studies only considering the actions in the day-ahead market, the market action planning for a period of a week is evaluated in this study. Moreover, the large hydrogen energy conversion systems are evaluated in large power scales in the VPP concept in the proposed methodology. Furthermore, an adaptive execution, monitoring and re-planning based load dispatching strategy is employed for the economic operation of the proposed VPP structure by the update mechanism of the meteorological condition forecasting strategies with the new measured meteorological data. In this regard, the most important novelty of the paper can be indicated as utilization of the wind and solar power predictions effectively in a VPP load dispatching concept. With this aim, the proposed forecasting approach is developed taking into account the components of the VPP concept, the required time horizon, the specifications of the site and the available data. After extensive simulation studies, the proposed approach is obtained by combining Empirical Mode Decomposition (EMD), Cascade-Forward Neural Network (CFNN) and Linear Model for the first time in the literature as well as including a fusion strategy and update mechanism as mentioned above.

The remainder of the paper is organized as follows. Section 2 describes the wind and solar power forecasting methodologies as well as the employed load dispatching strategy. Section 3 illustrates the results derived from the proposed VPP structure. Finally, the overall study is discussed and conclusions are presented with future possible researches in Section 4.

2. System description and methodology

The general VPP structure composes of two cascade phases: Producer to aggregator (Phase 1) and aggregator to electricity market regulator (Phase 2). First of all, the aggregator provides a power production profile due to the negotiations with the power producers also considering their possible predictions for further power production profiles in Phase 1. Being aware of the power production capability of his whole virtual hybrid power system, the aggregator starts negotiations with the electricity market regulator about the economic and technical value of his possible production capability in Phase 2. Phase 1 includes many details such as forecasting algorithms and unit commitment of system components considering their technical and economical specifications. On the other hand, Phase 2 includes a different structure focusing on more economic details than technical capabilities as the aggregator is already aware of his power production capability and can negotiate more economic details about the price of his possible power production profile. This accordingly requires a cascade unit commitment problem: First for the aggregator to be aware of the power production capability of his virtual hybrid power system, and second for the competition between many aggregators negotiating with the electricity market regulator. In this study, the first phase of the overall VPP structure for better focusing on the details of the negotiations between power producers and aggregator is evaluated. The proposed VPP-Phase 1 structure consists of a wind farm for wind energy conversion, a solar farm for solar energy conversion, a fuel cell (FC) park for hydrogen energy conversion and a conventional thermal power plant. A block diagram of the mentioned VPP structure is shown in Fig. 1. The related forecasting and load dispatching methodologies are presented as follows:

2.1. Wind power forecasting methodology

Short-term wind power prediction is of significant importance for operation of electric power systems in a cost-effective, reliable and energy efficient manner. The predictions can help wind plant operators meet regulatory requirements as well as achieve favourable trading performances for the sale of energy and help utility operators ensure grid stability. However, it is difficult to forecast wind power accurately due to intermittent and volatile nature of wind, especially for the horizons up to 24 h. Therefore, in the literature, the daily prediction approaches have been focused on hybrid or combined models which merge the capabilities of different