Neurocomputing 143 (2014) 322–330

Contents lists available at ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

A real-time optimal generation cost control method for virtual power plant ☆

Yang Yuan [a,*], Zhinong Wei [a], Guoqiang Sun [a], Yonghui Sun [a], Dan Wang [b]

[a] College of Energy and Electrical Engineering, Hohai University, Nanjing 210098, PR China
[b] Tianjin University, Tianjin 300072, PR China

ARTICLE INFO

Article history:
Received 9 January 2014
Received in revised form
28 March 2014
Accepted 27 May 2014
Communicated by H. Jiang
Available online 11 June 2014

Keywords:
Virtual power plant
Real-time control
Optimal control
Distributed generation
Coordinate controller
Interior-point method

ABSTRACT

Due to the emergence of distributed generation (DG) units, a novel conception called virtual power plant (VPP) has been proposed to deal with the new challenges. By premising the concept of VPP, this paper aims to illustrate a real-time control strategy in dispatching active power among DG units to cover variations of loads and fluctuated or intermittent active power outputs of non-controllable DG units, such as wind power generation, and further to optimize the average generation cost of VPP. Taking into account of the controllable DG capacity constraints, response to the target determined by upstream grid, and achieving equilibrium between generated power and load, a closed-loop control strategy is applied and the optimization problem can be well solved by the interior-point approach. Additionally, the simulation models on the IEEE 34 node test feeder with several controllable and non-controllable DG units installed are established, respectively. From these simulation results, it can be concluded that, the proposed real-time control approach could achieve active power control target well and make the average generation cost per kWh of VPP significantly stay low.

1. Introduction

With the development of electric industry, more and more new ways of planning, managing and operating transmission and distribution networks have emerged, due to the progressive liberalization of the electricity sector and the subsequent transition to a decentralized system [1,2]. These new ways may contribute to the access of different kinds of distributed energy resources (DERs) in facing the lack of fossil fuel and the terribleness of air pollution. In order to promote energy efficiency [3] and deal with environmental problems, there is an increasing trend to employ distributed generation (DG), which generates electric power from DER, especially renewable sources, in alternative to traditional generation. Therefore, in this context, DG and controllable demand will play important roles in participating in energy markets and providing ancillary services to system operators [4,5].

As is well known, most of the DG units have their own restrictions on connecting to the main grid, such as limited capacity and stochastic nature (e.g. wind and photovoltaic) [6]. With more and more DG units are integrated, the electric system will experience much more new challenges [7]. As the penetration of DERs in the distribution network, several critical issues, such as technical, commercial and regulatory barriers related to these units have emerged and should be worthy of being tackled [8].

In order to handle these problems, these DG units, as well as storage devices and controllable loads, etc. [9,10], have been integrated into virtual power plants (VPP), which can manage the DG units in an active control paradigm to participate in both energy and ancillary service markets [11–15]. In the literature, several logic algorithms have already been developed to determine the optimal control schedules for groups of domestic devices. In [16], the authors developed a methodology for designing and operating VPP according to “control-by-price” scheme, the price responsive characteristics for three different micro-CHP systems were analyzed based on cost and profit analysis, respectively. In [17], two DG units and a micro grid were integrated into a VPP control area, an optimization algorithm was proposed to provide electrical energy for loads in the VPP control area with maximal

☆This work was supported in part by the National Natural Science Foundation of China under Grants 51277052, 51107032 and 61104045, in part by the Science and Technology Project of SGCC (Research on Basic Problems of Smart Power Distribution and Utilization Technology System With Simulation), in part by Jiangsu Provincial Graduate Education Innovation Project CXLX13_225, and in part by the Fundamental Research Funds for the Central Universities 2013B27514.

* Corresponding author.
E-mail addresses: yy860618@163.com (Y. Yuan), wzn_nj@263.net (Z. Wei), hhusunguoqiang@163.com (G. Sun), sunyonghui168@gmail.com (Y. Sun).

http://dx.doi.org/10.1016/j.neucom.2014.05.060
0925-2312/

profit achieved from selling of energy. Taheri et al. in [18] presented a new risk-constrained scheduling for a VPP model, by considering the tolerated risks, such as price fluctuations, negative features of photovoltaic power and wind energy [19], the maximal profit could be achieved by using dynamic programming, however, the scheduling program highly depended on forecasted prices for the next 24 h. Kuzle et al. in [6] designed an optimal dispatch schedule by using linear programming, due to the poor forecasting performance of RESs power output, the model for VPP operation was proposed to minimize the conventional power plant costs. Setiawan in [20] gave the definitions of VPP, three DG control approaches, basic autocontrol system (BAS), smart autocontrol system (SAS) and tracking efficiency autocontrol system (TEAS) have been introduced through numerical simulations. Peikherfeh et al. in [21] presented another optimal dispatch schedule based on linear programming, where the profit was maximized by considering technical and economical constraints as well as uncertainties related to errors in DG forecasting.

However, most of the aforementioned results concerning the forecasted prices and loads, measuring the DG hourly or quarterly production may not be real-time controls [22]. It is difficult to get minimal resources waste when the intermittent power generators or loads change frequently, even hardly to be measured [23]. TEAS presented in [20] with the condition of similar or even the same efficiency craves of three DG units. However if they are significantly different, and with the increasing number of DG units, the control system will be more complex and this method seems no response to the upstream grid and non-controllable DG units, such as intermittent energy sources including wind and photovoltaic power generations. Therefore, based on the above discussion, in this paper, a real-time control algorithm of active power output is proposed for each DG unit in a VPP, and the economy optimization problem is formulated as a constrained minimization algorithm, where the objective function is the generation cost per kWh of VPP with supply of active power for all the loads. The proposed method could cover fluctuant non-controllable DG output and mutational load without measuring them. Furthermore, the average generation cost of VPP can be optimized by using the interior-point approach and the average generation cost per kWh of VPP could significantly stay low.

The rest of this paper is organized as follows. In Section 2, the VPP model is introduced and some necessary illustrations are provided. In Section 3, a real-time control algorithm is proposed in detail. Centralized VPP model with several DG units is introduced in Section 4, where the simulation models of the control approach are also provided. In Section 5, simulation results are provided to illustrate the effectiveness and usefulness of the obtained results. Finally, this paper is completed with a conclusion and some remarks.

2. Virtual power plant model

To aggregate the DG units either for trading electrical energy or providing system support services, VPP concept is proposed with the idea of aggregating the capacity of many DERs, such as generation, storage, or demand, and committed to create a single operating profile for power system [24]. The commonly accepted definition of VPP can be roughly summarized as follows: aggregation control of a number of DG units, storage devices and controllable loads, grid connected and installed near loads [3,25].

The aggregation control can be viewed as the centralized or decentralized system supported by logic control algorithm and communication infrastructure, then be treated as a single large power plant. Because of many different goals like, operation of a VPP can decrease the cost of production, consumption of fossil fuels, and power exchange with electrical network, and maximize the usage of renewable resources and energy storage systems [4].

To solve these issues, the standard paradigm of centralized control is established, which is shown in Fig. 1, where DG units can be combined together in an integrated entity [26]. DERs are controlled by control coordination center (CCC), which is consisting of interface and logic algorithms (responsible for the DG units power dispatch by controlling the information exchanging from the power signals). Thus, the DG units are able to dispatch power to the loads by means of logic algorithm in CCC. By this way, individual DERs could gain visibility and manageability to system operators, which optimize the output of each DG unit to achieve the target of VPP model [27,28].

Moreover, the system would benefit from an optimal use of the available resources, and the efficiency of operation could also be improved. In the presented model, VPP can be a participant of energy market with dual role including producer and consumer based on the direction of exchanged power with the upstream grid [3]. Compared to the conventional power plant, the VPP model has its own operating characters such as schedule of generation, generation limits and operation costs [1].

3. Real-time control algorithm

More and more DG units with small capacities and low voltage levels are accessing to distribution network, therefore the planning of distribution network based on DG has become an important issue. These inherent challenges to distribution network with the high penetration of unconventional resources are more complex for the following reasons: (1) too many different kinds of DG units (including different DERs or generator modes); (2) the power outputs of intermittent DGs are significant, but hard to know ahead of time, and not directly dispatchable; (3) the number of new small resources may be large and frequently changing; (4) their characters are not standardized, and system operators do not have ready-to-use models and parameters; (5) the measurement elements are not enough in distribution network. Thus, it requires very careful dispatch management in order to bate active power fluctuation of the grid, perform safe and stable operations of power system, and reach the target of rational utilization of the coming DERs in existing systems.

In this section, a real-time and economical control algorithm, as shown in Fig. 2, is designed for controlling the active power output of controllable DG units accessing to complex distribution network.

3.1. Basic circuit theory

At all times, the total power P_{VPP} generated in VPP can be calculated as $P_{VPP} = \sum(P_{DG\_C} + P_{DG\_N})$, where P_{DG_C} is the active power of controllable DG units and P_{DG_N} is that of non-controllable ones. At all times, it can be known from the basic circuit theory that:

$$P_{VPP} = \sum(P_{DG\_C} + P_{DG\_N}) = P_L + P_{export}, \tag{1}$$

where P_L denotes the load and P_{export} denotes the exported active power of VPP, respectively. Obviously,

$$P_{export} = \sum P_{DG\_N} - P_L + \sum P_{DG\_C}. \tag{2}$$

3.2. Optimization coordinated control of active power

According to Eq. (2), P_{export} may be changed by the fluctuation in active power of non-controllable DG units and loads, such as inter-temporal variations. However, it can be covered by coordinating outputs of controllable DG units without measuring