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Multi objective unit commitment with voltage stability and PV uncertainty

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HIGHLIGHTS

- A new formulation for multi-objective unit commitment with voltage stability and PV uncertainty is given.
- The proposed method can reduce operating cost as compared with conventional methods.
- This method can be an appropriate tool for planning with the stability and PV uncertainty.

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ABSTRACT

This paper proposes a novel multipurpose operation planning method for minimizing the prediction error of photovoltaic power generator outputs (PV); towards reducing the operating cost and improving voltage stability of power systems. The operation schedule (coordination) of demand response (DR) program and storage system are taken into account as the main parameters for achieving an improved voltage stability and reduction of PV output prediction error. In this approach, the stochastic programming algorithm is introduced for incorporating the uncertainty of PV output and the utility demand response for consumer side management. This is achieved by using the multi-objective genetic algorithm (MOGA) for multipurpose operation plan. The MATLAB optimization toolbox and neural network toolbox were applied in this research study. An IEEE-6 bus system is used to demonstrate the effectiveness of the proposed solution in power systems operation. The approach led to "$"25003.39(="$"99594.53−"$"74591.14) reduction in the system operating cost, compared to the conventional approach. The simulation results also show that by using the proposed algorithm, the capacity of installed PV generators was increased and the voltage stability was improved at the same time. This accounted for the reduction in the effective operating cost and the improved operating condition of the power system.

1. Introduction

In recent years, large amount of renewable energy (particularly photovoltaic power generation, PV) has been introduced into Japan energy mix. This is specifically encouraged by the Introduction of the Feed-in Tariff Scheme for Renewable Energy that has been in effect since July 2012 [1]. Also, in the Paris Agreement adopted at the 21st session of the Conference of the Parties (COP21) in December 2015, it is believed that there will be a further increase in the introduction of renewable energy generation facilities in the future towards preventing global warming [2,3]. However, it is expected that the introduction of the intermittent power from renewable energy generation facilities will increase the instability of the power system unless a large capacity energy storage is installed. Some of the challenges that come with the recent changes in the production of electricity, as a result of increasing penetration of renewable energy, are: disturbance of the supply and demand balance, fluctuation in the grid voltage and perturbation of the power system frequency. In addition, due to the electricity liberalization more efficient use of transmission line is required, because most of the existing power systems are operating near their voltage stability limit [4,5]. As a consequence, the possibility of voltage instability and voltage collapse is increasing. Therefore, the voltage stability analysis is a major area of study in the operation of electric power system. Hence, important operations such as accurate grasp of the power generated by renewable energy power generation facilities, planning of appropriate unit commitment program, operation planning with consideration of voltage stability, effective adjustment of load demand (using demand response, storage battery, etc.), and control of output of renewable energy generators, have become necessary for the efficient, effective and economical running of modern power systems.

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Over the past few years, the application of stochastic programming for the optimal operation of power systems with the incorporation of intermittent renewable energy has been widely reported [6,7]. In [8], an effective AC corrective/preventive contingency dispatch over a 24-h period is proposed based on security-constrained unit commitment (SCUC) model. The proposed method could solve both security constrained unit commitment (SCUC) and security-constrained optimal power flow (SCOPF) problems based on ac power flow constraints. In the report, a set of corrective/preventive control actions for the secure and economical operation of power systems was devised. According to [9], the dynamic economic dispatch (DED) problem was optimally integrated with incentive-based demand response programs (DRPs). Moreover, a mathematical load modeling approach was derived to show the effectiveness of the load curve estimation with the lowest error. The proposed model was applied on the ten-unit system; uncertainty analyses were carried out to investigate the impacts of important factors such as the amount of elasticity due to demand response and the impact of the load estimation model on the results.

Ref. [10] proposed an extension of the stochastic unit commitment problem to incorporate some demand response (DR) strategies. Simulation studies described in the paper show that DR-based reserve capacity can serve as an effective mechanism to counter for volatility and uncertainty. Ref. [11] presented a stochastic day-ahead scheduling model with flexible resource options, which include hourly demand response, energy storage, and up/down ramping capability of thermal generating units. They examined the impact of flexible energy resources on the operation of stochastic day-ahead market. The flexible resources include the flexible ramping capability of thermal units, hourly DR program, quick-start units and energy storage systems. A Multi-objective particle swarm optimization (MO-PSO) is developed as a solution to the multi-objective unit commitment (MO-UC) problem formulated by [12]. Experimental results show that the fuzzy value-at-risk (FVaR) is sensitive to different confidence levels and the MO-UC reflects the conflict between operation cost and system reliability, which provide effective information for system operators and help them to make the proper decisions. In [13], a combined UC-DRP algorithm is used to analyze the effect of contingencies, wind and load uncertainties, and DRP bids in the hourly generation scheduling. The proposed algorithm considered the curtailment of the wind generation as a scenario, thereby reducing the requirements for expensive regulations and spinning-down reserves.

The integration of aggregated plug-in electric vehicle (PEV) fleets and renewable energy sources (wind energy) in power systems is studied by stochastic security-constrained unit commitment (Stochastic SCUC) model, which minimizes the expected grid operation cost while considering the random behavior of the many PEVs in [14]. Once PEVs are connected to the grid, they can draw energy, store it in batteries, and inject it back to the grid at other times and locations in order to decrease grid operation costs through adequate renewable resources curtailment. Ref. [15] presents a novel energy management system (EMS) for a renewable-based microgrid. The results of the EMS showed the economic benefit of the proposed unit commitment with a rolling horizon (UC-RH) in comparison with a standard UC. The rolling horizon provides the advantage of dealing with updated data from the forecast variables. Ref. [16] reports a probabilistic unavailability evaluation method as a function of a dynamic unit commitment schedule. A multi-objective optimization problem, defined within a selected case study power system, is presented and solved. Two objective functions namely; generation cost function and unavailability of generating capacity function, i.e. loss of load probability (LOLP) are considered. A computational framework for uncertainty integration of distributed power systems (DPSs) with intermittent renewable energy sources (IRESs) is proposed by [17]. The load, wind and solar power forecast uncertainties, as well as the uncertainty from generator outages, are included in their proposed framework.

In most of the available reports, limited number of items required for effective operation of the modern power system were examined. The operation approach that consists of voltage stability, demand response menu and uncertainty of renewable is seldom reported. In this paper, we assume penetration of a large amount of PV generators into the IEEE 6 bus system. This paper focuses on achieving an optimum operation method which is reliable and cost-efficient; with prior consideration for the effect of fluctuation in the amount of solar radiation. This is achieved by incorporating stochastic operation plan, solar generation output prediction and control, storage battery and demand response program. In order to address the computational complexity, the operation plan is decomposed into smaller units for tractability and computational time reduction. We investigate the minimization of operational cost and maximization of voltage stability by applying the multi-objective optimization algorithm. The multi-objective genetic algorithm (MOGA) of MATLAB optimization toolbox is applied as the solution algorithm, and the effectiveness of the proposed method is shown through simulation as shown by the obtained results. The remaining part of this paper is organized as follows: Section 2 provides the forecasting techniques for solar power generation facilities, formulation of the proposed method is introduced in Section 3. The simulation results are discussed in Sections 4 and 5 concludes this paper.

2. Prediction method of solar radiation

In this paper, a neural network (NN) is introduced for the solar radiation forecasting method by applying the error back propagation algorithm [18]. The implementation of the neural network was achieved by using the Neural Network Toolbox in MATLAB. The NN structure consists of three-layers which are; the input layer, intermediate layer and output layer, as shown in Fig. 1. A sigmoid function is used for the coupling function. This NN receives the following variables as inputs: Inputs 1–5: hours $t-2$, $t-1$, t, $t+1$, $t+2$, Inputs 6–10: Forecasted air flow [m/s] of hours $t-2$, $t-1$, t, $t+1$, $t+2$, Inputs 11–15: Forecasted precipitation [mm] of hours $t-2$, $t-1$, t, $t+1$, $t+2$, Inputs 16–20: Forecasted temperature of hour $t-2$, $t-1$, t, $t+1$, $t+2$. The Output 1 is the solar radiation amount at the hour t. The learning period covers the period between 08/2009 and 08/2013. Prediction error is calculated from the prediction results obtained in each time zone at August 2014. The standard deviation σ was calculated from the prediction error. The PV output scenarios were created within $\pm 3\sigma$; this is considered for the stochastic operation planning.

3. Problem formulation

Fig. 2 shows the flow chart of the optimum operation method that is employed in this paper. The operation method is divided into three parts: the prediction section, the unit commitment (UC) section, and the multi-objective schedule section.

3.1. Stochastic UC problem

The introduction of stochastic UC problem is necessary due to the

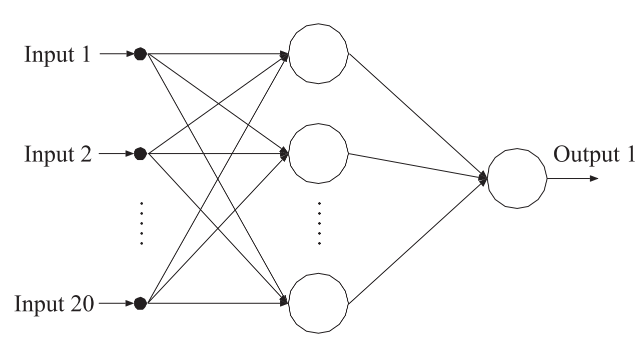

Fig. 1. Neural network.