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Stochastic optimal power flow incorporating offshore wind farm and electric vehicles

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ABSTRACT

In this paper, an optimal power flow model of a power system, which includes an offshore wind farm and plug-in electric vehicles (PEVs) connected to grid, is presented. The stochastic nature of wind power and the uncertainties in the EV owner's behavior are suitably modelled by statistical models available in recent literatures. The offshore wind farms are assumed to be composed of doubly fed induction generators (DFIGs) having reactive power control capability and are connected to offshore grid by HVDC link. In order to obtain the optimal active power schedules of different energy sources, an optimization problem is solved by applying recently introduced *Gbest guided artificial bee colony algorithm (GABC).* The accuracy of proposed approach has been tested by implementing AC–DC optimal power flow on modified IEEE 5-bus, IEEE 9-bus, and IEEE 39-bus systems. The results obtained by GABC algorithm are compared with the results available in literatures. This paper also includes AC–DC optimal power flow model, implemented on modified IEEE-30 bus test system by including wind farm power and V2G source. It has been shown that the uncertainty associated with availability of power from wind farm and PEVs affects the overall cost of operation of system.

Introduction

The share of wind power in the existing power grid is rapidly increasing all around the world on account of economical and environmental concerns. However, since the balance between the system load and power generation in the grid must be maintained, the intermittent generation of wind power presents a major challenge in the operation and control of power system. In fact, ample energy storage systems should be incorporated to cope up with the inherent fluctuations in the availability of wind power.To alleviate these uncertainties, the recent development in plug-in electric vehicles (PEV) technology is expected to provide an attractive energy-buffering solution to stabilize the grid [1]. The study presented in [2] shows that most EVs are not in use for up to 96% of a day. Through V2G (vehicle to grid) technology [3], these unused EVs can discharge electricity back into the power system [4]. Yet, the unpredictable driving behavior of vehicle owners brings another uncertainty in the power system.

The introduction of wind power generation is being advanced at a greater rate, in many regions of the world, to achieve the goal of generating substantial power with renewable energy systems [5]. Within this trend, the wind farms are shifting from onshore to offshore locations. The main reason for large deployment of offshore wind power generation is the availability of huge amount of wind resource without obstacles. However, since the offshore wind farms are generally located in shallow coastal area, the power transfer to onshore grid is a major challenge. If the distance between the offshore wind farms and onshore grid is large, a high-voltage DC transmission system (HVDC) is generally preferred instead of conventional high-voltage AC transmission line for power transmission.

The Carpentier [6] first introduced the economic dispatch problem to full AC network. Economic dispatch is nothing but providing an active power to the end consumer with minimum operating cost without violating the technical constraints. This problem is extensively studied. In the literature [7] the economic dispatch problem is defined as optimal power flow (OPF) problem by considering additional constraints. The objectives of OPF are the planning and secure operation of power system and operate power system economically without violating set of technical restriction. Such an optimal power flow (OPF) formulation has been extensively studied in the past considering fossil fuel based generation in power systems. However, OPF studies incorporating two terminal VSC HVDC links have not been conducted extensively. Furthermore, the different OPF models proposed in earlier studies assumes the impact of off shore wind power by deterministic approach

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[8,9]. In these studies, the objectives function is to minimize the losses within the wind farm and the HVDC transmission system for given wind power. The other studies of optimal power flow includes, modeling of uncertainties in the wind power availability using weibull probability distribution function [10,11]. In [10] the objective function considered the additional costs of managing wind intermittency based on probability/relative frequency histograms of forecasting error. The effect of skewness of the forecasting error distribution on wind–thermal coordination solutions has been quantified. The wind generation cost model proposed in [11] consists of the opportunity cost of wind power shortage and the opportunity cost of wind power surplus. In recent study [12], scenario based approach for wind power is assumed to determine the optimal operation of power system integrated with offshore wind farm. However, since the uncertainties in wind speed prediction are not included in objective function, this approach does not provide an insight into different costs associated with power forecasting.

The OPF problem is solved in the past by different numerical technique as well as evolutionary approaches. The OPF problem considering thermal power in the system is solved by different numerical techniques such as non linear programming, quadratic programming [13], Newton method, interior point method and linear programming [14]. All these methods depend on the basic assumption that fuel cost characteristics of generating units is convex function and smooth. But there are some situations like valve point effect, prohibited zone and piecewise quadratic cost characteristic where fuel cost characteristics of generating unit is not convex function and smooth. Recently, many evolutionary algorithms are used to solve OPF problem such as improved genetic algorithm [15], Enhanced genetic algorithm [16], artificial bee colony algorithm [17], differential evolution [18], gravitational search algorithm [19], imperialist competitive algorithm [20], hybrid modified imperialist competitive algorithm and teaching learning algorithm [21] and chaotic invasive weed optimization algorithm [22]. A new hybrid bacterial foraging and simplified swarm optimization algorithm [23] and scenario-based and fuzzy self-adaptive learning particle swarm optimization approach [24] are used to solve dynamic load dispatch problem. Hybrid modified imperialist competitive algorithm and invasive weed optimization [25] and hybrid modified teaching learning algorithm and double differential evolution algorithm [26] are used to solve optimal reactive power dispatch problem. To improve the power system stability multi-objective particle swarm optimization [27] algorithm is employed.

In this paper, guided g-best artificial bee colony (GABC) algorithm is used to solve the stochastic optimal power flow (SOPF) problem incorporating HVDC linked wind farms and stochastic EV source. The configuration of future power system will undergo a dramatic change owing to the high penetration of offshore wind power into the power grid and the introduction of electric vehicles (EV) into the transport system. This necessitates the development of new models to facilitate the operation and optimal control of the new structure of the power systems. This paper presents stochastic optimal power flow formulation considering HVDC–linked wind farms and EVs.

This paper contributes clearly in the literature with:

- The mathematical formulation of the stochastic optimal power flow (SOPF) problem incorporating HVDC linked wind farms and stochastic EV source
- Implementation of GABC algorithm for solving stochastic AC–DC optimal power flow of modified 5 bus test system, modified 9 bus test system and modified New England 39 bus test system
- The effect of different wind source parameters and V2G source parameters on stochastic optimal power flow is examined considering modified IEEE 30 bus system.

This paper is organized as follows. Section "Modeling AC–DC transmission system" gives stochastic optimal formulation considering HVDC linked offshore wind farm and V2G system. Section "Problem formulation" provides overview of optimization algorithm used. Section "Overview of gbest artificial bee colony algorithm and implementation of SOPF" describes implementation procedure of SOPF. Simulation results are presented in Section "Simulation results and discussion". Section "Conclusion" summarizes the findings of this work.

Modeling AC–DC transmission system

The following assumptions are made to derive equations representing the AC/DC converter.

- The AC side bus voltages are sinusoidal with constant frequency. The AC supply voltages and currents are balanced.
- The harmonic components of voltage and current produced by power electronic converters are removed by suitable filters and do not appear in the system.
- The resistance and magnetizing current of transformer of the converter transformers are assumed negligible.
- The waveforms of current and voltage are assumed to be smooth without any ripples.
- The power electronic devices used in the converters are ideal switches and have no voltage drop while conducting.
- The two poles of bipolar DC link are balanced.

For the sake of convenience, simple HVDC link connected to AC bus is shown in Fig. 1. In this arrangement, the generator is connected to the *i*th bus. P_{Gi} and Q_{Gi} are respectively the real and reactive power injected at the *i*th bus by generator. P_i and Q_i are respectively the real and reactive power demand of the load at the *i*th bus. P_{dr} is the active power transferred from ac side to the converter. Q_{dr} is the reactive power absorbed by the converter. Similarly the real and reactive power representation is shown in Fig. 2 for *kth* bus.

At converter end bus power balance equation can be written as,

$$P_{gi} = P_i + P_{dr} \tag{1}$$

$$Q_{gi} = Q_i + Q_{dr} \tag{2}$$

At inverter end bus power balance equation can be written as

$$P_k = P_{di} \tag{3}$$

$$Q_k + Q_{di} = 0 \tag{4}$$

The two terminal HVDC transmission link is shown in Fig. 3.

Rectifier side DC link equations

Two terminal HVDC link equivalent circuit is shown in Fig. 4.

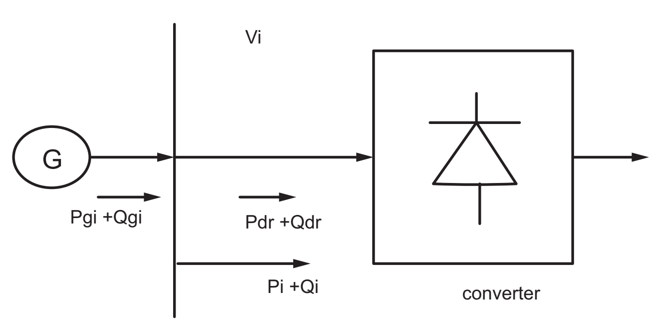

Fig. 1. HVDC link connected to ith bus.