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PSO based placement of multiple wind DGs and capacitors utilizing probabilistic load flow model

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ABSTRACT

Wind Power Distributed Generators (WPDGs) are being increasingly placed in the power system due to their several technical and environmental benefits. In this paper, a Modified Particle Swarm Optimizer (MPSO) based method is proposed for placement of multiple WPDGs and capacitors. Monte Carlo Simulation (MCS) based probabilistic load flow, considering uncertainty in load demand and wind generation, is developed. It is used to modify the WPDGs' and capacitors' sizes utilizing a sensitivity based approach, which maintains branch currents and bus voltages within their prescribed limits. The proposed method is simple, accurate and generic, and it can provide multiple choices to the utilities to place capacitors and WPDGs under various system constraints. Results on three distribution networks demonstrate the effectiveness of the proposed method. The impact of the DG placement on the system voltage profile, line loss, environment, and cost of generation has also been investigated on three distribution systems.

1. Introduction

The sustainable energy development is an important concern, all over the world, while achieving economical and industrial growth. Due to increasing load demand, the utilities, in several countries, have now been allowed to plan the Distributed Generation (DG), which help in reducing the load generation gap. The DG technology offers several challenges along with social-, technical- and economic-benefits. The challenges and benefits differ with DG technologies as presented in various research articles [1–22]. The main challenges with wind power based DG is intermittency and high operating cost with battery backup. Further, the output power from the wind DG and the load demand are time varying, causing the situation difficult to maintain the continuity of power from the wind DG due to technical constraints [1–10,15,16,19,20].

A vast literature survey is presented in [1,2] and it is showing the studies conducted considering several techniques for locating DGs in the distribution systems. It is observed that the uncertainties in load and generation have been considered in the power system since long, but it is still an active field of research due to difficulties faced in making a balance in demand and supply [3-14]. Hatziargyriou et al. [15] proposed a work incorporating such uncertainties in early nineties. In Ref. [16], Atwa et al. presented a methodology for allocation of only Wind Power DG (WPDG) units in the distribution system using mixed integer non-linear programming. The allocation of WPDG was based on energy loss minimization criteria as a single objective problem. The suggested approach was compared with a traditional planning technique, considering constant DG output and constant system peak demand.

Conti et al. [17] proposed an approach that deals with the solution of the load flow problem in distribution networks with Photo-Voltaic (PV) type DGs. Although, the Probabilistic Load Flow (PLF) has been used to calculate the yearly energy not supplied owing to overvoltage protections and consequent PV generators disconnection to avoid unacceptable overvoltage, the results were compared with those obtained with a deterministic load flow. Hong et al. [18] proposed an approach for VAR planning with existing WPDGs. The cost of static VAR compensators and MW loss in the system were minimized. The probability and only duration of the critical operating states with voltage violations were considered to conduct the VAR planning study. However, the solution for over voltage is not considered [17,18]. In case of the over voltage, the wind DG is disconnected from the grid. In [19], Ochoa et al. proposed a multi-objective programming approach based on the non-dominated sorting genetic algorithm to find configurations that maximize the integration of the WPDG. It considered a compromise between the maximization of energy export and the minimization of both power losses and short-circuit levels. Su et al. [20] addressed the issue of optimizing network operation and use for accommodating DG integration. An interconnection planning study framework, that included a

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coordinated feeder reconfiguration and voltage control to calculate the maximum allowable DG capacity at a given node in the distribution network, was presented. A Binary Particle Swarm Optimization (BPSO) technique was employed to solve the discrete nonlinear optimization problem and possible uncertainties associated with intermittent renewable DG resource and loads were incorporated using a stochastic simulation approach. In Ref. [21], an approach has been suggested to aid the intentional islanding process by the optimal DG placement. Though, the critical network conditions are not considered in the literature such as either maximum DG output supplying to a least system load or minimum DG output with peak load demand [1–22].

Several research papers have presented methods to obtain the optimal location and size of the capacitors employing evolutionary and conventional optimization methods. During last decade, the Particle Swarm Optimization (PSO) has come up as a popular technique, which was proposed by Kennedy and Eberhart in 1995 [23]. Later, many versions of the PSO have been proposed such as Constriction Factor PSO, Binary PSO, Modified PSO, Crazy PSO, etc. due to several advantages [5,14,24–29], which are as it requires only direct function evaluation and does not require calculation of gradient vector and Hessian, which is required in many conventional optimization methods. It has ability to get rid of local minima, being stochastic in nature, and there is no need of good initial guess. Apart from certain difficulties in parameter tuning and constraint handling, the PSO method can be considered as an efficient method to solve non-linear and convex/non-convex power system problems with either continuous or discrete variables. Therefore, many power system researchers have successfully applied PSO or other similar heuristic methods to solve various power system problems [5,23–29].

Yu et al. [25] also proposed a solution method employing PSO to search for optimal locations, types and sizes of capacitors to be placed considering harmonic distortion on small test feeder. Esmin et al. [26] developed an optimal power flow method based on loss minimization function using PSO to calculate the amount of shunt reactive power compensation. Ray [27] presented a constrained robust efficient optimal design using multi-objective evolutionary algorithm. In [29], Pourmousavi proposed the application of the PSO to find real-time optimal energy management solutions for a stand-alone hybrid wind-micro-turbine energy system. It is observed in the literature that the bus voltage and the line current limit violations are the critical issues in WPDGs planning, which affect the reliability of the supply, to be considered while planning of the WPDGs in the distribution system as observed in [1–10,15,16,19,20,29].

To address the important issues in WPDG planning, a generic Multi-Objective Function (MOF) is formulated in this paper for WPDGs and capacitors' placement, which not only takes care of bus voltage and current limit violation but also provides an economical solution to reduce the line loss and improvement in the system voltage profile with minimum environmental impact. The MOF is solved by a hybrid approach using PSO, Probabilistic Load Flow (PLF) and a sensitivity approach to obtain sizing and siting of multiple WPDGs and capacitors for wind potential sites. The PLF approach is used to determine number of hours of voltage/current limit violations in a year, considering hourly varying load pattern. The sensitivity method is used to adjust the capacitor and the DG size in order to eliminate the limit violations. The major contributions of the paper are

- The Monte Carlo Simulation (MCS), which is considered to be one of the best methods to incorporate the randomness [5,17] has been utilized for load flow formulation along with sensitivity methods for the DG and the capacitor planning.
- The results of the proposed method for the WPDG placement and capacitor planning can be adopted by the utilities under the time varying distribution loads (considering its randomness) and intermittency of the wind power generations.
- The proposed approach utilizes a multi-objective function, also incorporating the emission based index which takes into account of recent environment concerns worldwide.
- The algorithm can handle any desirable penetration level of DGs and number of capacitors, WPDGs in single/multiple stage (s) of implementation.
- The effectiveness of the proposed method is established by the technical, economic and environmental impact analyses on 12-bus, 41-bus (Indian) and 141-bus (Venezuelan) radial distribution systems with various load models.
- The proposed approach, which is robust and accurate, is shown in Fig. 1.

2. Problem formulation

The main objective of locating WPDG and capacitor is to get the maximum possible benefits by improving the system performance in terms of improvement in the system voltage profile, reduction in the environmental emission and line loss or cost reduction associated with the line loss, subject to the system constraints. This way, it includes economic benefits. The economic factor being a monetary expression is difficult to be directly included in Eq. (1) as all the considered indices in Eq. (1) are unit-less system performance indices.

The problem can be formulated mathematically as minimization of a multi-objective function [30–33].

$$Min.\,(f_m = \alpha_1(SLIP)+\alpha_2(SLIQ)+\alpha_3(SVPI)+\alpha_4(SGEI)) \tag{1}$$

where, *SLIP*, *SLIQ*, *SVPI* and *SGEI* are distribution system real power loss index, distribution system reactive power loss index, distribution system voltage performance index and distribution system gas emission index, respectively. The f_m is a Multi Objective Function (MOF) with $0 \le \alpha_1, \alpha_2, \alpha_3, \alpha_4 \le 1$ and $\alpha_1+\alpha_2+\alpha_3+\alpha_4 = 1$. The constants $\alpha_1, \alpha_2, \alpha_3$ and α_4 are the relevance factors of the MOF terms related to *SLIP*, *SLIQ*, *SVPI* and *SGEI*, respectively. The relevance factors are considered to give the corresponding importance to each of the impact indices in the presence of the DG and the capacitor. A utility can choose suitable values of the relevance factors according to the installation requirements [30–33].

The MOF, expressed in (1), is common for placement of both the WPDGs as well as the capacitors but, in case of capacitor placement, the fourth term (*SGEI*) is not considered.

2.1. Distribution system real and reactive line loss index (SLIP and SLIQ)

One of the objectives to place the DG in a distribution system is to reduce the line loss. The expression for the *SLIP* and *SLIQ* is given below.

2.1.1. Distribution system real line loss index (SLIP)

$$SLIP = \frac{\sum_{x=1}^{n_l} P_{L(x)dg}}{\sum_{x=1}^{n_l} P_{L(x)0}} \tag{2}$$

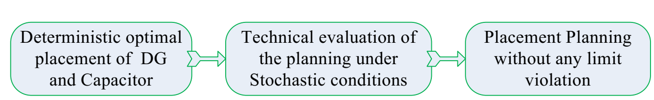

Fig. 1. A schematic diagram of the proposed approach.