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# An Improved Differential Evolution algorithm for congestion management in the presence of wind turbine generators

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ABSTRACT

Congestion management is imperative for reliable and secure system operation in restructured power systems. Since the installation of wind farms at proper locations offers the possibility of congestion relief, this paper investigates congestion management in power systems with specific consideration of wind energy sources. The optimal location of a wind farm is determined by the Bus Sensitivity Factor and the Wind Availability Factor. Differential Evolution is a population-based heuristics algorithm used for solving non-linear optimization problems. We propose an Improved Differential Evolution based approach to ease congestion in transmission lines by generator rescheduling and installation of new wind farms. In this approach, an enhanced mutation operator is introduced to improve the performance of the Differential Evolution algorithm. A standard IEEE-30 bus system is used to evaluate the proposed algorithm under critical line outages. The simulation results show that the proposed approach is more effective than other approaches.

## 1. Introduction

In competitive electricity markets, due to Transmission Open Access (TOA) the transmission networks are loaded up near to their stability limits. The electrical power that is transmitted has various limits, such as thermal, voltage, and stability limits. The system is congested if any one of these limits is reached [1]. The security of the power system will be violated if the system does not operate within its limits. This failure can cause the power system to experience widespread blackouts, leading to severe economic and social consequences. Congestion Management (CM) is thus the fundamental transmission problem to be addressed to ensure that transfer limits are observed [2].

Rescheduling generators, load curtailment, regulaing or tap setting transformers, FACTS devices, etc. can relieve congestion. The ISO generally prefers the approach of rescheduling generators as it does not alter the system topology. For CM, several techniques like optimum power dispatch and a price-based framework have been reported in [3]. In [4,5], CM techniques for different market structures like Bilateral/Multilateral and pool market structures are proposed. Voltage stability enhancement during congestion is discussed in [6]. In [7], the applications of FACTS devices, such as TCSC and TCPAR, for CM are discussed. In [8], the CM problem is formulated in an OPF framework. The congestion cluster-based method and ac transmission congestion distribution factor approach for CM are reported in [9] and [10]. Sensitivity Index has been proposed in [11] to identify generators to be rescheduled to alleviate congestion.

The CM is intuitively an optimization problem with ample constraints. Traditional techniques for relieving congestion can be found in [12–14]. Specifically, the Lagrangian Relaxation (LR) based algorithm and Linear Programming (LP) and Sequential Quadratic Programming (SQP) based approaches have been proposed for CM in these articles. As these techniques face difficulty handling the constraints of CM, they do not guarantee the global optimum solution. Recently, advancements in computation technology, like parallel computation, have stimulated many researchers to focus on the application of Artificial Intelligence (AI) techniques for CM problems in restructured power systems [15,16]. The CM problem has been successfully solved with the help of the Differential Evolution (DE) algorithm, which was originally proposed by Storn and Price [17,18]. Although DE is a very simple and efficient optimization algorithm, it sometimes suffers from slow convergence. It has been observed that mutation plays the key role in the convergence process. A new operator named the Double Best Mutation Operator (DBMO) has therefore been developed in order to speed up convergence and to obtain the optimal solution [24].

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In competitive electricity markets, as conventional energy tends to be exhausted, it is important to give exceptional attention to the advancement of renewable energy sources. Wind power has surpassed other renewable energy sources because of its reduced operational and maintenance costs [20]. Recently, incorporation of Wind Farms (WF) into power systems for congestion alleviation has been on the rise. Integration of wind energy sources not only provides congestion relief but can also help reduce active power losses in addition to improving the voltage profile [20]. An approach based on locational marginal prices (LMPs) for incorporating wind energy for CM is discussed in [19]. Incorporation of WF with congestion management problems using sensitivity factors is discussed in [20]. However, the WF locations were selected in [20] without considering wind availability at the locations.

Installation of a WF into a power system to alleviate congestion should be based on the following significant aspects:

1) Availability of the required quantity of wind.
2) The sensitivity of the location of the WF for alleviating congestion.

A new strategy for identifying the location of wind farms based on the Wind Availability Factor (WAF) and Bus Sensitivity Factor (BSF) is proposed in this paper.

Development of a CM strategy for integration of a wind energy conversion system using an Improved Differential Evolution (IDE) algorithm is the objective of this work. A standard IEEE-30 bus system is used to test the proposed technique. The paper is organized as follows. In Section 2, the wind farm model is presented. Section 3 describes the proposed methodology for placement of wind farms. Section 4 presents the congestion management problem in a deregulated environment. Section 5 provides an overview of the IDE algorithm. The CM solution methodology using IDE is elaborated in Section 6. Results showing the effectiveness of the projected method are discussed in Section 7. The major contributions and conclusions are discussed in Section 8.

## 2. Modeling of the wind turbine generator

The bus in which the wind turbine generator is connected is modelled as a PQ bus. The steady-state model of the wind turbine generator (induction generator) [21] is shown in Fig. 1. In order to compensate for the reactive power consumption of the induction generator a shunt capacitor is connected as shown in Fig. 1.

According to Boucherot's theorem, the reactive power consumption of the wind farm generator can be written as [21]:

$$Q = V^2\frac{X_c - X_m}{X_cX_m} + X\frac{V_2 + 2RP}{2(R^2 + X^2)} - X\frac{\sqrt{(V^2 + 2RP) - 4P^2(R^2 + X^2)}}{2(R^2 + X^2)} \tag{1}$$

$$Q \approx V^2\frac{X_c - X_m}{X_cX_m} + \frac{X}{V^2}P^2, \tag{2}$$

where

$V$ is the rated voltage,
$X$ is the sum of the stator and rotor leakage reactance per phase,
$X_m$ is the magnetizing reactance per phase,
$X_c$ is the reactance of the capacitor bank per phase,
$R$ is the sum of the stator and rotor resistance per phase, and
$P$ is the real power generated by the wind generator (positive when injected into the grid).

The real power output of the induction generator is expressed as [21]:

$$P = \frac{1}{2}\rho AU^3C_P, \tag{3}$$

where

$\rho$ is air density (kg/m$^3$)
$A$ is the area of rotor (m$^2$)
$U$ is the wind velocity (m/sec), and
$C_p$ is the coefficient of power.

## 3. Proposed method for placement of wind farm

A method for the placement of wind farms based on bus sensitivity and wind availability is proposed in this section.

### 3.1. Bus Sensitivity Factor (BSF)

The BSF for a congested line $k$ connected between buses $i$ and $j$ is defined as the change in the active power flow in the transmission line due to a unit change in power injection at bus $n$ [20]. Mathematically, the BSF for line $k$ is defined as,

$$BSF_n^k = \frac{\Delta P_{ij}}{\Delta P_n}, \tag{4}$$

where $\Delta P_{ij}$ is the change in real power flow of line $k$ for an active power injection $\Delta P_n$ at bus $n$. The BSF is calculated as follows.

The active power flow on the congested line can be written as

$$P_{ij} = -V_i^2Y_{ij}\cos\theta_{ij} + V_iV_jY_{ij}\cos(\theta_{ij} + \delta_j - \delta_i) \tag{5}$$

$$\Delta P_{ij} = \frac{\partial P_{ij}}{\partial \delta_i}\Delta\delta_i + \frac{\partial P_{ij}}{\partial \delta_j}\Delta\delta_j + \frac{\partial P_{ij}}{\partial V_i}\Delta V_i + \frac{\partial P_{ij}}{\partial V_j}\Delta V_j. \tag{6}$$

Eq. (6) can be rewritten as

$$\Delta P_{ij} = a_{ij}\Delta\delta_i + b_{ij}\Delta\delta_j + c_{ij}\Delta V_i + d_{ij}\Delta V_j, \tag{7}$$

where

$$a_{ij} = V_iV_jY_{ij}\sin(\theta_{ij} + \delta_j - \delta_i) \tag{8}$$

$$b_{ij} = -V_iV_jY_{ij}\sin(\theta_{ij} + \delta_j - \delta_i) \tag{9}$$

$$c_{ij} = V_jY_{ij}\cos(\theta_{ij} + \delta_j - \delta_i) - 2V_iY_{ij}\cos\theta_{ij} \tag{10}$$

$$d_{ij} = V_iY_{ij}\cos(\theta_{ij} + \delta_j - \delta_i). \tag{11}$$

We know that

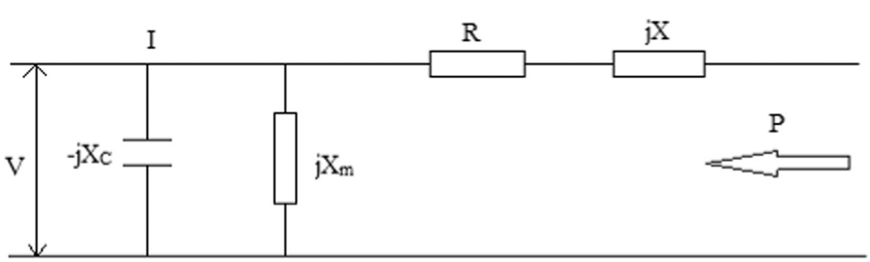


**Fig. 1.** Static model of Induction machine.