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Optimum economic and emission dispatch using exchange market algorithm

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ABSTRACT

In modern electric grid system, a decision maker (DM) has to operate the system with multiple aims in mind. Traditional electric system was not so complex and emphasis used to be given only in optimizing the cost of energy dispatch. However, recent regulations restrict the environmental emissions caused by the energy sources. Hence, optimum energy generation and dispatch is a very critical issue in modern grid system. When, viewed as an optimization problem complying with both economy and environmental restriction, it is a very challenging one. Researchers in the past have solved such problems as multi-objective Economic Load Dispatch (ELD) problem. This paper attempts to solve the same problem as an Optimum Active Power Dispatch (OAPD) problem using a very recently developed optimizer called 'Exchange Market Algorithm' (EMA). The problem is modelled as both single and multi-objective problem. The EMA algorithm proceeds for the global optima through two of its main phases; i.e. balance market phase and oscillated market phase, each having both exploitation and exploration. The superior search capability of EMA is successfully exploited in this paper to attain various objectives. Programs are developed in MATLAB and tested on standard IEEE 30 bus comprising of six thermal units. The results obtained using EMA are compared with other methods reported in consulted literature. Simulation results demonstrate the authority of EMA in terms of its computational efficiency and robustness.

Introduction

In modern electric power system operation, there are wide varieties of issues to deal with, such as; electric energy generation planning (short term or long term), maintaining transmission systems reliability, complying with environmental regulations, energy production as per schedule, and regulating the energy prices to acceptable limits. In this new era, economy, security and environmental issues have begun to play major role and the power system operation has become much more complex than ever before; although basic operation philosophy has not changed. Therefore, a Decision Maker (DM) has to look at various aspects while selecting the operating strategy of power systems. Minimizing only energy generation cost might cause increase in environmental emissions from thermal plants; on the other hand, adopting a strategy to reduce only emissions would raise energy generation cost. Due to the intensifying demand of clean air, environmental policies outlined by Government bodies have been notified to the industries to be strictly followed as the expansion of industrialization effects the climatic conditions adversely. Therefore, it's a key challenge for both researchers and power system practitioners to take care of these issues simultaneously. Hence, a challenging objective of emission dispatch has been appended to the fuel cost minimization which is a traditional objective of power industries. The common Economic Emission Dispatch (EED) problem is designed almost similar to the fuel cost optimization problem but, it aims to determine the energy output of thermal plants in such a way that it minimizes the environmental pollutions as well [1]. Environmental pollutants consists of Nitrogen Oxide (NOx), Sulfur Oxide (SOx) and Carbon Oxides (COx) which are emitted in hefty amounts during the burning of fossil fuels, especially in the thermal power generating stations. Recent research reports [1–3] show the formulation of basic EED problems and discuss the methods of simultaneous optimization approaches.

The shortcomings associated with the solution of common EED problem is that it ignores the insight view of other essential power system parameters, such as; the real and reactive energy flow through transmission channels, nodal voltages, and other energy controllers operating limitations. Therefore, the practical power flow constrained EED solution approach is more relevant in the present hour for modern grid systems. In this context, the most

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basic solution tool titled 'Optimum Active Power Dispatch (OAPD)' problem thus attracts attention. The OAPD problem handles the optimization of certain objectives which are critically related to active related control variables of power system i.e. active power generations. Hence, fuel cost minimization and emission dispatch problems of power system can be contemplated as the part of OAPD problem. Traditionally, the OAPD is formulated as Optimal Power Flow (OPF). The OPF seeks to locate the steady operating state of electrical power system that optimizes a given objective function and appeases a set of physical and operating constraints [4–6]. OPF was first introduced by Carpentier [5] and since then, this tool has been widely studied and implemented in Power system operation and planning.

When viewed as an optimization problem, an OPF problem is a high dimensional nonlinear problem, which optimizes several objectives with nonlinear constraints and variables [6–8]. Many classical optimization techniques [8–11] were successfully implemented to solve OPF problems in the past but, off late, researchers and practitioners have begun to show their interest on general purpose optimization techniques instead. The reason being, although classical optimization techniques have excellent convergence characteristics; but, they do not guarantee to converge to a global optimum solution. In order to overcome the drawbacks of classical optimization techniques, optimization based on behavior of natural evolution and natural objects have been proposed and applied to solve many power system problems. Algorithms like Genetic Algorithm [12–17], Evolutionary Programming [18–21], Tabu Search [22], Particle Swarm Optimization [23–26], Differential Evolution [27–31], Biogeography Based Optimization [32,33], Harmony Search Algorithm [34], Gravitational Search Algorithm [35,36], Black-Hole Based Algorithm [37], and Teaching Learning Based Algorithm [38,39] have shown promising results when applied to solve power system problems. These algorithms are generally population based and work diligently towards finding the global optima for constrained optimization problem. In [38–43], some hybrid algorithms are also reported. Multi objective optimization with different optimizers is also reported in [44–47].

In this paper, a new and very promising algorithm called Exchange Market Algorithm (EMA) is implemented to solve the proposed EED problem of power system. The EMA algorithm is developed by Ghorbani and Babaei in 2014 and is based on the behavior of shareholders in stock market [48]. In [48], many benchmark problems have been solved by authors and results looks very promising when compared against other reported literatures. The feature of double exploitation and exploration associated with EMA attracts the present authors to verify its performance in solving complex power system problems. Till date EMA has not been applied to solve many power system problems. Therefore, in this paper an attempt has been made to solve single as well as multi-objective OAPD optimization problems of power systems using EMA. The problem is formulated as nonlinear optimization ones with various vital objectives related to OAPD and implemented on standard IEEE test systems. The results are compared with those reported by other methods available in the literature. Moreover, the performance of EMA has also been verified with the most recent Spider Monkey Optimization (SMO) algorithm [50]. Simulation results confirm the superiority of EMA over several other contemporary methods.

Problem formulation

In general, OAPD problems of power system can be mathematically modelled as Optimal Power Flow (OPF). The OPF aims to optimize a defined objective function through optimal fine-tuning of various power system controllers while simultaneously satisfying various equality and inequality constraints. It is expressed as:

$$\text{Minimize} \quad f(x,u) \tag{1}$$

$$\text{Subjected to} \begin{cases} g(x,u) = 0 \\ h_{min} \leqslant h(x,u) \leqslant h_{max} \end{cases} \tag{2}$$

where f, x, u, $g(x,u)$ and $h(x,u)$ are the objective function to be minimized, set of dependent variables, set of independent control variables, sets of equality and inequality constraints respectively. The dependent variable in OAPD problems are generally slack generators' real (P_{G1}) and reactive power outputs (Q_{G1}), all load bus voltage magnitudes ($V_{L1},\ldots,V_{LNPQ}$), reactive power generations of all PV generators ($Q_{G2},\ldots,Q_{GNPV}$) and line loadings ($S_{L1},\ldots,S_{LNTL}$). Hence the vector of dependent variables '**x**' can be expressed as:

$$x^T = [P_{G1}, V_{L1},\ldots,V_{LNPQ}, Q_{G1}, Q_{G2},\ldots,Q_{GNPV}, S_{L1},\ldots,S_{LNTL}] \tag{3}$$

where NPQ and NPV represent number of PQ buses and PV buses respectively. The vector of independent/control variables '**u**' comprising of all PV generators' real power generations ($P_{G2},\ldots,P_{GNPV}$) and their generation voltages ($V_{G2},\ldots,V_{GNPV}$), tap changing transformers positions ($Tap_1 \ldots, Tap_{NT}$)), switchable capacitors VAr output ($SC_1,\ldots,SC_{NC}$). Similarly, the vector **u** is represented mathematically as

$$u^T = [\overbrace{P_{G2},\ldots,P_{GNPV}, V_{G2},\ldots,V_{GNPV}}^{\text{continuous}} \overbrace{Tap_1,\ldots,Tap_{NT}, SC_1,\ldots,SC_{NC}}^{\text{discrete}}] \tag{4}$$

where NT and NC represent number of tap changers and switchable capacitors respectively.

Constraints

Equality constraints

Real and reactive power balance equations correspond to the equality constraints involved in the optimization process. **g** is the general notation of equality constraints in the OPF formulation.

$$P_{Gi} - P_{Di} - |V_i|\sum_{j=1}^{NB}|V_j|\{G_{ij}\cos(\theta_i - \theta_j) + B_{ij}\sin(\theta_i - \theta_j)\} = 0 \tag{5}$$

$$Q_{Gi} - Q_{Di} - |V_i|\sum_{j=1}^{NB}|V_j|\{G_{ij}\sin(\theta_i - \theta_j) - B_{ij}\cos(\theta_i - \theta_j)\} = 0 \tag{6}$$

where N_G, NB, P_{Gi} and P_{Di} are the total number of generators, total number of buses, real power generation and demand respectively at ith bus of the network. Similarly, Q_{Gi} and Q_{Di} are reactive power generations and demand respectively at ith bus of the network. $|V_i|$ is the voltage magnitude at bus i and $|V_j|$ is the voltage magnitudes at bus j. The line conductance and susceptance between the bus i and bus j are represented by G_{ij} and B_{ij} respectively. The voltage phase angles between buses i & j is denoted as θ_{ij}.

Inequality constraints

OPF formulation also accommodates inequality constraints so as to incorporate the various operational limitations of the power system components as none of these apparatus can be operated beyond their capacities. Inequality constraints can be divided into two parts: (1) Inequality constraints on independent variable side and (2) Inequality constraints on dependent variable side.

(1) Inequality constraints on independent variable side

$$P_{Gi}^{min} \leqslant P_{Gi} \leqslant P_{Gi}^{max} \quad i \in \text{NG} \tag{7}$$