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Network Losses-Based Economic Redispatch for Optimal Energy Pricing in a Congested Power System

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Abstract

An efficient, low-cost and reliable operation of a power system by adjusting the available electricity generation resources to supply demand of the system is required to ensure satisfied economic plant dispatching. This paper proposes a scheme for economic redispatch model considering the transmission issues such as transmission congestion and network losses, in order to obtain an optimal energy price in supporting competitive electricity market under deregulated environment of a power system.

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Keywords: Economic dispatch, transmission congestion, electricity market, locational marginal prices, optimal power flow, DC-OPF, nodal price, energy price, deregulated power system.

1. Introduction

Competitive structure in deregulated electricity market is supposed to have the potential to promote economic efficiency of the electricity industry [1, 2]. However, as the power flow violates transmission constraints, redispatching generating units is required and this causes the price at every node to vary. Hence, transmission management should be assessed carefully in order to obtain an efficient and transparent price but satisfying all market participants [3-5]. However, congestion can cause the market players to exercise market power that is able to result in price volatility beyond the marginal costs [6-8]. In order to alleviate the system from further cascading failure, either preventive or protective actions must be taken such as load shedding strategy and DG penetration within congested zone [9-11].

Therefore, efficient, low-cost and reliable operation of a power system by adjusting the available electricity generation resources to supply demand of the system is needed to ensure economic plant dispatching. The main idea of the importance of economic dispatch is to minimize the total cost of generation while meeting the operational constraints of the available generation resources.

This manuscript introduces a scheme for economic redispatch model considering the transmission issue in order to obtain an optimal energy price, especially when transmission congestion occurs. A proposed scheme is presented to briefly review the main idea behind the energy price calculation, which is represented by locational marginal price (LMP), and further discuss the techniques used to incorporate transmission congestion taking into account network losses minimization into the model.

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2. Economic Dispatch Considering Network Losses

The definition of economic dispatch as cited in [12] is "*the operation of generation facilities to produce energy at the lowest cost to reliably serve customers, recognizing any operational limits of generation and transmission facilities*". The production cost of generation is analysed during the dispatch, subject to data that is concerning fuel cost and electrical power output [13-15]. A quadratic equation is utilised to approximate the cost function along with several cost coefficients. The key objective of the economic dispatch problem is to find a set of active power delivered by the committed generators to satisfy at any time the required demand subject to the unit technical limits and at the lowest production cost. For this reason, it is of great importance to solve this problem as fast and precisely as possible. The configuration of the economic dispatch problem with network losses considered is slightly more intricate to set up compared to the dispatching ignoring losses. This is because the network losses are added as an additional constraint to the equation. Figure 1 illustrates a thermal power generation system connected to an equivalent load bus through a transmission network.

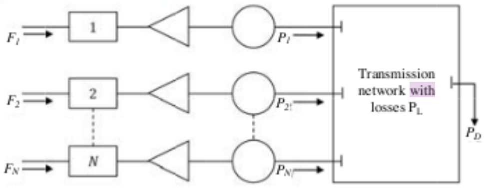

Fig. 1 *N* thermal units serving load through transmission network

The objective function of the system operation, F_T, is the same as that defined in the previous section. However, the equation must now include the network losses P_L as a constraint. Therefore, the optimization problem considering network losses may be stated as

Minimize

$$F_T = F(P_{gi}) = F_1 + F_2 + F_3 + \ldots + F_N = \sum_{i=1}^{N} F_i(P_{Gi}) \tag{1}$$

Subject to:

- The energy balance equation $(\mathcal{E} = 0 = P_D + P_L - \sum_{i=1}^{N} P_{Gi})$
- and the inequality constraints $(P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max}$ for $i = 1, 2, \ldots, N)$

The same procedure involving Lagrange function is also performed in order to establish the required condition for the solution of the minimum operating cost, hence,

$$\mathcal{L}(P_{Gi}, \lambda) = F(P_{Gi}) + \lambda \left(P_D + P_L - \sum_{i=1}^{N} P_{Gi} \right) \tag{2}$$

The set of equations involving the computation of network losses is more difficult to solve than the set of equations with no losses. Nonetheless, there are two general approaches to solve this problem [14]. The first approach is the *loss-formula* method that generates a mathematical expression for the losses in the network only, as a function of the power output of each unit. The second approach is by integrating the load–flow equations as crucial constraints in the formal establishment of the optimization problem which is known as the *optimal power flow*.

2.1. Network Losses Model

Generally, the power loss is represented in the terms of active power generation only. This is called the *B-coefficient* method and was first developed by Kron in 1951, then popularized by Kirchmayer in 1958 and extended by Happ and Meyer [13]. The transmission losses is given by

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_{Gi} B_{ij} P_{Gj} \tag{3}$$

Where, P_{Gi}, P_{Gj} is the real power generation at i and j plants and B_{ij} are the power loss coefficients which are constant under assumed conditions. Then the loss equation based on bus impedance matrix and current vector is given by

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\frac{R_{ij}\cos(\delta_i - \delta_j)}{|V_i||V_j|}\right](P_iP_j + Q_iQ_j) \quad (4)$$

2.2. Optimal Power Flow Techniques

The optimal power flow is a very large and complex mathematical program. Optimal power flow can be described as the minimization of real power generation cost in an interconnected power system while real and reactive power, transformer taps and phase-shift angles are controllable and various inequality constraints are required. This procedure consists of methods of employing power flow techniques for the economic dispatch while definite controllable variables are adjusted to minimize the objective function such as the cost of active power generation or the power losses, while satisfying physical and operating limits on various controls, dependent variables and function of variables. The OPF problem can be solved using either AC or DC power flow models. The word "optimal" is aimed to minimize total system operational costs and maximize benefits.

3. Case Study and Analysis

In this study, the economic redispatch scheme in which the transmission congestion and the network losses are taking into consideration is tested on a particular case study to determine the value of energy price at every bus. The proposed method is carried out with a 3-bus system with a total load of 800 MW. Fig. 2(a) shows the output of the proposed method for economic redispatch scheme developed in MATLAB optimization tools. It can be seen that there are 5 variables involved in the calculation process with 30 total function evaluation. The five variables representing two for generators and three for phase angles of the buses, respectively as figured out at the first graph of the Fig. 2(a). It needs four iterations to obtain first-order optimality condition of the objective function. The first-order optimality is an optimal point of Karush-Kuhn-Tucker condition needed in order to optimize the energy price, which is in this case characterized by the term of locational marginal price or LMP.

The simulation is conducted in two steps. Firstly, the transmission network is assumed to be unconstrained, meaning that there will be no congestion happen in the system. Under this condition, it is found that transmission line *L1* flowing the power about 39.23 MW, while transmission line *L2* and *L2* are transmitting the power at 464.85 MW and 360.77 MW, respectively in order to fulfill the system load 800 MW. Even though there is no transmission congestion occurs on a particular line, energy price at every bus shows a discrepancy, which are $26.384/MWh at bus 1, $26.41/MWh at bus 2, and $28.056/MWh at bus 3. Meanwhile, the amount of network losses resulted from the three transmission lines is 25.62 MW. This makes the total power generation to be 825.62 MW, which is the summation of the system load and network losses. Generator 1 is scheduled to generate 425.62 MW, and the rest 400 MW need to be transmitted from Generator 2 as shown in Fig. 2(b). It should be noted here that the network losses is now only becoming 24.52 MW. Accordingly, delivered energy cost due to fulfill the system load can be further reduced as well. Furthermore, other outcomes of the simulation as shown in Fig. 2(a) inform that the objective function is achieved at 18273,759 $/h with merchandizing surplus of 2790.59 $/h. This merchandizing surplus consists of the cost for the network losses and the transmission congestion, which are 673.37 $/h and 2117.22 $/h, respectively.

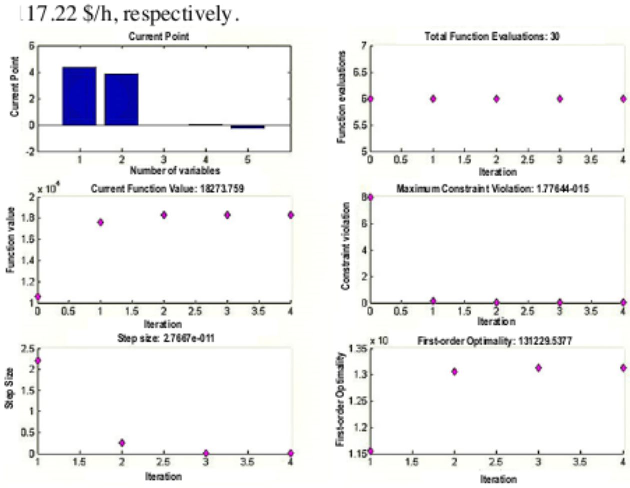

Fig.2 (a) Output of proposed economic redispatch model with DC-OPF

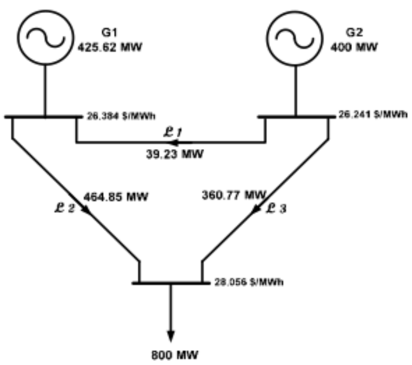

Fig.2 (b) Constrained branch flow of the 3-bus system

4. Conclusion

An economic redispatch scheme has been modeled in this study considering the transmission congestion and the network losses in the calculation. An optimization tool based on the proposed economic redispatch model was then developed in order to obtain optimal energy price at every bus. The results show that the proposed model has contributed in lowering the network losses, especially when transmission line is more likely in congestion condition. It is supposed that findings of this study can be utilized to support the standard market design of deregulated environment of a power system to deal with competitive electricity market by promoting economic efficiency and lowering delivered energy costs.

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