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Congestion management with distributed generation and its impact on electricity market

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ABSTRACT

Congestion management became more complicated with the increase of complexity in the system. The complexity arose due to restructuring of the utilities alongside the penetration of alternative sources of energy. This paper presents a sensitivity method for allocating distributed generators (DGs) considering congestion relief and voltage security simultaneously. The sensitivities of the overloaded lines with respect to bus injections are considered for ranking the load buses. The new generation capacities for DGs connected at these load buses are then computed by genetic algorithm (GA) with an objective of enhancing the system performance by reducing the system losses and maintaining the voltage profile of the various buses nearest to its nominal value. The *N*-1 contingency criterion has been taken into account in this work. The expected cost consists of operating cost under normal and contingency states along with their related probabilities to occur. Maximizing social welfare is the objective for normal state while minimizing compensations for generations re-scheduling and load side operation as well as in case of contingency also. Though installation cost of DGs is required, they are useful as cost effective, which can reduce in fact the annual costs for generations re-scheduling and load shedding. It has been shown that the method can assist the ISO to remove the overload from lines in both normal and contingency conditions in an optimal manner. The improvement is measured in terms of available transfer capability (ATC), congestion cost and reliability risk indices of Loss of Load Expectation (LOLE) have also been studied.

1. Introduction

Provision of ancillary services (ASs) is playing an important role in ensuring system reliability and security. Recently, the distributed generators are also participating in the provision of AS alongside the main services. Independent system operators and researchers have been looking for appropriate mechanisms for utilizing the energy for DGs in the context of deregulation [1–4]. Restructuring of electricity industry have created an augmented interest in distributed generation, which is expected to play an increasingly essential role in electric power systems operation and planning because of being dispersed throughout distribution and sub-transmission systems to provide load services [5]. Fuzzy *c*-means clustering approach is presented in [5] to identify the impacts of DGs on congestion management. Currently, there are several kinds of DGs [6], such as diesel turbines with the capacity under 1 MW, gas turbines with the capacity in the range of 1–20 MW, micro-turbines range from 30 to 200 kW, and hydro generation capacity in the range of 100 kW–1 MW. It is expected that DGs will cover 25% of the load increase in the coming 10 years in North America [7]. In [8–11], it is shown that in some cases, the control of load demand can be more effective than rescheduling of the generators in case of congestion.

In the literature, direct methods of line overload alleviation using generator rescheduling and load shedding is described in [12–14]. In [15], a method of overload alleviation by real power generation rescheduling based on relative electrical distance concept has been introduced. The method minimizes the system losses and maintains the voltage profile. However, the rescheduling cost is not considered by this method. In [16], a direct method has been proposed for line overload alleviation using sensitivities of the bus injections to the overloaded lines. This method calculates the sensitivity factors (SFs) that relate changes in real and reactive power injections at buses to changes in line currents. The SFs are ranked for selection of targeted buses for generation rescheduling and load shedding. However, while selecting the buses, the cost of generation rescheduling or the lost opportunity cost of load shedding were not considered. Methodologies for congestion management with placement of series Flexible Alternative Current Transmission Systems (FACTSs) controllers have been proposed in [17]. The concept of Static VAR Compensator (SVC) allocation using expected annual operating cost has been proposed by the authors in [18], where OPFs for contingency states are incorporated in a single

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large-scale optimization problem; the Bender decomposition technique is utilized for optimal placement of SVC. The Bender decomposition technique requires the convexity to solve the problem but it is not always guaranteed. An analysis of congestion management problem and associated issues in a power pool that incorporates nodal pricing is presented in [19]. A methodology to calculate transmission congestion cost and LMP for a given time period at any selected bus in the transmission system is proposed in [20]. Two congestion management schemes used in the Noord-Pool market are studied in [21]. A unified framework for the study of the congestion management schemes in different jurisdictions is provided, using a consistent set of metrics. The study provides a side-by-side comparison of the various congestion management schemes analyzed through the use of these metrics providing good insights on the impacts of congestion in the various jurisdictions. It provides a detailed analysis of different congestion management techniques used in different electricity markets throughout the world and a general congestion-relieving algorithm. In [22], a complex network based assessment of CM schemes in a bilateral market is developed based on an evolutionary bipartite network. Demand response based congestion management with generation re-dispatch and impact of FACTS devices was proposed in [23]. Among several various congestion management approaches [24–30], two well-known approaches to congestion management in a deregulated environment stand out in particular, that is the zonal pricing approach and the countertrade approach. Under the zonal pricing approach the power systems are split into different zones connected by frequently congested lines. In case of congestion, a different market clearing price is set in each zone in such a manner that trading between zones results in power flows that are smaller or equal to the transfer capability. If there is no congestion between the zones, their market clearing price is uniform. The problem with zonal pricing is that it does not prevent internal congestion, since the zonal boundaries are defined ex-ante. To account for this deficiency, the countertrade approach is often utilized.

With the countertrade approach the system operator re-dispatches power in such a way that the resulting power flows do not overload any lines. Market players can bid to increase or decrease their production and/or consumption in a similar manner as this is done in a balancing market, while the responsibility of the system operator is to select bids in the most efficient way. The countertrade congestion management approach utilizing Generalized Generation Distribution Factors (GGDFs) [31] to obtain the relation between re-dispatched power and change of line power flow was presented in [32]. Due to the nature of these factors, Linear Programming was used to obtain an optimal re-dispatch of power production. In case of load re-dispatch, loads are considered as negative injections and GGDFs are calculated in the same manner as for generators, which enable a simultaneous re-dispatch of generators and loads. The concept of countertrade approach has been used in this work.

In the present work, determination of sitting and sizing of DGs for congestion management under sever contingency have been proposed. Line flow sensitivity factor has been used to select the load buses for DG allocation with respect to the overloaded lines in the system. Genetic algorithm (GA) has been used to determine the optimal value of the DG capacity to be connected with the existing system thereby enhancing the system performance by reducing the system losses and maintaining the voltage profile of the various buses. It has been shown that the method can assist the ISO to reduce the overload from lines in both normal and contingency conditions in an optimal manner. The Impact analysis of DG allocation on congestion management has been observed in terms of available transfer capability (ATC), reliability and congestion cost has been also presented in this work. The effectiveness of the proposed method for DG allocation has been compared with

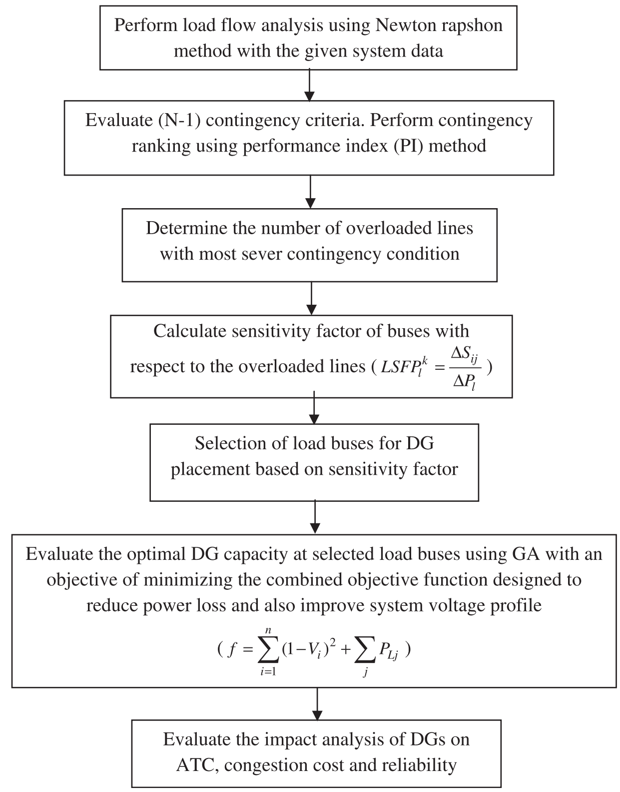

Fig. 1. Flow diagram for the proposed methodology of congestion management with DGs.

the methods suggested in [15,35], in terms of its impact on reducing the power flow, congestion cost and improvement in the voltage stability during the normal and critical contingencies cases. Fig. 1 shows the step by step scheme of the proposed methodology for relieving transmission congestion in the system with optimal placement of DGs.

The rest of this paper is organized as follows: Proposed DG allocation method for congestion management is presented in Section 2. Calculation of impact analysis of DG allocation on electricity market has been presented in Section 3. Section 4 analyzes the illustrative example and Section 5 concludes this paper.

2. Problem formulation

DG allocation for congestion management considering the (N-1) contingency criteria will have more impact on system from security point of view. A suitable allocation will be that which would give better performance in most of the operating conditions (normal and alert states). Contingency ranking has been carried out using voltage security and power flow performance indices.

2.1. Contingency selection

Contingency analysis has been carried out to assess the impact of severe contingencies on the system security and to alert the system operators about the critical contingencies that violate the equipment operating limits. The most common limit violations include transmission line and/or transformer thermal overloads and inadequate voltage levels at system buses. Given this information, a system operator can judge the relative severity of each contingency and decide if preventive actions should be initiated to mitigate the potential problems [34].

The general performance index for a system is defined as,