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Application of electricity tracing theory and hybrid ant colony algorithm for ranking bus priority in power system

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ABSTRACT

Locating the most suitable locations in power system for any corrective and preventive actions is not an easy task especially for large scale network. The recent methods for determining the suitable generators for power scheduling and locations for shunt elements placement such as capacitor bank and Flexible Alternating Current Transmission System (FACTS) devices are sensitivity analysis, optimization approach, and stability index calculation. Meanwhile, there are also various power tracing techniques have been developed, but only applicable for transmission service pricing in deregulated environment. For a new approach, this paper proposes a technique to determine the suitability of locations in power system for any preventive and corrective actions via Fast Voltage Stability Index Tracing (*FVSI*-T) with the assistance of a new hybrid algorithm, Blended Crossover Continuous Ant Colony Optimization (BX-CACO). After experimentation and comparative studies, the proposed technique reflects a potential performance for real system applications.

1. Introduction

Electricity tracing or commonly termed as power tracing is a technique used for allocating transmission usage charge on consumers in a manner that is free from discrimination. By tracing the powers contributed by generators and loads while considering the physical constraints of power system, the consumers of a transmission service provider (TRANSCO) will be charged fairly based on their associated usage capacity. This is totally different with traditional method such as postage stamp allocation and contractual path method in which the usage charge is based on transaction regardless of physical constraints like generation-demand balance and current flow direction [1,2]. Despite various power tracing methods have been developed by researchers, the application is only for charge allocation in the field of transmission service pricing. So far, there is no research tries to adopt the theory of electricity tracing into voltage stability improvement, especially under multi-contingencies condition. Corrective and preventive actions become the main subject of discussion when preventing the voltage collapse phenomenon. Power scheduling and Flexible Alternating Current Transmission System (FACTS) devices are the instances for preventive actions before the occurrence of voltage collapse. However, if all the manners are exhausted, load shedding will be the last resort for corrective action to counteract such disturbance [3]. To perform the actions, identification of suitable locations is necessary as this will affect the performance after improvement. The recent methods employed by many researchers regarding on identification of suitable locations are sensitivity analysis, stability index calculation, and optimization technique.

A proportional sharing principle (PSP) based power tracing has been proposed by Bialek [4,5], namely Topological Generator and Load Distribution Factor (TGLDF). Being noted as a pioneer method in the field of electricity tracing, the method has established the concept of '*net flow*' and '*gross flow*' for providing a lossless power system prior to performing the tracing task. Article [6] has proposed a power tracing algorithm based on circuit theory approach. In the method, the basic Ohm's Law and bus impedance matrix were implemented to obtain the complex powers contributed by generators. Optimization approach via Linear Programming (LP) has been firstly introduced by Abhyankar et al. [7] for real power tracing. The research presented a systematic formulation technique including control variables, types of constraints to be considered and objective function to be utilized. However, it is discovered that such formulation technique resulted to computational burden during optimization due to various constraints have to be considered. Prediction based power tracing has been invented by Sulaiman et al. [8] via Support Vector Machine (SVM), in which the Artificial Intelligence (AI) tools have been firstly incorporated into electricity tracing problem. To provide optimal performance of SVM, Genetic Algorithm (GA) and Artificial Bee Colony (ABC) have been adopted to optimize the related parameters in providing better accuracy during prediction process.

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So far, the fastest convergence speed promoted by meta-heuristic optimization algorithm is the Ant Colony Optimization (ACO) which was firstly introduced by Dorigo and Stutzle [9]. In virtue of that, various researches have implemented ACO for solving problems either in business or technical fields. Article [10] proposed optimal reactive power pricing by incorporating ACO. In the research, the fitness has been formulated based on reactive power production cost and after experimentation, the algorithm provided fine improvement within tolerable computation time. Optimal economic dispatch via ACO has been proposed by Pothiya et al. [11] considering non-smooth cost function. To provide effective searching mechanism, the research introduced three additional techniques in ACO which are priority list, variable reduction, and zoom feature. It was justified that ACO has great capability to perform fast optimization with reliable solution concurrently. Other works that justified ACO performance can be accessed in [12,13]. Contrary to Dorigo's ACO, a new version has been proposed by Socha and Dorigo [14] for continuous domain optimization, which is called as ACO_R. This algorithm has great ability to perform continuous optimization problem like tuning or sizing while maintaining the fast convergence property of the original algorithm. The performance of ACO_R has been validated in [15,16].

This paper presents a new technique for ranking the priority of buses in a power system to be used for any preventive and corrective actions, that is, by means of tracing the stability index contributed by generators and loads. The ranking list can be used by a system operator (SO) to select the most suitable locations for any countermeasures against power system disturbances like voltage collapse phenomenon. For more reliable results, Fast Voltage Stability Index (*FVSI*) has been selected as the index to be traced via a new hybrid optimization algorithm, namely Blended Crossover Continuous ACO (BX-CACO). The proposed algorithm has been formulated systematically in accordance to the developed tracing technique.

2. Formulation of *FVSI*-Tracing (*FVSI*-T)

2.1. Fast Voltage Stability Index (FVSI)

As a matter of fact, Fast Voltage Stability Index (*FVSI*) is a line based index derived from quadratic equation, as justified by Musirin and Rahman [17]. The reliability and simplicity of *FVSI* in voltage stability assessment viewpoint has been proven by Musirin and Rahman [18,19]. Such justification has motivated this research to utilize it as the index to be traced in the developed algorithm. The *FVSI* of an *l*-th line can be represented as in following equation:

$$FVSI_l = \frac{4Z_l^2 Q_r}{V_s^2 X_l} \tag{1}$$

where Z_l is the line impedance; X_l the line reactance; Q_r the reactive power at the receiving end and V_s is the voltage at the sending end.

In addition, *FVSI* has also been used for monitoring load margin between the operating point and nose point in *Q–V* curve. For a stable power system before the occurrence of voltage collapse phenomenon, *FVSI* on each line should be less than unity or the loading condition on a certain bus should be kept below than its maximum loadability, Q_{max} as depicted in Fig. 1.

2.2. The concept of FVSI-Generation Tracing (FVSI-GT)

In the field of power tracing, the term generation tracing means a task to trace powers (line flows, losses, and load power) contributed by individual generator. Thus, *FVSI*-Generation Tracing (*FVSI*-GT) signifies a task to trace the stability index *FVSI* on a particular line contributed by each generator. The rationale of doing so is to

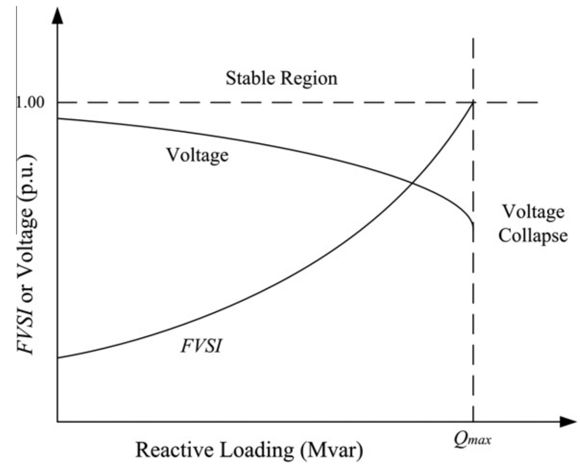

Fig. 1. *FVSI* and voltage variation with respect to reactive loading.

identify the generator that becomes the major contributor on a stressed line. From that, a ranking list indicating the priority of generators for any countermeasures like economic dispatch or power scheduling can be obtained by a system operator (SO). According to [7], the power to be traced can be expressed as a summation of individual power contributed by each generator. By the same token, *FVSI* of *l*-th line can also be expressed as a summation of contributed *FVSI* by generators, as follows.

$$FVSI_l = FVSI_l^1 + FVSI_l^2 + \cdots + FVSI_l^{k,\,ngen} \tag{2}$$

Substituting (1) into (2) in generation tracing viewpoint:

$$FVSI_l = \frac{4Z_l^2 Q_r^1}{V_s^2 X_l} + \frac{4Z_l^2 Q_r^2}{V_s^2 X_l} + \cdots + \frac{4Z_l^2 Q_r^{k,ngen}}{V_s^2 X_l} \tag{3}$$

$$FVSI_l = \frac{4Z_l^2}{V_s^2 X_l}(Q_r^1 + Q_r^2 + \cdots + Q_r^{k,\,ngen}) \tag{4}$$

$$\therefore FVSI_l = \frac{4Z_l^2}{V_s^2 X_l}\sum_{k=1}^{ngen} Q_r^k \tag{5}$$

where *ngen* is the number of reactive power sources in the system; Q_r^k the receiving end reactive power contributed by *k*-th reactive source; and x_r^k the receiving end reactive power fraction contributed by *k*-th reactive source.

According to [7], the participation of a generator with power Q_{gk} in receiving end line flow can be expressed as in following equation:

$$Q_r^k = x_r^k \cdot Q_{gk} \tag{6}$$

Thus, substituting (6) into (5):

$$FVSI_l = \frac{4Z_l^2}{V_s^2 X_l}\sum_{k=1}^{ngen} x_r^k \cdot Q_{gk} \tag{7}$$

It can be deduced that from (7), the traced *FVSI* on *l*-th line due to *k*-th generator is represented as in following equation:

$$FVSI_l^k = \frac{4Z_l^2}{V_s^2 X_l}(x_r^k \cdot Q_{gk}) \tag{8}$$

Thus, it is revealed that the traced *FVSI* can be determined by tracing the fraction x_r^k due to that generator. The ranking list of generator buses is then constructed based on the magnitude of the traced *FVSI*. It is essential to note that since *FVSI* is based on reactive power, then reactive power tracing shall be employed