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A wide area synchrophasor-based load shedding scheme to prevent voltage collapse

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ABSTRACT

This paper presents a new method based on wide area voltage stability index for optimal load shedding to prevent voltage instability phenomena. Phasor Measurement Units (PMUs) have widely been used in recent years due to their great advantages in power systems wide area monitoring, protection and control. The purpose of this paper is to provide a new optimal load shedding method, which disconnects the least possible amount of load from optimum buses. Not only the system stability is considered as main goal in this research, but also minimum load shedding is taken into account. Moreover, the problem of optimal load shedding is applied using modified Discrete Imperialistic Competition Algorithm (DICA) in mid-term and long-term voltage instability scenarios. In all investigations, certain limitations are considered to obtain practical answers. In addition, some modifications are applied to the conventional ICA, which make it proper for solving the optimal load shedding problem. New modifications result in fast convergence characteristic and less run time, which are crucial in dealing with power system instability problems.

Introduction

Nowadays, power systems are operated close to their stability limits. Due to the large scale and natural complexity of power systems, the risk of blackout is high when they are operated near their stability boundaries. Voltage collapse caused several power system blackouts around the world, thus, the voltage stability is one of the major concerns of power system operators. Various definitions have been introduced for voltage stability of power systems [1–4]. Voltage stability is concerned with the ability of power system to maintain acceptable voltages at all buses in the system under normal condition and after being subjected to a disturbance [5].

There are many solutions for controlling voltage stability problem, such as shunt compensators, tap changer control, generators reactive power control, FACTS and Under Voltage Load Shedding (UVLS). The UVLS is the last step in protecting the power systems, facing voltage instability [6].

Various schemes have been proposed for UVLS. These schemes can be categorized in two groups: local and wide area. In local methods, the UVLS relays operate using local measurements. The stability index could be voltage magnitude or a voltage stability indicator [7]. Although the voltage stability state of the power system has direct impact on voltage magnitude, the latter is not proper stability index for UVLS decision making. Not only voltage stability state, but also various parameters affect the voltage magnitude. In [8], an adaptive under-voltage load shedding scheme, using model predictive control, is proposed to protect power system against voltage instability. A new approach based on hybrid Particle Swarm-Based-Simulated Annealing Optimization technique (PSO-B-SA) is proposed in [9] for solving under-voltage load shedding (UVLS) problem. A method for determining the location and quantity of the shedding load, in order to avoid risk of voltage instability is presented in [10]. This method is based on the indicators of risk of voltage instability suggested in [11]. A method is developed in [12] to study the load shedding problem in emergency states, where power flow solution cannot be found for the stressed system. The algorithm is divided into two sub-problems including restoring solvability sub-problem and improving voltage stability margin (VSM) sub-problem.

The second group of methods are wide area measurement-based algorithms. In these methods, the load shedding decision making process applies wide area measurement-based voltage stability indices. In recent years, Wide-Area Measurement Systems (WAMS) is developed for the real time monitoring, control and protection of power systems, to prevent system blackouts [12]. PMUs are newly developed instruments, which take advantage of

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synchronized measurement technology, available to the power system operators. In [13] a linearized local voltage stability index, based on Wide-Area Measurement Systems, is addressed [14]. Deals with the detection of an impending voltage collapse from the system states provided by PMUs. In [14], the algorithm performs efficient sensitivity computation, in order to identify when a combination of load powers has passed through a maximum laudability limit. In [15] a new wide area voltage stability index is proposed which considers the whole system topology and loads impact on the local voltage stability index.

In this paper, a new optimal load shedding (OLS) method is proposed for preventing mid-term and long-term voltage collapse. The proposed load shedding method uses wide area voltage stability index, which result in accurate and efficient load shedding decisions. Modified version of Discrete Imperialistic Competition Algorithm (DICA) is utilized for OLS problem solving. The modified DICA is improved from speed and accuracy points of view. In this method, all loads of the network contribute in load shedding procedure. The result of optimization problem includes the location and the amount of loads, which should be disconnected from network for preventing voltage collapse. The efficiency of proposed method is tested on the practical high-voltage network of the Khorasan province, a part of the Iran national grid.

The rest of this paper is organized as follows. In Section 'Wide area voltage stability index', a wide area voltage stability index is reviewed. The details of the new wide area OLS algorithm are presented in Section 'Wide area optimal load shedding'. The new modified DICA and its application to load shedding method are presented in Section 'Modified discrete imperialistic competition algorithm'. Simulation results of the application of proposed algorithm are presented in Section 'Simulation results'. Section 'Analysis of the results' includes analysis of the results from different viewpoints. In Section 'Discussion', a brief discussion on the proposed algorithm and the obtained results are presented. Finally, S ection 'Conclusion' provides the conclusion.

Wide area voltage stability index

As mentioned in previous section, various voltage stability indices have been proposed in the literatures. An accurate stability index is essential for a proper load shedding algorithm. In recent years, by developing WAMS, various researches have been performed on wide area voltage stability indices.

A group of indices which have attracted a lot of interest includes techniques based on the impedance match concept [16–20]. The main idea of these techniques is based on calculating the Thevenin equivalent of system, seen from bus, using local voltage and current phasors measurements. A load impedance matching to the system Thevenin impedance is tantamount to voltage collapse. In spite of its elegance and simplicity, this technique has some major defects. The first drawback is related to considering the power system as a system with constant state during the calculations. This requirement is not satisfied mostly in cases, when the system is close to voltage collapse. In such cases, different elements such as transformer taps, generator excitation systems and shunt compensators are changing. Thus, power system variations cause inaccurate stability index. The second major drawback is theoretical issue. In this technique, the interactive effects of different loads on the indices of other loads are neglected. This defect, causes error in multi-load systems. Further explanations on this issue and illustrative examples are provided in [15].

An accurate stability index has the most significant role in an effective load shedding algorithm. In the proposed optimal load shedding method of this paper, a wide area voltage stability index is utilized. This index is firstly introduced in [21] and then developed in [22].

In this method, in order to model all loads and generators for index calculations, the multi-port system is modeled [22]. As Fig. 1 shows, in this well-known model, load buses and generator buses are brought outside of the network. The remainder of the network is modeled using Z_{LL} matrix, which will be introduced, later.

The multi-port modeling equations are as follows [22]:

$$\begin{bmatrix} -I_L \\ 0 \\ I_G \end{bmatrix} = \begin{bmatrix} Y_{LL} & Y_{LT} & Y_{LG} \\ Y_{TL} & Y_{TT} & Y_{TG} \\ Y_{GL} & Y_{GT} & Y_{GG} \end{bmatrix} \begin{bmatrix} V_L \\ V_T \\ V_G \end{bmatrix} \tag{1}$$

where L, G and T subscripts stand for the Load, Generator and Transmission buses, respectively. Eliminating the tie buses, the load bus voltage vector is as follows:

$$V_L = E_{eq} - Z_{LL} I_L \tag{2}$$

where E_{eq} and Z_{LL} are calculated as follows [22]:

$$E_{eq} = Z_{LL}(Y_{LT} Y_{TT}^{-1} Y_{TG} - Y_{LG}) V_G \tag{3}$$

$$Z_{LL} = (Y_{LL} - Y_{LT} Y_{TT}^{-1} Y_{TL})^{-1} \tag{4}$$

Using (1)-(4), voltage of the load bus j is calculated as follows [22]:

$$V_{L\,j} = E_{eq\,j} - Z_{LL_{jj}} I_{L\,j} - \sum_{i=1, i\neq j}^{n} Z_{LL_{ij}} I_{Li} \tag{5}$$

The third term of the right side of (5) represents the effect of other loads on the voltage stability index of the jth load bus. As (5) shows, the index is not only related to the load of bus j, but also dependent on the loads of other buses. The mentioned third part of (5) can be modeled as virtual impedance in calculating voltage index of bus j. Fig. 2. Shows the virtual impedance model [22]. According to the virtual impedance model, the voltage stability index is defined as follows [22]:

$$Index = \frac{|Z_L|}{|Z_{eqj} + Z_{cj}|} \tag{6}$$

where Z_L is the load impedance. Z_{eqj} is equal to the Z_{LLj}, where it denotes the ith diagonal element of Z_{LL}. Z_{cj} is the coupling impedance, which represent the interactive impacts of loads on each other. Z_{cj} is defined as follows:

$$Z_{cj} = \frac{\sum_{i=1, i\neq j}^{n} Z_{LL_{ij}} I_{Li}}{I_{Lj}} \tag{7}$$

In calculations of index using (6), the whole system state is available through the WAMS. The data of PMUs from the whole network are concentrated in system control center. The control center calculates the wide area voltage stability index, using synchronized data, for each load bus. Thus, the drawback related to the constant state assumption is solved in this index. The effect of loads of the system on each other are modeled using the virtual impedance. Hence, the second shortcoming is resolved by the wide area voltage stability index, as well. Based on index value and

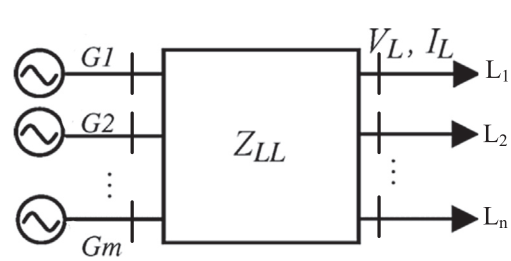

Fig. 1. The model of multi-port system.