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Voltage collapse detection using Ant Colony Optimization for smart grid applications

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ABSTRACT

Load demand levels in power networks are continuing to increase especially considering the penetration of Plug-in Hybrid Electric Vehicles, and as a result bus voltages are requiring more support from generators elsewhere in the network in order to maintain the voltage within specified limits. If the network is unable to support the increasing demand, bus voltage will begin to degrade until the point of voltage collapse which can lead to catastrophic network failure. Previous studies have shown that evolutionary computing techniques are effective methodologies for locating voltage collapse points. Ant Colony Optimization techniques allow for the optimization of many independent parameters simultaneously, the loading parameter for each bus is considered in this work. In this study, Ant Colony Optimization is applied to detect voltage collapse conditions in power networks, to obtain faster computing time with the future goal of providing online detection and prediction for use in smart grids. Two case studies are considered in this study to assess the performance of the proposed detection algorithm; the first case study includes 9-bus system while the other case study involves IEEE 118-bus system. Results obtained from both cases and conclusions drawn are also presented.

1. Introduction

The ever-increasing demands in modern power networks have resulted in several large blackouts in recent years. Given that these demands increase show no signs of slowing, there is a need for further study into the stability of power systems to avoid more blackouts in the future. Voltage collapse has been identified as the cause of many of these power system events. It is characterized as a gradual decay of bus voltage magnitudes until a sharp drastic drop occurs. This drastic drop, or "collapse point," has been tied to the occurrence of saddle-node bifurcation, and is discussed in Section 2.

There have been many studies conducted to identify these collapse points using the direct method [1,2,4] as described in Section 3. The continuation power flow method [3–5] was introduced as an alternative to the direct method as a way to deal with numerical difficulties associated with the direct method. Study [7] has begun using Genetic Algorithms (GA), such as Particle Swarm Optimization (PSO) and Differential Evolution (DE), in conjunction with these methods to locate the collapse points, or Ant Colony Optimization (ACO) to determine maximum loadability levels [8].

The ACO, introduced by Dorigo in 1996 [9], is an analog to the foraging habit of ants in nature. This algorithm, like many other GA-based algorithms, relies on the past experiences, or solutions of previous iterations, to move towards a globally best solution based on a describing function or fitness value. This algorithm has an advantage over other GA-based algorithms in that it can optimize a large number of independent parameters to create an optimal solution. The ACO is further described in Section 4.

This paper utilizes an ACO algorithm to locate the voltage collapse point in power systems. The voltage collapse point is commonly tied to a loading parameter λ^*, at which the system experiences a bifurcation [1,2]. This parameter is a single scalar value used to equally load all buses. The proposed approach utilizes the ACO algorithm's ability to optimize groups of independent parameters and thus λ^* becomes a vector of scalar values each associated with a single system parameter. The proposed approach is described in detail in Section 5. The proposed approach is then applied to two case studies involving an IEEE 9-bus system and an IEEE 118-bus system while results are summarized in Section 6.

2. Voltage collapse and saddle-node bifurcations

In an electric power system, the flow of the electric power can be represented by a set of power flow equations at equilibrium

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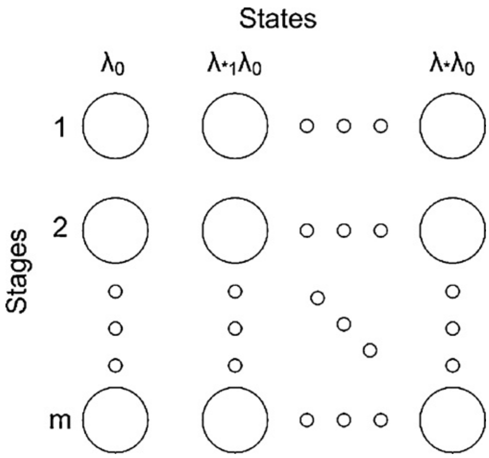

Fig. 1. Construction space.

containing state variables z and load variables λ [1].

$$F(z, \lambda) = 0$$
$$z = (|V_2|, \delta_2 \ldots |V_n|, \delta_n, t_1 \ldots t_n) \tag{1}$$
$$\lambda = (P_2, Q_2 \ldots P_n, Q_n)$$

The current operating point of the system is defined as λ_0 and it is assumed that there is a set of state variables z_0 that exist to satisfy (1). Therefore (z_0, λ_0) is an equilibrium solution of the power flow model. The initial value of the load variables λ_0 is obtained through iterative techniques, such as Gauss–Seidel and Newton–Raphson methods. It is also assumed that λ_0 is chosen so that the Jacobian matrix $D_zF(z,\lambda)$ of the power system model evaluated at the equilibrium point is non-singular [1].

Bifurcations result when a slowly varying parameter results in a drastic change to the state variables as discussed in [6]. In the case of voltage collapse, this parameter is λ^*, a scalar loading parameter, and the state variable that experience the sudden change is a bus voltage magnitude. The parameter λ^* is applied to the power system [8] as a loading parameter for system buses:

$$\lambda = \lambda^* \lambda_0 \tag{2}$$

More specifically, the real power generated (P_G), the real power demand (P_D) and the reactive power demand (Q_D) are defined in (3) where P_{G0}, P_{D0}, Q_{D0} are the values of λ_0. Since the entries of the Jacobian matrix associated with voltage-controlled buses can be removed, the reactive power generated (Q_G) is not included in this formulation.

$$P = P_G - P_D = \lambda^* P_{G0} - \lambda^* P_{D0}$$
$$Q = Q_D = \lambda^* Q_{D0} \tag{3}$$

Saddle-node bifurcations occur at singularity points of the Jacobian matrix. It follows from (1) and (2) that there exists a value λ^* that results in an equilibrium point (z_x, λ_x), such that the Jacobian is singular. Given that $D_zF(z,\lambda)$ is non-singular, it follows that $D_zF(z,\lambda)$ evaluated at the equilibrium (z_x, λ_x) will have a unique zero eigenvalue with normalized right and left eigenvector v and w. It is the aim of bifurcation analysis to determine this equilibrium point.

3. The direct method

The direct method has been studied to determine the proximity to voltage collapse points. A basic description of the method follows; for a more complete description refer to [1,2,4]. The direct method requires an equilibrium point identified by (1) to meet the requirements of (4) to identify the location of a saddle-node bifurcation.

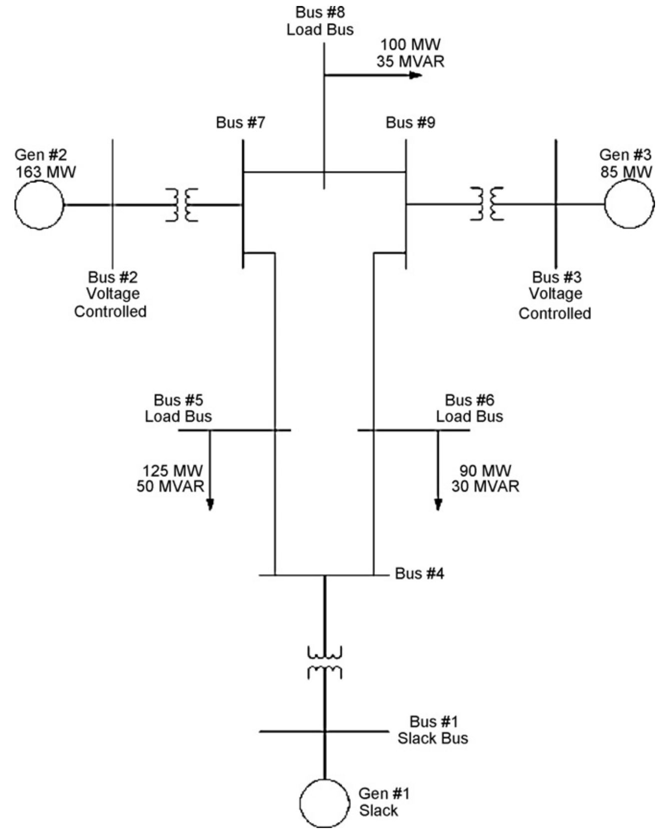

Fig. 2. The nine-bus system case study.

$$D_zF(z, \lambda)^T w = 0$$
$$\|w\|_\infty = 1 \tag{4}$$

4. Ant Colony Optimization

Ant Colony Optimization (ACO) was introduced by Dorigo in 1996, and is based on the foraging habits of ants. A brief description of ACO follows; for further information the reader can refer

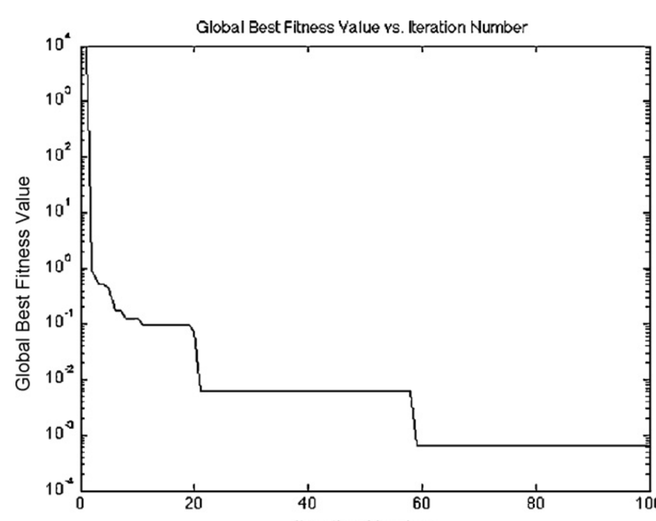

Fig. 3. Global fitness function results (9-bus system).