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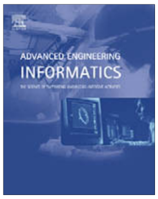

Slow coherency and Angle Modulated Particle Swarm Optimization based islanding of large-scale power systems

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ABSTRACT

Power system islanding is an effective way to avoid catastrophic wide area blackouts, such as the 2003 North American Blackout. Islanding of large-scale power systems is a combinatorial explosion problem. Thus, it is very difficult to find an optimal solution within reasonable time using analytical methods. This paper presents a new method to solve this problem. In the proposed method, Angle Modulated Particle Swarm Optimization (AMPSO) is utilized to find islanding solutions for large-scale power systems due to its high computational efficiency. First, desired generator groups are obtained using the slow coherency algorithm. AMPSO is then used to optimize a fitness function defined according to both generation/load balance and similarity to the desired generator grouping. In doing so, the resulting islanding solutions provide good static and dynamic stability. Simulations of power systems of different scales demonstrate the effectiveness of the proposed algorithm.

1. Introduction

Though designed to be robust and tolerant to disturbances, power systems may become unstable during severe faults, especially when they are operated close to their stability margins. The sources of such severe disturbances include earthquakes, hurricanes, human operation errors, control system failures, hidden failures in protection system, malicious attacks, etc. These disturbances may cause the system to lose stability and even lead to catastrophic failures [1], such as the North American Blackout on August 14, 2003.

Studies show that many blackouts (including the 2003 Blackout [2]) could have been avoided and significant losses could have been reduced if proper defensive islanding operations were taken prior to or following a catastrophe. Defensive islanding, also called system splitting or controlled system separation, is different from passive islanding. Passive islanding is a reactive measure and usually results from damages and protection. On the contrary, defensive islanding intentionally splits an interconnected power system into a number of islands by opening selected transmission lines [3]. If defensive islanding and necessary load shedding are properly deployed during or prior to dangerous events, although the power systems will operate in a less versatile and degraded state, catastrophic losses can be avoided because the blackout is isolated and prevented from further spreading.

In the literature, several authors have investigated the islanding problem. In [1,2,4–7], the generators are first grouped according to normal forms [4] or slow coherency [1,2,5–7] and then search algorithms are employed to find the minimum cut set from the interface network between the generator groups. Since the slow coherency algorithm considers the dynamic behaviors of large-scale power systems, the solutions can not only maintain good active power generation and load balance, but also provide good dynamic transient performance during islanding operations. Simulation studies demonstrated that the proposed algorithms could effectively improve system stability and avoid the possibility of wide area blackouts. Lu's group presented a different method for system splitting based on its steady state stability [3,8]. To narrow the search space of large-scale power systems, the original power network is first simplified by graph theory, and then ordered binary decision diagrams are used to find the splitting strategies candidates.

As shown in [3], the balanced partition problem is an NP-complete problem. It is very difficult to find the optimal solution for a large-scale power system using deterministic searching algorithms, because these algorithms are not efficient in exploring a large NP-hard search space. Currently, most of the island search algorithms are optimized based on either a simplified version or a selected subset of the original power system. These simplifications make it possible to miss better solutions that may exist in the original system. It is preferable to consider the original power system configuration data directly. However, in order to do this, one must conquer the computational complexity. The proposed solution in this paper is to take advantage of the computational

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efficiency of random search algorithms to improve the search speed and exploring capability. It has to be mentioned that the random search algorithms cannot guarantee the optimality of solutions. There may exist many solutions having similar performance for large-scale power systems. Given that decision time is significant for islanding, finding a good solution faster is much more important than finding the optimal solution. Thus, the objective for this paper is to find a number of efficient solutions within limited time.

This paper proposes a new islanding algorithm based on slow coherency and AMPSO [9] applicable to large-scale power systems. AMPSO is a Particle Swarm Optimization (PSO) algorithm that employs a trigonometric function as a bit string generator. It is more computationally efficient than Binary PSO, because the algorithm avoids evolving a high-dimensional bit vector and the discretization process. Moreover, by reducing the high dimension problems into 4-dimensional problems that will be shown in Section 2, AMPSO saves memory and is easier to implement.

An effective islanding solution should possess both good static and dynamic stability properties. The fitness function should be properly defined to reflect this requirement. Since slow coherency algorithm groups generators based on oscillation modes of power systems, the calculated generator groups yield good dynamic stability properties. Thus, the defined fitness function contains a term reflecting the candidate solutions' similarity to the slow coherency based generator groups. The static stability of the solution is considered according to the balance between generation and load in each island. The optimized candidate solutions based on such a fitness function will have good static and dynamic stabilities.

In addition to the application to power system islanding as discussed in this paper, the optimization algorithm can also be applied to other large-scale discreet optimization problems. For different applications, different cost/fitness functions need to be designed to address the application-specific problems. The authors hope, with implementation details and the simulation results, this paper can provide readers more confidence on the AMPSO algorithm.

The rest of the paper is organized as follows. Section 2 introduces the problems to be considered during defensive islanding, slow coherency, and the AMPSO algorithm. Section 3 presents the details of the slow coherency and AMPSO based islanding algorithm. Section 4 provides simulation results of power systems of different scales, and finally, conclusions and discussions follow in Section 5.

2. Background

2.1. Power system defensive islanding

The issues to be considered during power system defensive islanding are summarized as follows:

(1) Generation/load balance and load shedding

The core of power system operation is to maintain a state of operating balance between supply and demand of electric power. Since reactive power can be locally compensated, active power balance is the most significant issue for power system operation. Power imbalance between generation and load can affect power system stability in many ways. An example of voltage stability issue is depicted in Fig. 1.

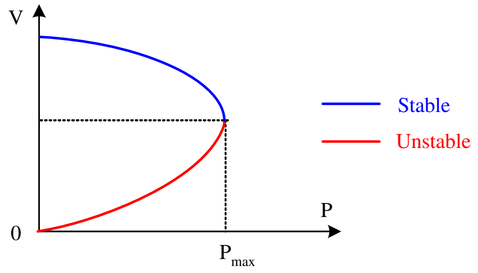

Fig. 1. Power–voltage characteristics.

Fig. 1 illustrates the relationship between bus voltage (V) and active power load (P). Normally, power system operates at the upper part of the P–V curve (blue[1] curve) for stable operation. If load demand increases, bus voltages will drop according to the curve. Once load demand exceeds the critical point of P_{max}, it is not possible any more to find a stable operating point, and bus voltages will collapse progressively. Therefore, it is important to maintain active power balance so that the load is always less than the maximum power generation P_{max}.

For islanding problem, the active power balancing issue needs to be considered for every island. One should try to create islands with sufficient generation to supply all the loads. If the power generation in an island is insufficient, necessary load shedding will become unavoidable. Thus, islanding algorithms should be able to provide load shedding information in addition to the transmission line switching information.

(2) Transmission System Capacity Constraint (TSCC)

Since the capacity of the transmission system is limited, it is necessary to check for thermal or static stability limits. Thus, the islanding algorithm should be able to provide a number of candidate solutions for the TSCC check. If one candidate solution fails, the algorithm should be able to provide another set of solutions until a feasible solution is found.

(3) Priorities of loads

Some customers (or loads), such as hospitals, airports, and government buildings, should have higher priority to obtain power supply over other loads. Thus, loads should be classified into different classes according to their difference in importance, such as critical loads and non-critical loads, and given corresponding priority indexes. The performance of an islanding solution should not only be evaluated according to the amount of operational loads but also the priorities of these loads.

(4) Computational efficiency

Since the status of transmission lines can be either open or closed, a power system with n transmission lines will have a total number of 2^n possible solutions. As mentioned in Section 1, our objective is to find some efficient solutions within limited time rather than the optimal one. Even so, finding the efficient solutions from a huge searching space is a difficult job. Thanks to the recent development of evolutionary computation techniques, a number of random search based optimization algorithms can be utilized.

(5) Isolation of possible impacted region

During some predictable events, such as the approaching of a destructive hurricane, it is desirable to isolate the possibly impacted region from the rest of the system. This kind of isolation can prevent the spreading of blackout originated in the impacted region. To minimize possible losses, further islanding of the isolated region may help.

(6) Dynamic response consideration

To form islands, some transmission lines need to be opened, the interruption of power flow through these

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[1] For interpretation of the references to color in this figure, the reader is referred to the web version of this article.