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Three-stage power system restoration methodology considering renewable energies

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ABSTRACT

This is a study of a combined load restoration and generator start-up procedure. The procedure is structured into three stages according to the power system status and the goal of load restoration. Moreover, for each load restoration stage, the proposed algorithm determines a load restoration sequence by considering renewable energy such as solar and wind park to achieve objective functions. The validity and performance of the proposed algorithm is demonstrated through simulations using IEEE-39 network.

1. Introduction

With the development of modern societies, power supply reliability becomes one of the most important issues for today's network operators. The blackout state of a power system is defined as the interruption of electricity generation, transmission, distribution and consumption, when operation of the transmission system or a part thereof is terminated. A power system blackout can cause serious consequences by restricted operation of medical facilities, road, air, and rail traffic congestion, internet breakdown, and interruption in manufacturing processes, etc. Normally, most of the supply interruptions are caused by temporary failures such as lighting and overhead line swing which can be removed by protection relays. However, incorrect handling of failures may lead to cascading outage which eventually results in a partial to complete collapse. To reduce the economical impacts and minimize the negative influences brought by power system blackout, an efficient power system restoration plan is of utmost importance for power system recovery.

A power plant can be classifed as Non-Black Start (NBS) and Black Start (BS) unit. A NBS unit has to receive cranking power to start its auxiliary devices before rebooting, while BS unit can reboot itself without external power. In the initial power system restoration process without tie line, the primary task is to reboot BS units to send cranking power to start NBS units. Normally, during the booting process, the BS units, such as hydro power plants are utilized to control frequency and voltage due to their fast response speed. In some cases, the output of BS units decreases in order to keep the frequency and voltage stable. Under normal conditions, the booting process of NBS units, whose output increases almost linearly, dominates the power system restoration time as the booting process of NBS units is much longer than the BS units. Depending on status and characteristics of NBS units, start-up sequence of NBS units has to be determined, which influences power system restoration time. After that, the skeleton of network should be energized to make a good foundation for massive load restoration. This study is towards load restoration process whose main task is to determine the sequence and the amount of load that can be picked up in one step. In each load restoration step, the active power of restored load must be limited according to the active output of online generators or else the constraints of frequency stability cannot be satisfied. In similar way, to ensure voltage stability, the online generators have to have enough reactive power reserve to balance the reactive power of restored load. Besides the control systems of online generators, such as the excitation systems, turbine governors, etc, the static and dynamic behavior of load have great impact on the frequency and voltage deviations during the load restoration process.

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2. Overview of three-stage load restoration process

Power system restoration subdivides into build-up and build-down strategies [1,2], and consists of tasks such as start-up of generators, energizing unload transmission lines and load restoration. In [3–7], general challenges and guidelines for a network restoration process are discussed. According to [3,4], power system restoration can be divided into three steps: booting generators, energizing the network skeleton, and load restoration. Based on these three steps, the overall load restoration process is classified into three stages in this paper as illustrated in Fig. 1.

1. Normally, BS units are hydro power plants, diesel generators, etc. with limited capacity. At the beginning of power system restoration, NBS units (such as fossil fuel power plant) with large capacity have to be restarted and re-connected to grid. Therefore, the main objective in this stage is to send cranking power to NBS units that can be energized by BS unit. The number of NBS units that can be rebooted simultaneously in this stage is determined by the capacity of BS unit. In this stage, the entire power system suffers from blackout. BS unit has to restart immediately and energize the network between BS and NBS units. Generally, most of BS units require to reach the minimal output as soon as possible to ensure stable operation. Therefore, the primary task of load restoration in this stage is to restore commensurable load, that is not less than the minimal output of BS unit. Since the main task in this stage is to reboot NBS units, the load restoration process halts when the restored load approaches the maximal restorable load (except cranking power of NBS units) in this stage.
2. In this stage, some NBS units are booting or waiting for the cranking power from grid, while the output of online generators increases. During the waiting period of connection of NBS units, the increased output of online generators can be used to re-energize the important load center substations. The goals of second stage are the followings:
   - energizing the network skeleton to next NBS units,
   - sending cranking power to NBS units and picking up load for stable operation of power system,
   - connecting additional high priority load when the full network skeleton is energized and all NBS units can receive cranking power from grid.
3. After re-energizing all substations and NBS units in the grid, the load restoration enters into the third stage whose main task is to restore as much load as possible within minimal time. In the third load restoration stage, the load restoration process can be conducted by determining the load restoration sequence based on the load priority and load size. The third load restoration stage terminates when all load in the grid is restored or the maximal capacity of generators is reached.

The contributions of this paper are:

- Define three load restoration stages according to status of power system restoration process. In each stage, the tasks and goals of load restoration are defined.
- In each load restoration stage, a load restoration methodology is developed to achieve the goal functions and satisfy the operational constraints.
- A novel algorithm is proposed based on fuzzy system to determine the energizing sequence of the network skeleton.
- Determine the negative/positive spinning reserve power by considering the renewable energy.
- Determine the minimal/maximal restorable load by considering generator start-up sequence.
- Consideration of renewable energy as NBS units.
- Integrating dynamic simulations to check on transient stability criteria.

The limitations of this paper are:

- This paper focuses on load restoration process for the situation that total power system is blackout and the collapsed grid cannot receive exteral power via tie line.

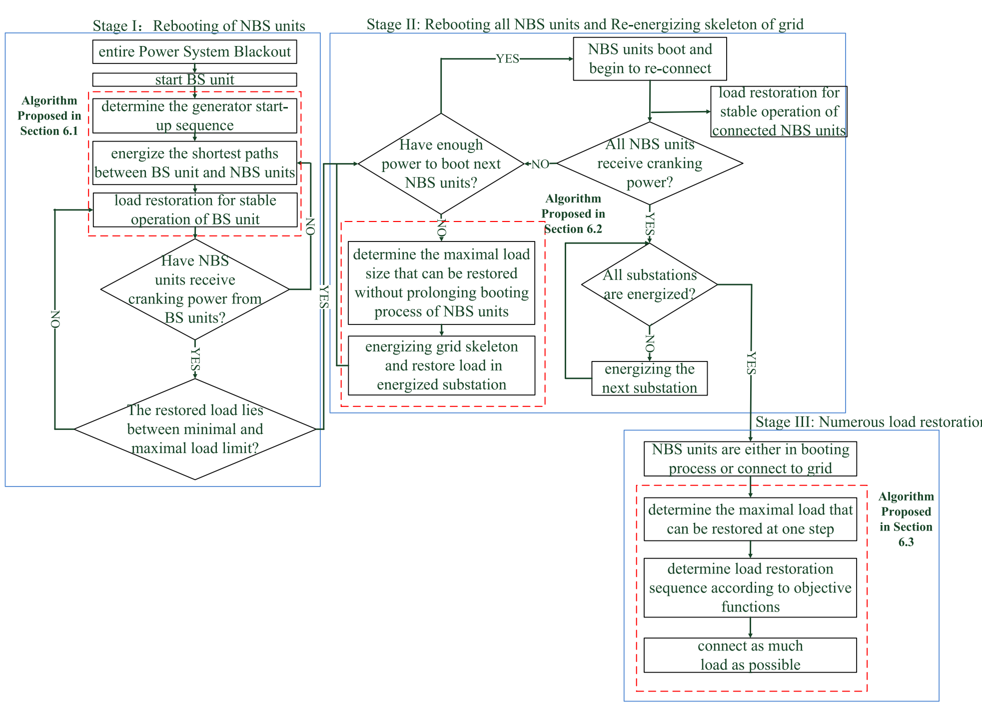

Fig. 1. Power system restoration stages and tasks.