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Optimization of Generator Units Start-Up Scheduling for Power System Restoration - A Review

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Abstract- Power System Restoration following the incident of a wide area disturbance which results into blackout, is a very complex task. In recent years, many techniques were suggested to solve the limitations of the predetermined restoration strategies and procedures used by a majority of system operators to restore a system following a blackout. A number of control actions has to be executed on the time of power system restoration, while constraints such as generator capability, power balance and system stability have to be carefully considered. During power system restoration, it is difficult to utilize the available black-start (BS) units to provide cranking power to non-black-start (NBS) units in such a way that the overall system generation capability will be maximized. The aim is to maximize the total MWh load served over a restoration period whilst considering the corresponding constraints.

Index Terms- Power system restoration, Generator constraints, Units start-up sequence, Black-start unit, Non-black-start unit.

1. INTRODUCTION

Large interconnected power systems may be seriously affected by severe occurrences that could lead to a cascade of automatic actions. These types of events may be the source of an uncontrolled network splitting with harmful effects on power quality to end-users. In highly stressed operating conditions, a cascade outage may eventually conduct to a partial or complete blackout. The power systems operated by the utilities in developing countries suffer from a large gap between demand and generation, inadequate transmission capacity, and non-uniform location of the load centers and generating stations. In most of the cases, occurrences of faults in such systems end up with the worst consequence, which is complete blackout [1].

Recently, power systems have become more complex due to the continuous upgrading of equipment and the introduction of the deregulated and unbundled power market operational mechanism. Consequently, power systems will be operated under increasingly stressed conditions. Specially, in recent years, several severe power blackouts took place in some countries involving Europe and North America [2]. Power system blackouts are rare events. However, when they occur, the effects on commerce, industry, and everyday life of the general population can be quite severe. As occurrence of a blackout, a subject of critical importance is the rapidity with which electric service is restored [3]. In order to reduce the economic and social costs of a blackout, the majority of electric utility companies have pre-established guidelines and operating procedures to restore the power system. These guidelines and operating procedures contain sequential restoration steps that an operator should follow in order to restore the system. However, the highly stressful conditions encountered in the aftermath of a blackout together with the fact that these guidelines are based on assumed system conditions which may not be present, diminishes the success rate of the technique [4]. The main reason for unsuccessful restoration attempts based on this technique is that the prevailing conditions of the power system can differ significantly from the assumed conditions when the restoration plan was developed.

Hence, how to restore power system after blackout rapidly and safely has become more and more important issue of interest in power engineering [5]. In order to get a suitable and effective restoration strategy, deciding the generators start-up sequence is an important task [6-8]. It should be pointed out that a proper sequence of generators start-up can increase the system MW outputs as well as keeping the constraints satisfied. Optimal generators start-up strategy in system restoration is a complex, multistage decision optimization problem. In general, the solution to the problem is based on a kind of experience-driven algorithm [9]. The goal of the proposed model is to maximize the total MWh load served over a restoration period whilst considering the corresponding static and dynamic constraints including the cranking power constraint, critical maximum interval constraint and critical minimum interval constraint

The restoration process is divided into three stages: preparation, system restoration, and load restoration. Nevertheless, one common thread linking these stages is the generation availability at each stage [10]. Dispatchers must be able to identify the available black-start capabilities and use the black-start power strategically so that the generation capability can be maximized during the system restoration period. This requirement originates from the concept of generation dispatch scenario (GDS), Power system dispatchers are likely to face extreme emergencies threatening the system stability [11]. They need to be aware of the situation and adapt to the changing system conditions during system restoration. Therefore, utilities in the Reliability Council regions conduct system restoration drills to train dispatchers in restoring the system following a possible major disturbance. However, practically no system restoration decision support tool has been widely adopted in an online operational environment of the bulk transmission systems. Decision support tools have been developed and implemented in the distribution system level.

2. POWER SYSTEM RESTORATION PROCEDURE

In the case of a total system outage, system restoration must begin from the black-start unit(s). Black-start units are units that do not require off-site power to start, such as: diesel generator sets and hydroelectric units. As the Black-start units themselves can only supply a small fraction of the system load, these units must be used to assist in the starting of larger units, which need their station service loads to be supplied by outside power sources. Full restoration of system load can only occur when these larger units can come on line. In order to achieve a suitable and effective restoration strategy, deciding on the generators startup sequence is an important task. It should be pointed out that a proper sequence of generators start-up can increase the system MW outputs and keep the constraints satisfied. Optimal generators start-up strategy in system restoration is a multistage decision optimization problem.

A number of studies have been carried out to determine generators start-up sequence using heuristic methods which do not guarantee their optimality. A comprehensive strategy to facilitate power system restoration is to develop computational modules for the generation, transmission, and distribution systems. The primary modules in Fig. 1 are generation capability maximization, transmission path search, and constraint checking. Identification of generator start-up sequence in order to maximize the MW generation capability is a complex combinatorial problem. The quality of solution depends on available black-start capabilities, transmission paths, and technical and nontechnical constraints.

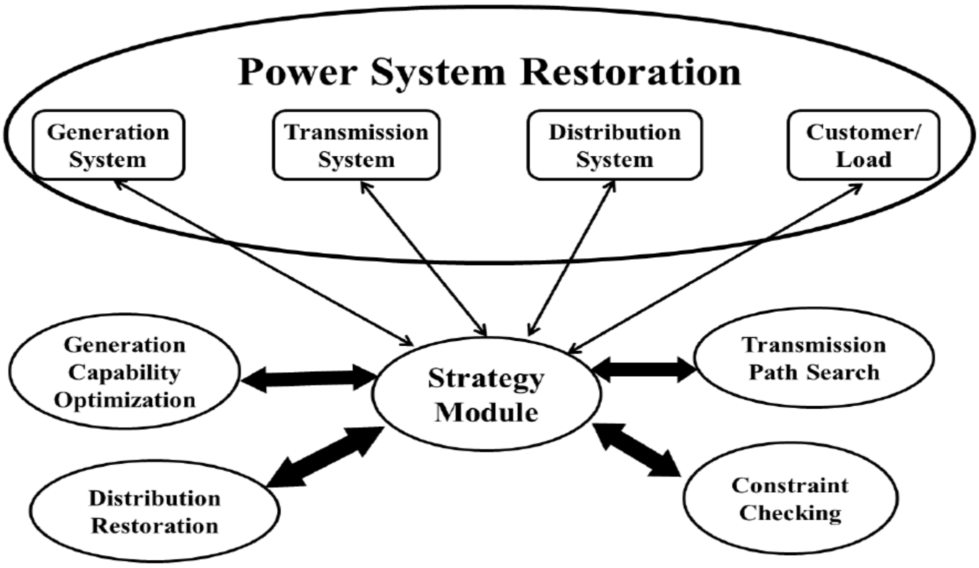

Fig. 1 power system restoration strategy.

The modules shown in Fig. 1 are not separate from each other. Rather, they interact with each other to develop a feasible plan that incorporates generation, transmission, distribution, and load constraints. The Generation Capability Optimization Module is used to calculate a starting sequence of generating units. Then the Transmission Path Search Module is needed to identify the paths for implementation of the cranking sequence. If a path is not available, say, due to a fault on a line, the Generation Capability Optimization Module will determine a new cranking sequence so that the unit can be cranked with other units that are available to provide cranking power through other paths.

3. LITERATURE REVIEW

[SHU HONGCHUN, SUN XIANGFEI AND YU JULAI, 2005] In the present study the authors have analyzed the Ant Colony Optimization Algorithm (ACO) for the optimal generator start-up scheduling during power system restoration. ACO algorithm determine the generator start-up sequence to maximize the overall generator capability over a restoration period and avoid violation of constrains. This approach is based on Different physical characteristics and requirements of different types of generating units have to be considered. In order to maximize consumer service and minimize the duration of a blackout, restoration duration must be estimated considering the switching operations. The effectiveness of the proposed approach has been demonstrated through the test system and the result is compared with that obtained by the conventional drill. The path that requires the minimum number of switching action, between the supplying unit and non-black-start unit is selected [14].

[QIANG LIU, LIBAO SHI, MING ZHOU, GENGYIN LI AND YIXIN NI, 2008] In this paper author study a novel method for optimization of generators start-up strategy from the global optimization point of view. The goal of the proposed model is to maximize the total MWh capacity served over a restoration period whilst considering the corresponding static and dynamic constraints. The proposed model is first discretized as a series of knapsack problems with respect to each time step. The classic backtracking search method is employed to solve those knapsack problems. Moreover, the optimal generators start-up solution procedure is illustrated as well. The effectiveness and validity of the proposed method is demonstrate with Case studies based on a modified 15-generator test system as bench mark. The proposed method can make the trade-off between the simulation precision and the computing efforts better [15].

[ARTURO S. BRETAS, AND ARUN G. PHADKE, 2003] In this paper author have proposed the use of Artificial Neural Networks (ANNs) for service restoration plan, since it has generalization capability and high processing speed. Certain operational constraints like allowable over and under voltages, thermal limits of transmission lines, number of lines used in the restoration plan, stability limits, and recognition of locked-out circuit breakers are considered. A breadth-search restoration program was compared with ANNs restoration program to analyse the proposed scheme's processing time performance. The large number of possible fault conditions and the need to provide a restoration plan in minimum time are arguments in favour of this technique. ANNs based restoration scheme can provide a more complete restoration plan in a shorter processing time [16].

[N.A. FOUNTAS, N.D. HATZIARGYRIOU, K. P. VALAVANIS, 1997] In this paper author has concentrated on the analysis of the applicability of Hierarchical Time-Extended Petri Nets (H-EPN) to model and evaluate the power system restoration process. At the present stage of development, this effort has shown a promising potential for providing a qualitative analysis of the power system restoration problem. As a future objective, an integrated environment of the proposed H-EPN framework in conjunction with powerful analytical tools and the SCADA/EMS database would help the power operators to handle with the power system restoration problem in a more efficient and better co-ordinated way [17].

[K. SHIMAKURA, J. INAGAKI, Y. MATSUNOKI, M. ITO, S. FUKUI, S. HORI, 1992] In this paper author proposed method for use in event of power system blackout which uses general-purpose restoration knowledge not only dependent on pre-outage system states in order to generate post-restoration target. Knowledge based method in which system operations in both blackout systems and sound systems are combined according to the amount of load in the pre-outage systems, so that post-restoration system states with minimum outage loads from post-outage systems will be generated. A sample system incorporating actual power systems was built and tested under simulated conditions. Method exhibited a high degree of practicality even in cases of support power deficiency as experienced with outages occurring under heavy load, not to mention cases with sufficient amount of support power for outage loads as experienced with outages under light to medium loads [18].

[WEI SUN, CHEN-CHING LIU, AND LI ZHANG, 2011] In this paper author provides a new design for generator start-up scheduling as a mixed integer linear programming (MILP) problem. The linear formulation leads to an optimal solution for the problem that clearly outperforms heuristic or enumerative methods in quality of solutions or computational speed. The proposed generator start-up scheduling method is proposed to deliver an initial starting sequence of all Black Start or Non-Black-Start units. The MILP method gives updates on the total MW generation capability as the restoration process progresses. The IEEE 39-Bus system, American Electric Power (AEP), and Entergy test cases are used for validation of the generation capability optimization. The simulation results show that the proposed MILP-based generator start-up scheduling algorithm is highly efficient. The numerical results shows the accuracy of the models and computational efficiency of the MILP algorithm [20].

[T. NAGATA AND H. SASAKI, 2002] In the present study the authors have analysed a multi-agent approach to power system restoration (PSR). The proposed method contain a number of bus agents and a single facilitator agent. Bus agents is developed to select a suboptimal target configuration after a fault occurrence by interacting with other bus agents based on only locally available information, while facilitator agent is to act as a manager in the decision process. The interaction of several simple agents leads to a dynamic system, allowing efficient approximation of a solution. Bus agents intends to conduct the local search, facilitator agent is to carry out the global search. The validity and effectiveness of the proposed multi-agent system have been demonstrated by applying it to a practical size model network [19]

4. CONCLUSION

Power system restoration has developed a field of growing interest. Optimal generator start-up strategy for bulk power system restoration following a blackout is a complex task. Several methods based on artificial intelligence have been suggested to improve power system restoration. The use of the computer as an operator aid instead of the use of predefined operating instructions for restoration. The stressful conditions following a large power failure and the pressure for achieving a restoration plan in minimum time can lead to poor judgment by the system operator. The use of Artificial Neural Networks (ANNs) for service restoration strategy, since it has generalization ability and high processing speed. The various possible fault conditions and the need to provide a restoration plan in minimum time are arguments in favour of this technique. ANNs based restoration scheme can provide a more complete restoration plan in a shorter processing time.

FUTURE WORK

In the upcoming work, the load rejection, under-excitation capability of generators, and low-frequency isolation scheme should also be combined for better performance. It can be accomplished by incorporating the developed module with power system simulation software tools.

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