PARALLEL BREADTH- AND DEPTH-FIRST MONTE CARLO TREE SEARCH ALGORITHMS FOR INVESTIGATING POWER SYSTEM RESTORATION

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Introduction

Blackouts are rare events, and have major consequences on economy and society as recently reported worldwide [1]. Offering a fast, secure and reliable restoration after blackouts, which is the aim of the ongoing project RestoreGrid4RES, is of great importance. For this purpose, an automated power system restoration (PSR) algorithm is developed for investigating different PSR strategies [2]. This algorithm is programmed in MATLAB and includes load flow calculation and evaluation of the system's dynamic behavior. Moreover, parallel depth-first search (DFS), parallel own depth-first search, (oDFS) and parallel breadth-first search (BFS) based on Monte Carlo approach are implemented to identify possible PSR paths.

For the evaluation of all generated possible PSR paths, key performance indicators (KPI) are implemented. Based on the evaluation of KPI, possible paths can be put into different categories of PSR strategies based on the developed matrix of network restoration strategies in [3].

Method

PSR is represented as a high dimensional tree [4], that is explored by a Monte Carlo tree search algorithm. Two general strategies are applied: BFS always starts with the currently lowest level of stored unexplored nodes, which makes the root of the tree wider. DFS takes and calculates one of the last generated unexplored nodes, which means a fast growing tree. BFS and DFS can be implemented in parallel, namely different processors execute several MATLAB scripts with the same algorithm (BFS or DFS) at the same time. In addition, parallel oDFS means that MATLAB scripts are run on different processors and each processor can only access its own created unexplored nodes. This paper focuses on the sequential combination of parallel oDFS and parallel BFS considering static load flow, dynamic frequency deviations and cold load pickup.

To speed up the performance of path identification, either BFS or DFS, or a combination of both are carried out in parallel by running several MATLAB scripts among a number of processors on the most powerful Austrian supercomputer - Vienna scientific cluster (VSC-3)[5]. Furthermore, to shorten communication time and the time needed to store all calculated nodes, the indicated algorithm is extended to save the calculated children nodes on a MySQL database located at VSC.

As depicted in Figure 1, the search algorithm begins by expanding the initial state. All children nodes of initial states are calculated through parallel BFS by executing MATLAB scripts on parallel processors. Afterwards, all children nodes of nodes in level 1 are calculated up to a certain level (e.g. level 3 in this paper). The generated and stored children nodes from this level are defined as initial states for parallel

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oDFS. At each later step, one of the previously generated children nodes is expanded until an end node is reached. For generated paths, an end node is defined as having 50% of the total load supplied.

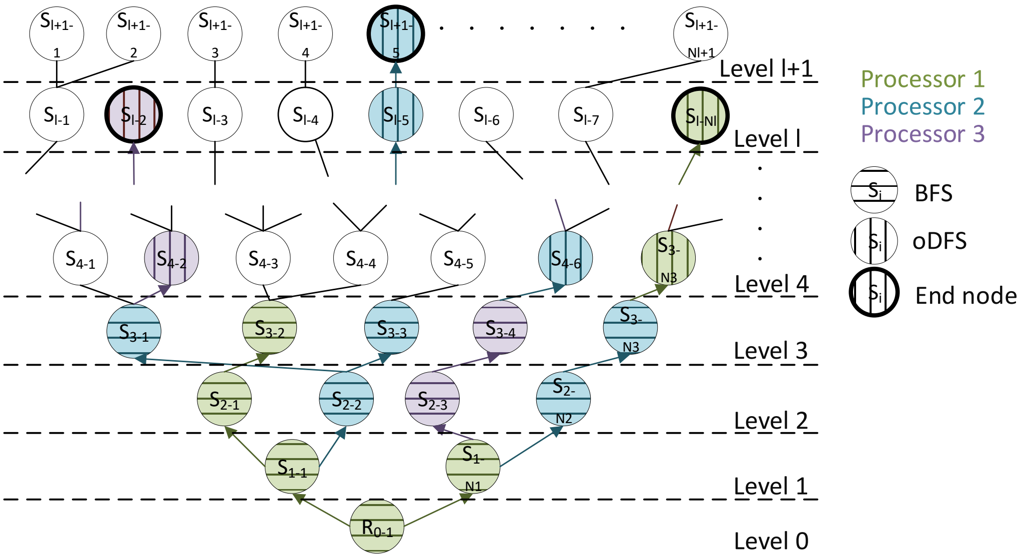

Figure 1: Combination of parallel BFS and parallel oDFS based on Monte-Carlo approach

Results Represented by Key Performance Indicators

Global and individual KPI are defined to evaluate possible PSR paths. Some representative global KPI, such as speed of restoration, the required number of switching actions, energy provided during restoration, maximum and minimum voltages as well as static and dynamic frequency deviation, are presented in [2].

Apart from those global KPI, individual KPI are introduced and investigated in this paper. Individual KPI are valid only for a specific state occurring during the system restoration. Generally, any individual KPI may be made global by integrating or averaging it over the system restoration time. However, a normalization may be necessary if PSR paths with different PSR times are compared, as these values might differ significantly.

System step load ability is defined by the maximum load step $\Delta P_{max}(t)$ that the system can support during transient conditions and in steady state without reaching critical frequency limits. Besides, active power reserves in the system, $P_{\text{reserve,up}}(t)$ and $P_{\text{reserve,down}}(t)$, are defined as:

$$P_{\text{reserve,up}}(t) = P_{\text{system,max}}(t) - P_{\text{system}}(t) \tag{1}$$

$$P_{\text{reserve,down}}(t) = P_{\text{system}}(t) - P_{\text{system,min}}(t) \tag{2}$$

where $P_{\text{system}}(t)$ is active power of load supplied by the total system. $P_{\text{system,max}}(t)$ and $P_{\text{system,min}}(t)$ are total maximum and minimum connected available generation capacity, respectively. The same approach is possible for reactive power. However, reactive power reserves are not further addressed and analyzed in this paper. A combination of global and individual KPI gives a suggestion which PSR path is best, meaning the most efficient, reliable and secure path.

References

[1] H.-W. Borries, „Blackouts-Szenarien und ihre Bewältigung durch Krisen-/Verwaltung-/Katastrophenschutzstäbe der öffenlichen Hand,“ Conference Blackout, Cologne, Germany, 2018.

[2] E. Torabi, et al. „An Approch for Fast, Secure and Reliable Network Restoration after Blackouts,“ submitted to PSCC, Portugal, 2020.

[3] Y. Guo, et al. „Review on Network Restoration Strategies as A Part of the RestoreGrid4RES Project,“ 15. Symposium Energieinnovation, Graz, Austria,

[4] E. Torabi, et al. "Impact of renewable and distributed generation on grid restoration strategies." CIRED, Madrid, Spain, 2019.