Electric Power Systems Research 144 (2017) 13–22

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Fault-tolerant location of transient voltage disturbance source for DG integrated smart grid

Guoqing Weng[a], Feiteng Huang[a], Yufei Tang[b], Jun Yan[c], Yurong Nan[a], Haibo He[c,*]

[a] College of Information Engineering, Zhejiang University of Technology, Hangzhou 310023, China
[b] Department of Computer & Electrical Engineering and Computer Science, Florida Atlantic University, Boca Raton, FL 33431, USA
[c] Department of Electrical, Computer, and Biomedical Engineering, University of Rhode Island, Kingston, RI 02881, USA

ARTICLE INFO

Article history:
Received 8 June 2016
Received in revised form
13 September 2016
Accepted 29 October 2016

Keywords:
Transient voltage disturbance source (TVDS)
Automatic location
Distributed generation (DG)
Direction-judgment
Fault tolerance
Improved particle swarm optimization (IPSO)

ABSTRACT

In this paper, a new fault-tolerant approach based on improved particle swarm optimization (IPSO) is proposed to automatically locate the transient voltage disturbance source (TVDS) for smart grid with distributed generation (DG) integration. We first analyze the influence of the DG integration on the TVDS direction-judgments. Two new credibility indexes, the monitoring-credibility and the partial-credibility, are defined to measure the reliability of direction-judgment result at each power quality monitor (PQM) with consideration of multiple factors, including DG integration, disturbance intensity and fluctuation characteristic. By using these credibility indexes and a newly defined search space, a heuristic searching approach, called IPSO, is then proposed to obtain the optimal solution of the TVDS location. Simulation study is carried out on the IEEE 34 node test feeder, and the results demonstrate that the proposed approach has significantly improved fault-tolerant capability with satisfactory convergence speed.

1. Introduction

It is widely recognized that power quality (PQ) will increasingly play an important role in providing economic, secure and stable energy in modern power systems [1]. In intelligent diagnosis of PQ disturbance events, in addition to the detection and classification problem [2–4], another important task is to locate the PQ disturbance sources. Statistically, transient voltage disturbance events (e.g. voltage sag and voltage swell) account for the highest number of occurrence compared to other PQ events [5]. Usually, these transient voltage disturbance events are caused by short faults, switching of capacitors, energization of large induction motors, lightning striking, etc. The accurate location of the transient voltage disturbance source (TVDS) can help provide accurate identification of the disturbance source, and facilitate suitable mitigation measures to reduce the economic loss.

In general, there are two distinctive categories of research methodologies for the automatic location of the TVDS. The first is based on pattern recognition and artificial intelligence [6–9] using a small quantity of power quality monitors (PQMs) for location, but these methods require complicated training processes for different types of TVDS and are sensitive to the grid's size and structural changes. With growing installation of networked power quality monitoring system (NPQMS) in modern smart grid [10], another category is based on the graph theory and matrix algorithm [11–13]. The existing matrix methods commonly consist of two major steps. The first step is the direction-judgment at each PQM to identify the relative direction of the TVDS to each PQM. In the literature, the disturbance energy (DE) algorithm was first proposed for the voltage-sag events [14]. Following this work, some improved algorithms have been presented for the direction-judgment of TVDS [15,16]. After the direction information is collected, the second step is the automatic location of the TVDS at the monitoring center. With the development of optimal placement techniques [17] and state estimation theory [18,19], the PQ information of nodes not equipped with actual PQMs could also be observed by viewing these nodes as virtual PQMs [13]. Compared with the first category, the latter has many advantages, including applicability to different types of TVDS, little influence from the grid's size and structure, and no need for training.

However, we notice that most of the existing matrix methods lack fault-tolerant capability, as the accuracy of the location result

* Corresponding author.
E-mail address: he@ele.uri.edu (H. He).

http://dx.doi.org/10.1016/j.epsr.2016.10.063
0378-7796/

of the TVDS is largely dependent on the absolute reliability of the direction-judgment at each PQM in the NPQMS. Even worse, it is difficult to guarantee the accuracy of all the direction-judgment results in a practical distribution grid. Particularly, distributed generation (DG) connection to the smart grid for utilization of the renewable energy is gradually increasing, which will have noticeable impacts on the power quality [20] and bring great challenges to the existing methods to locate the TVDS [21]. Moreover, many factors, such as the intensity and fluctuation characteristic of the PQ disturbance signals, the external interferences, state estimation, etc., can affect the reliability, or credibility, of the direction-judgment result. As an attempt, the disturbance measure (DM) was defined to describe the reliability of the direction-judgment result [22] with consideration of the disturbance intensity. Nonetheless, with more factors influencing the judgment result, it still requires more efforts to develop methods with high fault-tolerant capability.

In this paper, we first analyze the influence of DG integration and other factors to the reliability of the direction-judgment result at each PQM in the NPQMS. Then, a novel fault-tolerant approach based on an improved particle swarm optimization (IPSO) is proposed to locate the TVDS for DG integrated smart distribution grid. The main contributions of this paper are summarized as follows:

1. Two important influence rules of DG integration based on the detailed analysis with a scalable grid model are proposed. The rules show the scenarios that may lead to mistakes or reliability weakening in direction-judgment at the PQMs, which is the basis to solve the problem of TVDS location caused by DG integration.
2. Two new credibility indexes called monitoring-credibility and partial-credibility are defined. The first index can denote quantitatively not only the direction-judgment result of TVDS at each PQM but also the reliability of the result considering multiple influence factors. The later one can verify whether the direction misjudgment takes place at each PQM according the first influence rule.
3. A novel fault-tolerant approach, based on an IPSO algorithm is proposed to automatically locate the TVDS for DG integrated smart grid. In the IPSO, the evaluation function has been carefully constructed to synthetically utilize the credibility indexes, and the search space has been reduced greatly. Simulation results demonstrate that the proposed approach has significantly improved fault-tolerant capability, fast convergence speed and good applicability for various types of TVDS.

The rest of this paper is organized as follows. Section 2 describes the limitations of existing methods. Section 3 presents the influence rules of DG integration on direction-judgments. Section 4 constructs the credibility indexes based on comprehensive factors. Section 5 describes the IPSO model with the key steps to obtain the optimal solution. Section 6 carries out the simulations and analyzes the results, and Section 7 draws the conclusions.

2. Limitation of existing matrix-based methods

In the existing methods for locating the TVDS based on the matrix algorithm [11–13], a coverage-matrix $S^{cov}_{l\times m}$ is first generated to represent the relative positions between each line and each PQM in the grid, where l and m are the total numbers of lines and PQMs. Then, the direction-matrix $D^{dir}_{m\times 1}$, representing the relative positions between the TVDS and each PQM, is obtained based on the direction-judgment algorithm when PQ event happens. The elements of the two matrixes $S^{cov}_{l\times m}$ and $D^{dir}_{m\times 1}$ are defined as follows:

$$s_{ji}, d_i = \begin{cases} +1, & if \quad L_j \ \text{or} \ TVDS \ \text{is in down-area of PQM}_i \\ -1, & if \quad L_j \ \text{or} \ TVDS \ \text{is in up-area of PQM}_i \end{cases} \quad (1)$$

In the DE and its improved algorithms [14,16], the final polarity of the DE signal determines the relative position (upstream or downstream) between the TVDS and PQM. The result-matrix $R_{l\times 1}$ can be calculated by $R_{l\times 1} = S^{cov}_{l\times m}\cdot D^{dir}_{m\times 1}$. If the maximum of R, e.g. $r_j = max(r_1, r_2, \ldots, r_l)$ equals to m, then the line L_j corresponding to r_j is determined as the TVDS. If any error exists in the direction-judgments, then the location result of the TVDS would be incorrect [22,23]. Although it is fairly clear to use the signed binary integers (i.e. +1 or −1) to denote the relative positions of the TVDS with respect each PQM, this requirement of absolute reliability of all the direction-judgment results in $D^{dir}_{m\times 1}$ leads to a lack of fault-tolerant capability. In general, the factors that will cause misjudgment could be summarized as follows.

(1) DG integration: The traditional radial network with single power supply is evolved into multi-source distribution system, which will have a significant variation of the power flow distribution [20,21]. In general, the DG integration affects the intensity of the transient voltage disturbance signal, and at worst, may cause the direction misjudgment [24]. The detailed influences of the DG integration will be discussed in the next section.

(2) Disturbance intensity: Due to line loss and bypass flow, the intensity of the transient voltage disturbance signals detected at monitors far away from the TVDS are relatively weak [22,23]. Given the same condition of external interferences, such as noise signals, errors caused by measurement, transmission or state estimation, the direction misjudgment is more likely to happen with weak disturbance signal.

(3) Fluctuation characteristic: The polarity of the disturbance power may change frequently due to the energy-storage, reactive load, etc. These changes will further induce intensive fluctuation of the DE signal, resulting in uncertain monotonicity or even reversed final polarity of the DE signal [14]. In either case, the direction-judgment result is more likely to be incorrect.

3. Influence of DG integration

3.1. Scalable model and denotations

To analyze the influence of DG integration to the entire grid when a transient voltage disturbance event occurs, we designed a scalable grid model with one DG interconnection, whose topology is shown in Fig. 1. The partial networks $\{N_a, N_b, N_c, N_n\}$ in this figure represent the equivalents of sub-networks with a tree structure, enabling the scalable model to be expanded into most of the distribution systems with radial structure.

Similar to the area-dividing method in [12], the entire scalable model can be divided into up-area and down-area based on the

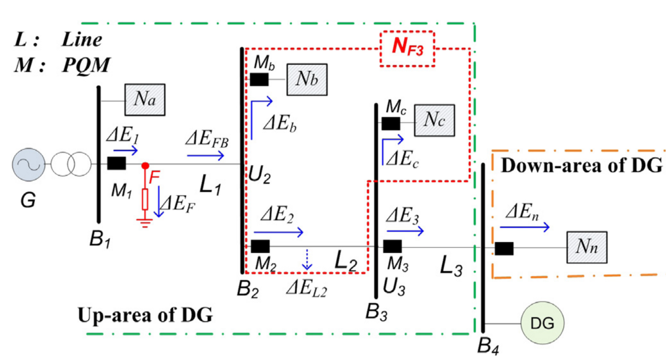

Fig. 1. Scalable grid model and up/down area of DG.