A standards-based approach for Auto-drawing single line diagram of multivendor smart distribution systems

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\section*{1. Introduction}

Distribution automation systems utilize computer and communication technologies to remotely monitor and manipulate power equipment from the main control center without visiting the actual site physically. Distribution systems can be represented by geographical and/or single line diagrams and are used as a user interface for distribution automation system (DAS). The geographical diagrams follow the geospatial arrangement of power equipment. The ge-referenced data is maintained in the geographical information system. Single line diagrams (SLDs) are orthogonal diagrams, which do not necessarily follow the geospatial location of the power equipment. SLDs are based on the relation of the electrical connection between the power equipment. SLDs are usually used for operating the distribution network, which is interlocked with applications such as blackout restoration, protection coordination, topology recognition, and optimization. Normally, open switches of distribution lines are altered frequently depending on the operating conditions and load distribution. SLDs for the newly designed distribution system also need to be modified accordingly. In conventional systems, all SLDs were drawn and saved in advanced and loaded when needed. By using the conventional method, it is difficult to display the modified SLD when the topology is changed and/or system is reconfigured.

Research on DAS has been conducted by various researchers in numerous areas of distribution networks. Blackout identification using fuzzy logics was proposed in [1,2], an expert system was proposed in [3,4] and a multi-agent based system was proposed in [5]. For reducing restoration time, the recloser’s dead time-based algorithm was proposed in [6] and the importance of individual distribution lines was evaluated in [7]. For optimization of normally open switches, G-nets were suggested by [8] and a genetic algorithm was proposed by [9]. The computer aided design-based technique for user interface was suggested by [10] and a Monte Carlo-tree-based approach was presented in [11]. Auto drawing of SLD was a gray area in modern DAS. Due to advancements in computer technologies, the area of the auto-drawing of SLD for DAS was also addressed by different researchers in the last few decades. An algorithm for the extraction of geospatial topology and graphics for DAS was suggested by [12]. A research was conducted by [13] for extracting the SLD from geographical information system (GIS) plan using a spring embedded technique, [14] proposed a method for extracting SLD from supervisory control and data acquisition of a substation based on common information model (CIM)/extensible markup language (XML). An auto SLD technique for radial systems based on a genetic algorithm was presented in [15]. A visibility representation based auto SLD was proposed in [16].

Most of the algorithms proposed in these papers are focused on...
Nomenclature

- CIM: common information model
- DAS: distribution automation system
- ESB: enterprise service bus
- GIS: geographical information system
- SLD: single line diagram
- SOA: service oriented architecture
- SVG: scalable vector graphics

2. Power grid visualization

In the power grid visualization field, various researches have been conducted on methodologies for translating data into information, using visual information for taking a variety of actions, analyzing graphical contingencies are several other related topics. The need of power system visualization, key challenges, and future research directions has been discussed in [17]. Requirements of structural data representation for visualization of information have been summarized in [18]. The two major tools, which are widely used within the industry, are AREVA’s energy management system and PowerWorld’s simulator, which provide visualization support. The major functionality of both of these tools is to depict collected and/or processed data on the top of a geographic map by making use of different colors and/or icons. This approach fails to take advantage of the analytical strength gained by visualization [19].

Various visualization techniques are used for visualization of power systems. These techniques include line flow visualization, contouring bus data, contouring line data, data aggregation with flow rates, interactive 3D visualization, single line diagrams, and GIS-based diagrams [20]. New methods used for visualization of power systems have been discussed in [21,20]. Various visualization methods for power systems along with their utilization in real time-monitoring of power systems have been analyzed by [22] while artificial neural network-based visualization methodology has been proposed by [23]. A data-driven approach for visualization of interactive power systems has been proposed by [24]. Various ways for defining the electrical distance of empiric power systems are proposed by [25] and 2-D projections are formulated. These projections are utilized for visualizations of empiric power systems, which provide useful insights into their electrical connectivity and structure. SLDs and GIS-based diagrams are most popular techniques for representing power systems.

2.1. Visualization through GIS diagrams

The purpose of GIS is to capture, store, analyze, manipulate, manage, display, and share all types of geographical data [26,27]. The electric utility sector is well suited for application of GIS technology due to the presence of various system components (physical assets) distributed in a wide geographical area. GIS-based diagrams have been used in parallel to SLDs by power industries. However, there are some major limitations of GIS-based diagrams. Firstly, GIS-based diagrams fail to represent the electrical view of a power system. Secondly, GIS-based diagrams are complex and are economically inefficient, which makes them less desirable visualization option in many cases. A typical GIS-based diagram of a selected region is shown in Fig. 1.

2.2. Visualization through SLDs

SLDs are orthogonal diagrams, which are simplified notations for representing 3-phase power systems. The major application of SLD is in power flow calculations, fault location, identification, separation, and service restoration. In addition, SLDs are also used for monitoring of power systems, analysis of power systems, optimization of power systems, and many more. In SLDs, elements of the diagram do not represent the actual size and physical location of the power equipment. Various types of SLDs have been summarized by [28]. A typical SLD of a 6-feeder distribution network is shown in Fig. 2.

Both GIS-based diagrams and SLDs are used in parallel by the power industry. GIS-based diagrams are more beneficial when the actual physical location of components is important. On the other hand, SLDs are more beneficial for recognizing electrical connections. In additions, various studies are conducted for converting GIS-based diagrams into SLDs. In [29], geospatial data from GIS is used for auto-drawing of SLDs. Intelligent routing algorithms are used for elimination of intersections and overlap in different facilities. A method for drawing SLDs from GIS data is suggested by [30], where a graph algorithm is utilized that permits the elimination of superposition of buses. In order to

Fig. 1. A typical GIS-based diagram of a locality.

Gas-insulated remote control switch (open) Recloser
Gas-insulated remote control switch (closed) Circuit breaker
Manual switch Substation
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