Electrical Power and Energy Systems 96 (2018) 357–367

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

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

Akhtar Hussain[a,*], Muhammad Aslam[b], Syed Muhammad Arif[c]

[a] Department of Electrical Engineering, Incheon National University, Incheon, South Korea
[b] Department of Electrical Engineering, Myongji University, Yongin, South Korea
[c] Department of Design and Creative Technologies, Auckland University of Technology, New Zealand

ARTICLE INFO

Keywords:
Graphical visualization
Electrical power systems
Graphical representation
Information visualization
Single line diagrams
Visualization techniques

ABSTRACT

This paper presents a technique for the auto-drawing of single line diagram (SLD) of multivendor distribution systems. SLDs are used in electric power system visualization, which is very important for the control and monitoring of distribution systems for fault location, identification, separation, and service restoration. The task of auto-drawing an SLD for distribution systems has been made complicated due to the introduction of distributed generations and multivendor distribution systems. This paper proposes an algorithm for auto-drawing SLD, based on a ternary tree and collision avoidance algorithm. In addition, a standards-based approach is suggested for incorporating different distribution system planned and run by different vendors. Initially, client converts the distribution system diagram to a standard model, which is then sent to the server. The server draws the SLD by using the auto-SLD drawing algorithm and sends it back to the client, which can be verified by the client.

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 geo-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

* Corresponding author.
E-mail address: hussainakhtar@inu.ac.kr (A. Hussain).

http://dx.doi.org/10.1016/j.ijepes.2017.10.003
Received 31 January 2017; Received in revised form 13 August 2017; Accepted 1 October 2017
0142-0615/

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

auto-drawing SLD for single vendor distribution systems. In reality, there are several distribution systems in a central DAS, which are planned, managed, and run by different organizations. The central DAS has to gather all the information and make a centralized plan for overall load distribution and restoration in case of service failure. Each company might be using its own technique for drawing SLDs. In order to ensure the proper inter-operation among all these multivendor distribution systems, the central management team needs to maintain and update separate SLD techniques for each distribution system, which results in extra usage of resources and is more prone to maloperation due to the involvement of various SLD techniques.

This paper suggests a measure of innovatively enhancing flexibility, expandability, and reusability of software for automatically drawing SLDs. The proposed algorithm utilizes only those standards, which are accepted by electrical and computer engineers. SLD for multivendor DAS is automatically drawn by utilizing a service oriented architecture (SOA)-based technique. Web service technology is used for realizing SOA, and CIM is used for modeling power distribution components. SLDs are drawn by applying alignment and collision avoidance algorithms on ternary tree sorted data. Saleable vector graphics (SVG) is used for exchanging SLD files. SVG generates XML based files and these files are transferred via the internet using the hypertext transfer protocol (HTTP). This ensures the interoperability between different applications by allowing the exchange of data irrespective of the operating system and technology being used by individual vendors. Jungkwan district of Busan city in South Korea has been chosen for testing the performance of the proposed algorithm.

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 lesser 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

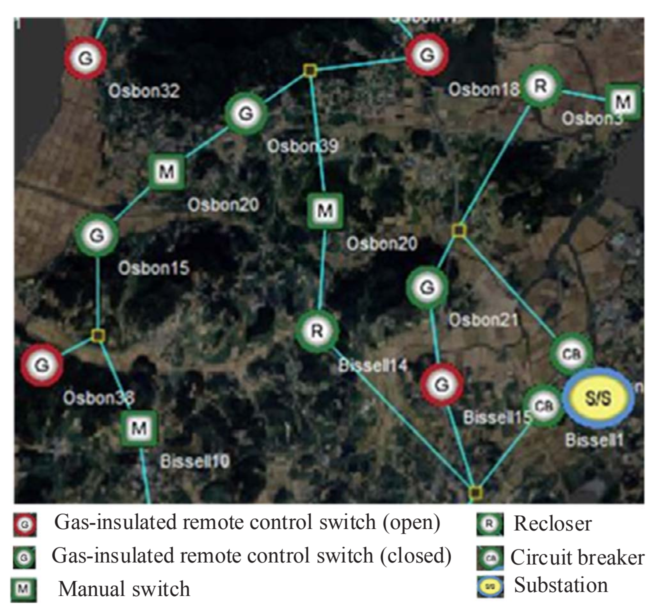

Fig. 1. A typical GIS-based diagram of a locality.