Design and Development of a Graphical Application for Electrical Power System Studies

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ABSTRACT

This paper presents an improved version of a graphical application for managing and analyzing Electrical Power Systems. The design of the application accommodates the integration of visual representation of HV and LV systems, information management and planning studies. Features and the look and feel of the application have also been presented. Few standard IEEE networks have been created using this application. Summary of usability testing is provided. This application can be used effectively to train students and even utility engineers in system analysis, management as well as to develop a sense of appreciation towards graphical tools in system analysis. This application can be freely downloaded from the author's SkyDrive: http://sdrv.ms/12aErO2

Keywords: Power System Studies, Asset Management, Graphical Tool, Software Application

1. INTRODUCTION

'Power Transmission System' and 'Power Distribution' networks differ from each other in many ways. Generally 'Power System' refers to a High Voltage (HV) power network (132 kV and above) that connects generating stations to the high power transmission lines through appropriate power apparatus. HV networks (known as transmission networks) have different electrical characteristics and usually occupy a lesser percentage of the total system. They transmit power from generating stations to the major distribution stations (or substations). The term 'Power Distribution' refers to a relatively lesser voltage power network (11 kV to 132 kV) and these networks essentially connect substations, distribution transformers and customers. Distribution networks actually carry power from major distribution substations to the customer premises and are very complex in nature due to their vast geographical spread and interconnectivity. HV networks are generally operated in ring and LV networks are operated in radial basis. The methods of analyzing the HV and LV networks are different, as the electrical properties of the lines are different due to differences in their R/X ratios. Hence any power system is a combination of HV and LV networks.

Several types of diagrams and representation methods have been used to display the power networks. With the advent of digital computers, graphical representation of power networks became important. Vector representation, depicting the exact location and orientation of connections is popular as it supports the physical GPS coordinates on the ground. The classical single line diagram version is very popular, widely used and is considered as 'Engineer-Friendly'. Engineers and general users expect the computer applications to represent the power networks just as they appear on the drawing sheets. However, there are challenges in displaying the networks on digital computers; the major one being transforming the physical ground coordinates to screen coordinates while maintaining the scale.

Several authors, engineers and researchers have contributed in the area of Computer Applications in Power Engineering. Since 1980s, utility majors have developed graphical applications for power dispatch centers, generating stations etc, using contemporary technologies like Silicon Graphics, Unix etc. The role of digital modeling and simulation in power engineering education is illustrated by Kezunovic et al in 2004. With the advent of Microsoft Windows based graphics and relational databases, the developmental efforts have shifted to the modern era. Shoults (1992) demonstrated the use of graphics in high voltage DC power system control applications. Ono et al (1997) presented the design and evaluation aspects of visualization methods in power system education. Jun et al (1997) and Ines et al (2000) illustrated how objected oriented approaches can be applied in developing the educational software systems for power engineering. The Institute of Electrical and Electronics Engineers (IEEE), USA has developed recommended standards and practices for the operation and control of power networks (IEEE, 1997). A novel technique to improve power engineering training using computers is presented by Karady (2004). Commercial packages have been developed by different software companies especially for the analysis of power systems and these include PSS/E, PSS, InterPSS, PowerWorld etc.

There are very few contributions on the development of software applications for educational training purposes in this area. The basic idea of using a graphical interface for training in distribution systems is presented by Sastry et al (2007) and this contribution lacks the treatment of HV networks. Eminoglu et al (2010) presented a Matalab based graphical interface for distribution analysis. However, this package does not display the network and interface works with menus and buttons for application studies.

Generally, at the undergraduate level, the electrical engineering students will undergo at least 2 to 3 courses in power systems. The focus is mostly on HV network analysis with well-known algorithms such as G-S and N-R methods. Rigorous treatment of LV networks is generally less. There is a considerable gap between the university training and the expected knowledge in power utilities. Most power utilities end up training new recruits in operation, maintenance and planning aspects using different software applications and tools. Our application is supposed to address this knowledge gap at the starting level. A basic version of this application was presented previously (Sastry, 2008). This application is a much improved version and combines high voltage and low voltage systems. Aspects like design, development and implementation of a Microsoft Windows based user-friendly graphical application for the real-time operation and management of power transmission and distribution systems are illustrated. With its scalability, modularity and several technical features this application can be used for training purposes both in universities and utilities.

The organization of the paper is as follows. Section 2 presents the overall architecture and design. Section 3 illustrates the aspects of implementation and major features. Section 4 presents the digitization experience with the standard IEEE-30bus system. Data organization and component information is presented in Section 5. Application testing and usability evaluation details are provided in Section 6 and then Section 7 concludes the discussion.

2. OVERALL ARCHITECTURE AND DESIGN

One of the major aspects that was kept in mind while designing this application was ‘improvisation’. If the design is very rigid and implemented with a mind-set that the current version will be the final, then such approach kills the evolution process over the time. For instance, the data of the power systems could have been stored in an ideal way using a database product. However, the current design uses simple text files to store the data. As the application is put to rigorous use by wide ranging users for different configurations, then data organization and its end use can be seen more prominently than now.

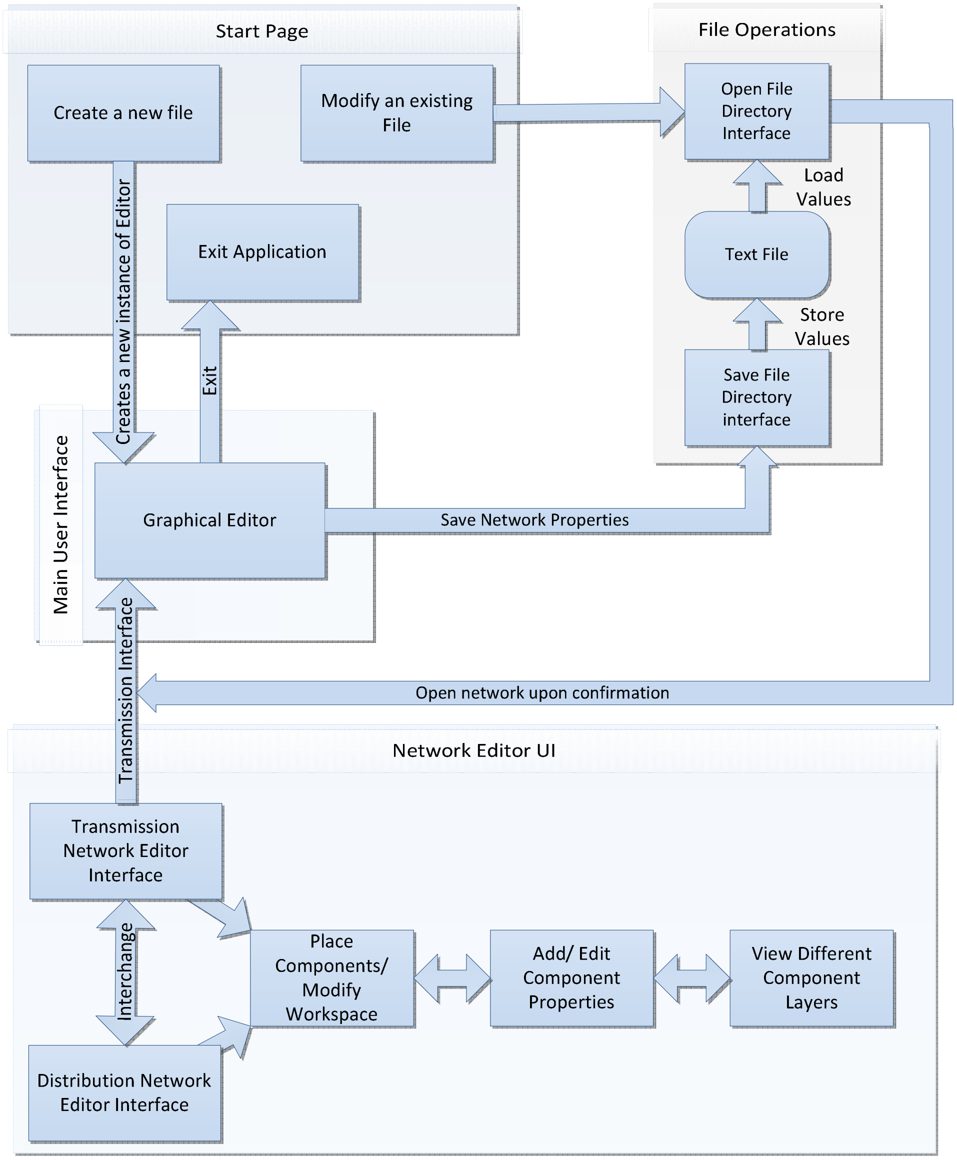


Figure 1: Overall architecture and design of the application

Then user operation of the application should be simple and intuitive to reduce or totally eliminate the overwhelming burden of training on a new platform'. The reporting of component information is within the application for now; however improvements can be taken up such as using XML formats/HTML screens. Hence, the design is kept as simple and flexible as possible for the purpose of future development. The overall design process is shown in Figure 1.

3. MAJOR FEATURES AND IMPLEMENTATION

Several features with the standard 'Windows Look and Feel' have been added to push the using experience to that of any other commercial application, so that users are not made to look around through lengthy manuals for most of the simple operations. Some of the major features include:

- It is a simple standalone windows application, no installation or customization or configuration.
- Capability to handle both HV and LV networks
- Multiple instances and access of networks

- Data is maintained in text files so that both input and output can be channelled independently of the application
- Users can set the background to a dotted grid or an image (for digitization with physical location) or leave to the default ‘no background’
- Zooming, Layering and Clustering.
- Utility symbols: A library of standard utility icons, symbols etc. for facility features like transformers, and other facilities.
- Undo/ Redo features - step by step, for non-posted data and for rebuilding
- Graphic data query - Area districting and zoning, Retrieve information from any objects with a point and click scenario
- Separate functions for mouse double click and right click

Apart from the above, several algorithms, rules and restrictions have been implemented to realize various features and some of those algorithms are proposed for the first time. However, treatment of algorithms is out of scope of present paper; however a snapshot of the categorized development is presented in the Table 1.

Table 1: Categorized Development of the Application

	Features	Rules and Restrictions	Algorithms developed for:
Component Placement & Properties	• Creation of networks • Modification to component properties	• Position on form • Intersections with other components • Delimiters/ multiline may not be input in text based properties	• Defining component areas • Drawing connection lines • Determining interconnections
Multilayer Views	• High/ low voltage components • Individual component layers • Scaling	• HV & LV components on separate layers • Editing functionality for shown components only	• Determining components to be displayed • Scaling factors
File Operations	• Save/ open / modify networks	• Allow opening of “.nwk” files only	• Parsing properties to and from text file

Visual C++ .NET 2012 is used for coding and implementation of the design. The main GUI interface consists of a Windows form with various controls such as - buttons with tooltips (for selecting components), status strip, drawing panel (workspace), save & open file dialogs, multiple cursors, visual representation of opened/ closed circuit breakers, property style sheets etc. The .Net Graphics class was used to create vector graphics for each component type. Vector graphics were chosen over bitmaps for their ability to maintain their resolution regardless of their scaling. Bitmaps also leave whitespace around the components.

3.1 HV Side Representation

The HV side representation comprises of generators, power transformers, buses, transmission lines, loads, etc. Based on the standard notation (IEEE, 1995). Symbols have been designed for the major HV components, users may click the desired component and may place as may times as they wish on the canvas. Network components can be interconnected as needed. Information related to any given component can be accessed by right-clicking on that particular component and information can be updated as needed. Wide ranging zoom-in and zoom-out features are incorporated so that users can see the networks at 50% to 200% of actual size. A typical HV network as digitized by this application is shown in Figure 2.

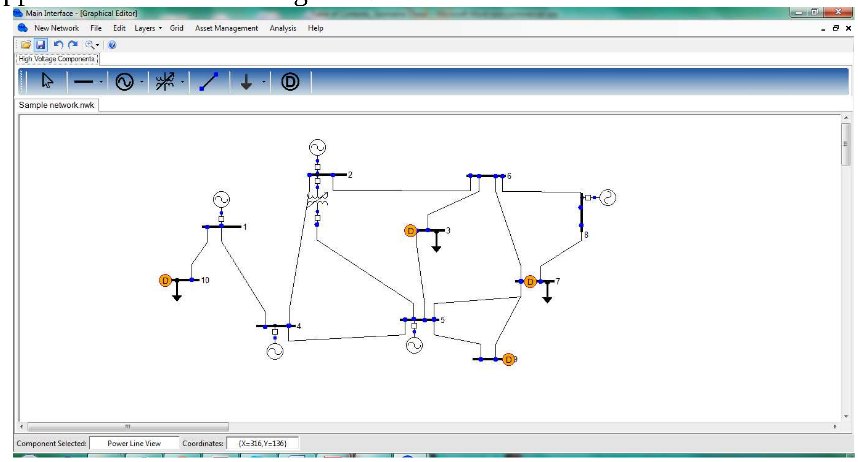


Figure 2: High voltage layer of a power network

3.2 LV SIDE REPRESENTATION

The LV side representation comprises of substations, distribution transformers, LV lines and customers. Based on the standard notation (IEEE, 1995). Symbols have been designed for the major LV components, users may click the desired component and may place as may times as they wish in the LV canvas. Different symbols have been provided to distinguish between residential, commercial and industrial customers. Just as HV networks, components and information can be manipulated. LV netoworks are connected to HV buses. This application does not show both networks together to avoid cluttering on the screen. A typical screen representation (See Figure 4(b)) is used to denote the presence of LV network on a given HV bus. When user right-clicks on any HV bus, the summary of the LV network connected to that bus is presented and an example is provided for this in Figure 3.

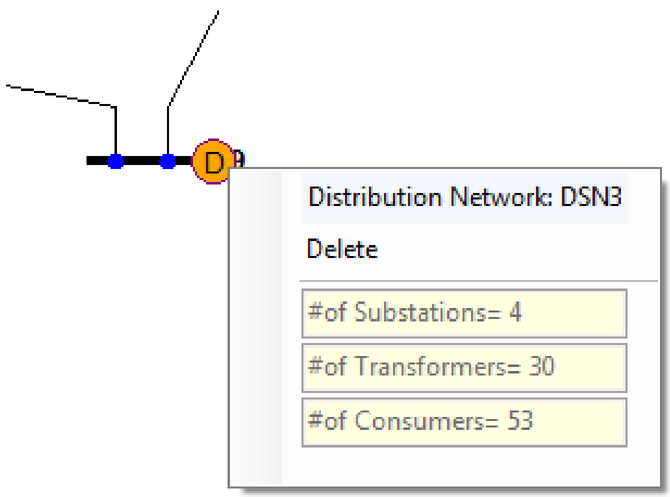


Figure 3: Context menu for distribution network connected to a high voltage bus

3.3 TOGGLING BETWEEN HV AND LV NETWORKS

The power network is created inclusive of the distribution network nodes (See Figure 4(a)). User needs to double click to access the LV network on the HV bus where the LV network is present (See Figure 4(b)). The distribution layer is then displayed from which substations, distribution transformers, customers and low voltage lines may be connected to the distribution network nodes (See Figure 4(c)).

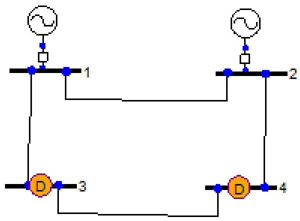


Figure 4(a): HV network

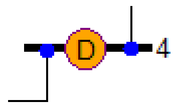


Figure 4(b): HV bus with LV network

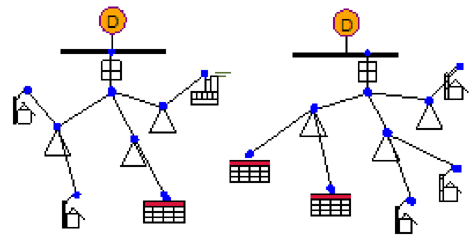


Figure 4(c): LV network

4. DIGITIZATION OF IEEE STANDARD NETWORKS

Standard IEEE networks were digitized using this application for comparaitve purposes. Figure 5 shows a diagramatic representation of a standard IEEE 30 bus test system (UWEE, 2013) while Figure 6 illustrates the system as was replicated using this application. Figure 7 shows the same system at a reduced scale to demonstrate the zooming feature.

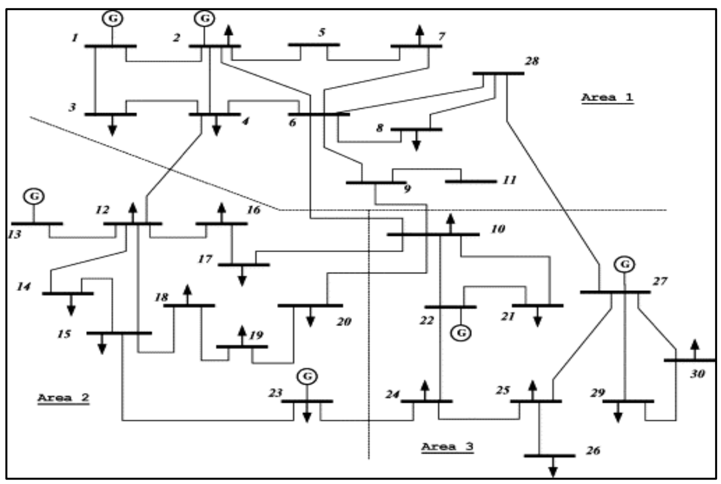


Figure 5: IEEE 30 Bus Network (as seen in the image, Source: UWEE, 2013)

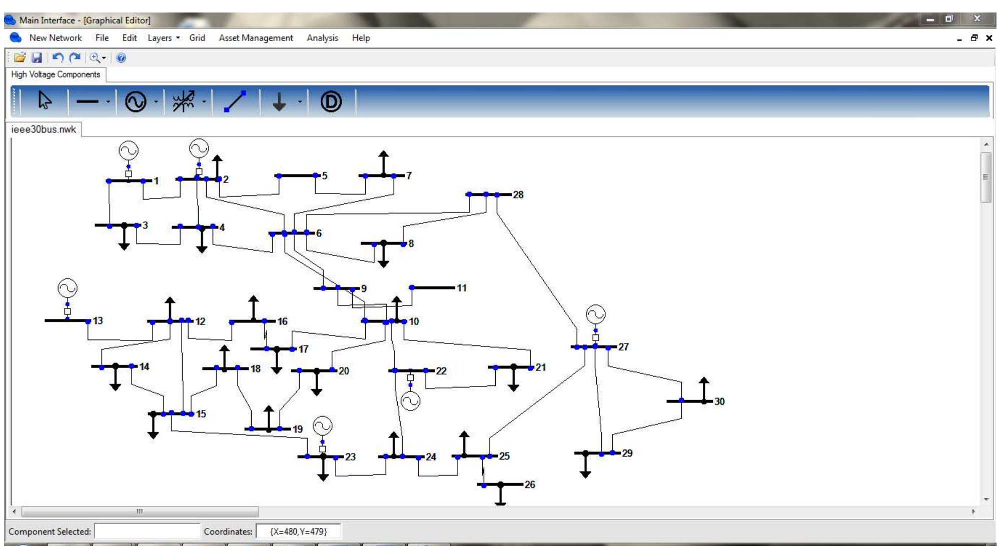


Figure 6: IEEE 30 Bus Network

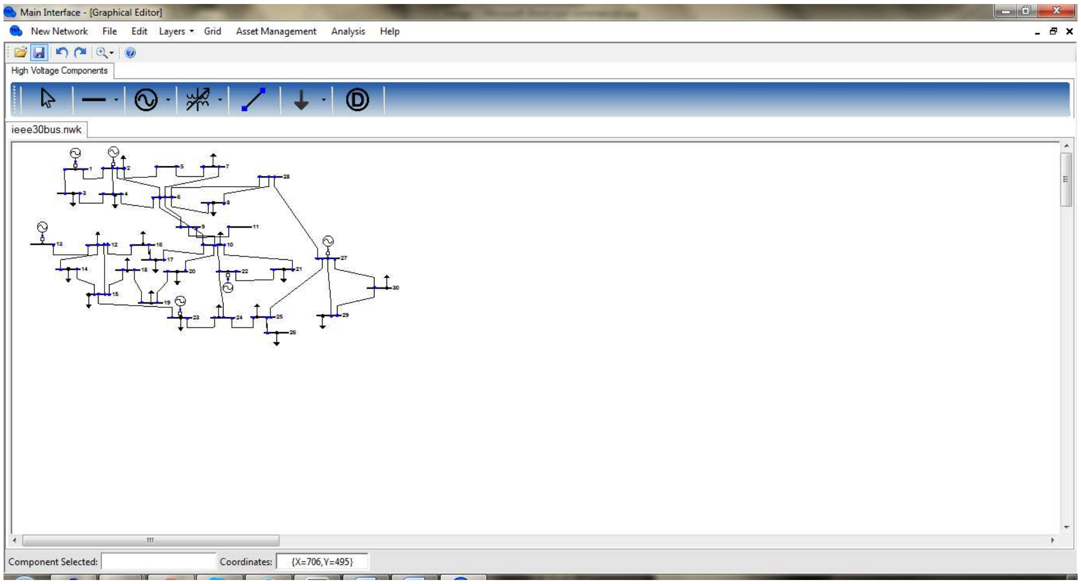
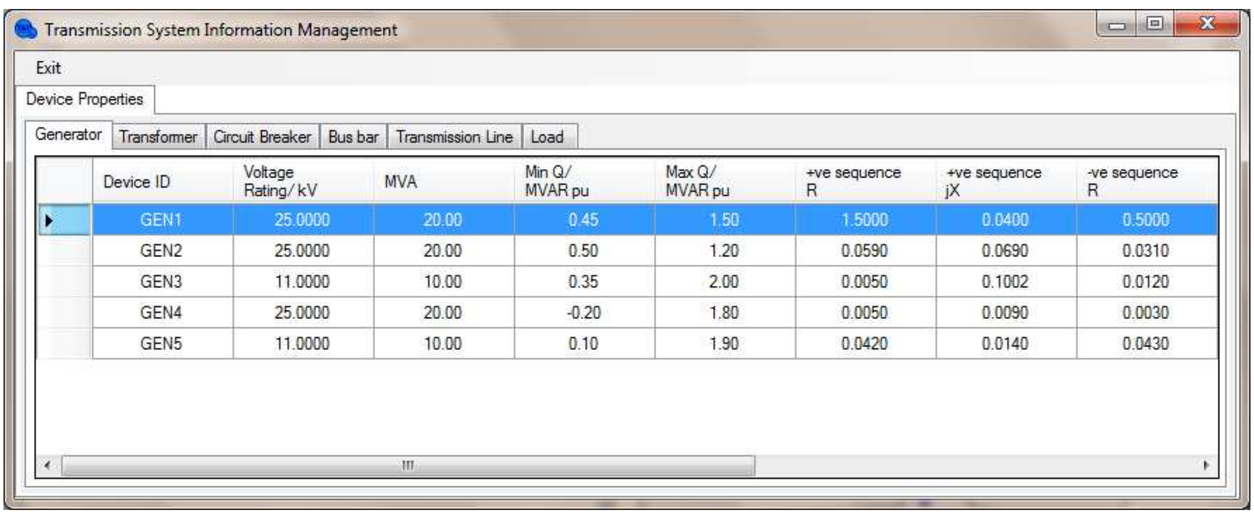


Figure 7: IEEE 30 Bus Network at 50% scaling

5. COMPONENT DATA AND INFORAMTION MANAGEMENT

The application stores the data of all the components in a unique text format. This facilitates opening the existing networks and saving them as needed. Within the application, users can update the data and can also view the component information of the network. Figure 8 shows the component information of a network.



Device ID	Voltage Rating/ kV	MVA	Min Q/ MVAR pu	Max Q/ MVAR pu	+ve sequence R	+ve sequence jX	-ve sequence R
GEN1	25.0000	20.00	0.45	1.50	1.5000	0.0400	0.5000
GEN2	25.0000	20.00	0.50	1.20	0.0590	0.0690	0.0310
GEN3	11.0000	10.00	0.35	2.00	0.0050	0.1002	0.0120
GEN4	25.0000	20.00	-0.20	1.80	0.0050	0.0090	0.0030
GEN5	11.0000	10.00	0.10	1.90	0.0420	0.0140	0.0430

Figure 8: Information Management Screen

6. APPLICATION TESTING AND USUABILITY EVALUATION

This application is an integration of several modules and hence comprehensive testing and evaluation has been undertaken to determine its overall performance and effectiveness. Detailed discussion of this evaluation process is out of scope of this paper. The usability aims at capturing user feedback on the overall effectiveness in understanding the power networks in terms of representation, information management, field operation etc. Each user was provided with a feedback instrument and the application on a computer. The feedback instrument comprises of questions – starting with user's background knowledge; look and feel of the application, ease of operation and handling etc. Users are required to operate the applications and provide responses to the questions in the feedback instrument simultaneously. At the end, summary of user experience was captured in six major areas, see Table 2.

Table 2: Feedback Instrument for Summary of Usability Test Experience

User Experience	**1**	**2**	**3**	**4**	**5**
How familiar are you with transmission networks?	☐	☐	☐	☐	☐
How familiar are you with distribution networks?	☐	☐	☐	☐	☐
How easy was it to navigate around the various screens of environment?	☐	☐	☐	☐	☐
How helpful do you think this application will be in your learning process?	☐	☐	☐	☐	☐
By using this application, did you have a better understanding of the relationship between transmission and distribution networks?	☐	☐	☐	☐	☐
What is your overall rating for the general usability of this application?	☐ Poor	☐ Fair	☐ Average	☐ Good	☐ Superb

The summary feedback from the users is shown in a pie chart in the Figure 9.

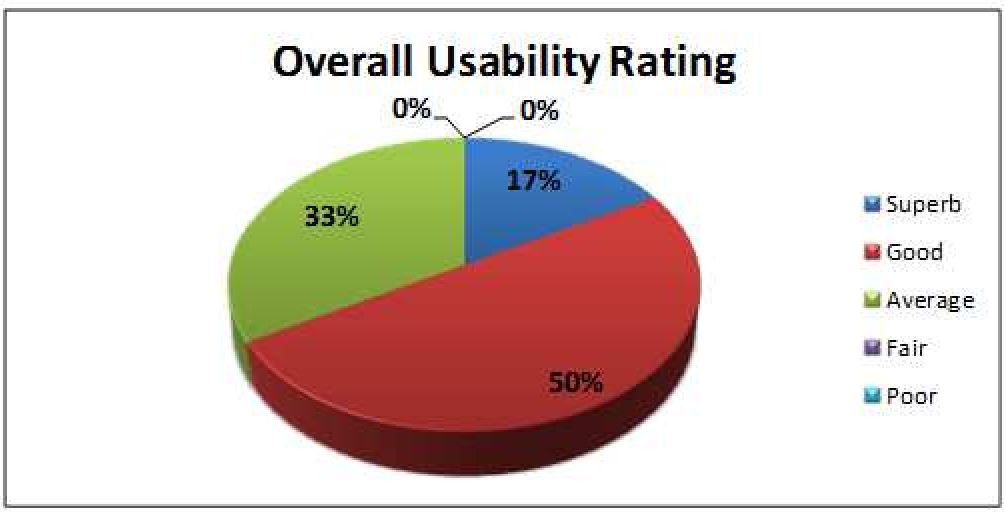


Figure 9: Pie Chart illustrating the overall usability rating of the application

7. CONCLUSION

A framework for the design and development of a new user-friendly graphical training environment for power systems with both HV and LV networks has been presented. The technical studies have been benchmarked with standard products. The suggested design and developmental approach can be adopted by universities or utilities to build their own IT training solution. Using such IT products, universities can train students and utilities can cut training costs as this approach of building own IT products indeed is a long term sustainable solution for ever changing needs. This application can be freely downloaded from the author's SkyDrive: http://sdrv.ms/12aErO2

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