A Conceptual Approach to Data Visualization for User Interface Design of Smart Grid Operation Tools

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Abstract

This paper deals with a conceptual approach to visualization of the operation and simulation tools in electric power systems. Since the introduction of graphic user interface (GUI), many application programs have adopted graphics for user interface and the display of information. GUI increases the amount of data to be handled on a screen and improves the readability of information. As software technology evolves, the number of applications for power system operations has been increased rapidly to encompass most of functions, such as electronic commerce, facility operation, research simulation, etc. Electric power system is a huge system operated on real time basis and requires to process massive data. We believe visualization is critical to the operation and analysis the electric power system. On this background, the study proposes a concept design for visualization process on the control systems used in the electric power industry.

Keywords: *Visualization, Electric Power Systems, Smart Grid, Readability of Information*

1. Introduction

Control systems require the interaction between machine and human. With the advances in information technology, many functions in control systems are performed by automated computer programs, and computers are taking the role of an interface between machine and human. As the computer provides the interface between the machine and the human, the needs for humans to directly interface with machines are decreasing.

As humans interact more with computers, human-computer interaction (HCI) is getting more attention than human-machine interface (HMI) these days. HCI is more important in control systems than general information systems. Dynamic interaction is essential in control systems, because they should monitor and control the physical systems responding to various environment conditions on real-time basis. Therefore, it is important for a human operator of a control system to understand a huge amount of information about the physical system status, provided and updated by the computer, in a short period. In smart grid environments, visualization is more important than in traditional electric power industry, because the final consumers actively participate in the system operation with demand-response activities.

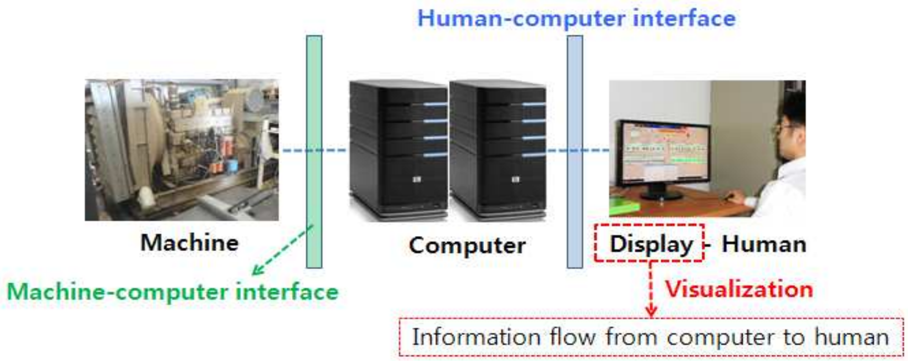

Figure 1. Visualization of Human-Computer Interface

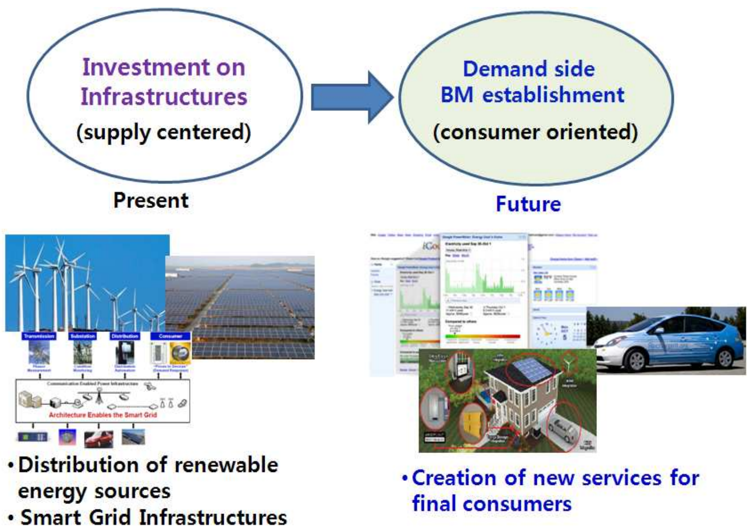

Figure 2. Paradigm Shift in Smart Grid Environment

2. Visualization in the SCADA system

2.1 SCADA system

The electric power system is the biggest artificial system on earth and connected with many other systems, because the physical infrastructures of the modern civilization have been built on electricity. The power system is operated by a certain type of control scheme. The power system, originally started with manual operation of human operators, introduced several automated processes as local power systems started to be connected with each other and thereby integrated into a bigger system. As the integration continues with the help of automation and communication technologies, the power system has grown to a huge system covering the entire country. It is impossible to operate the power system with manual operation. In addition, electricity is not stored, which requires a huge amount of data and information required to be processed on real-time basis and many components in the system to be controlled interactively. Therefore, an automatic control scheme is not an option but an imperative. As the information technology advances, the telephone was fully replaced by computer communication. Automation was accelerated with IT, and the control system was extended to a wider area. The control system used at present time is called SCADA which stands for supervisory control and data acquisition system. Fig. 3 shows the development history of the SCADA systems from manual operation on a local basis to automated operation for wide-area system.

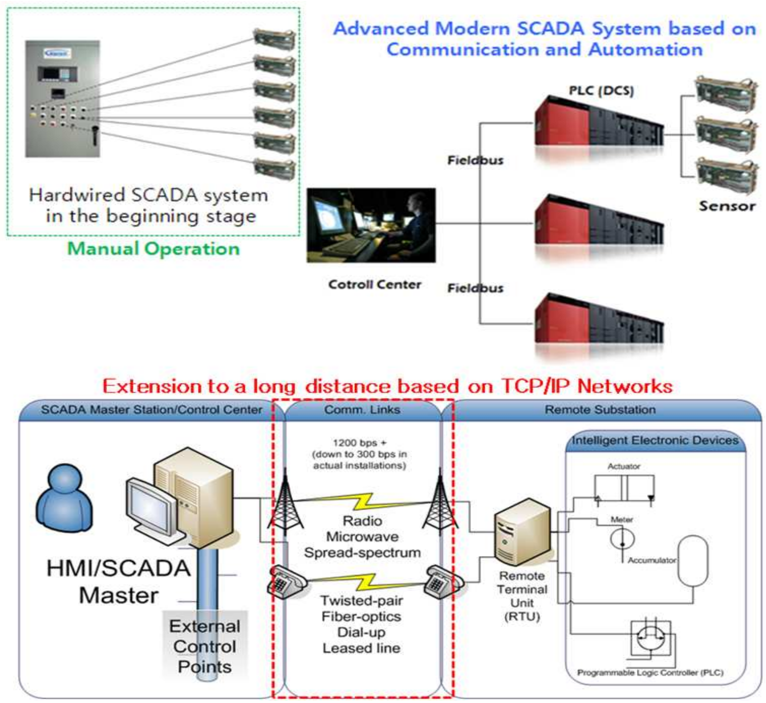

Figure 3. History of SCADA developments

2.2 Data Visualization Process for Producing Information

Data visualization is the graphical representation of information. Bar chart, scatter graphs, and maps are the examples of simple data visualizations that have been used for decades. Information technology is able to combine the principles of visualization with powerful applications and large data sets to create sophisticated images and animations [1]. Visualization has become an essential method to deal with large data sets. One representative characteristic in the SCADA system is to deal with the large data retrieved from many local data-acquisition units on remote sites as shown in Fig.4. The SCADA system covers the entire country, so the amount of data overwhelms the human capacity on information process. Furthermore the data is updated every 2 second, which increases the quantity of data exponentially over time horizon. Therefore it is impossible to follow the entire raw data in text forms. Instead it is more effective to transform the data into a visualized form. The visualization does not just mean to make the image of raw data but to produce the meaningful information through the process as shown in Fig.5.

In spite of advances in automation, computer programming bugs or unexpected system situations may cause several contingent situations which still require human operators to handle the contingencies. In this context, a good HCI is critical for operators to monitor and control the system. Moreover the massive data in the power system that are updated every 2 second increase the quantity of information more rapidly during a certain time period. There is a clear limit on the information quantity a human can recognize and process in a short period of time. So there exists a contradiction between two factors, information quantity and human capability. It is expected that visualization takes a role of the interface between two different properties originated from human and machine respectively.

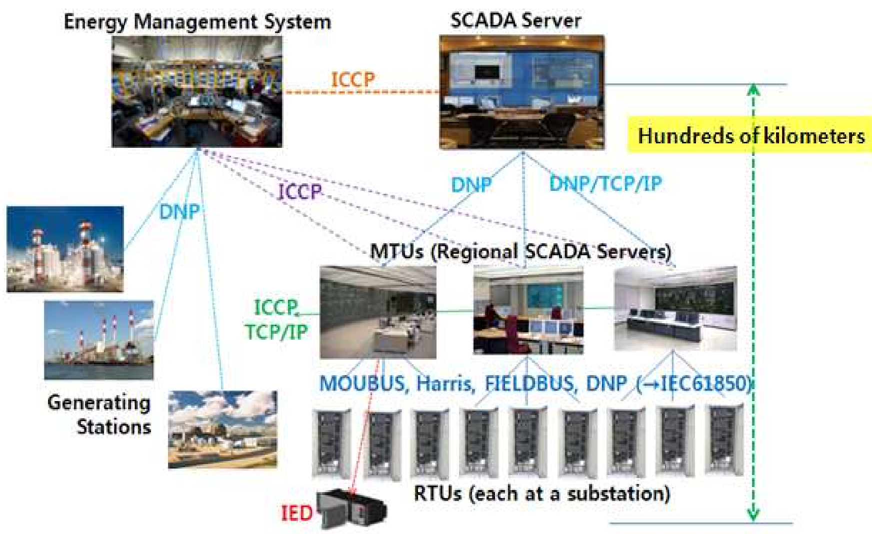

Figure 4. Wide-Area SCADA System

Figure 5. Examples of Monitoring Screen in Control Center

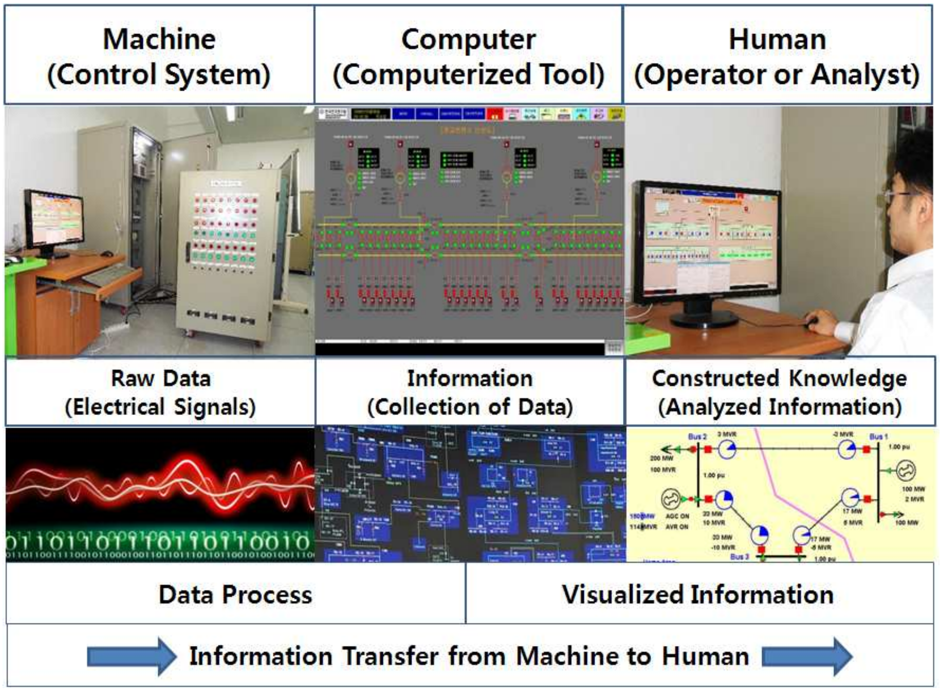

Figure 6. Visualization Process

The terms data and information are often used to mean different things. SMALE Consulting Ltd. defines the difference between the two as follows [1]. Information is defined as useful knowledge derived from the data, while data is defined as raw, unanalyzed facts, figures and events. This means the information is produced by transforming the data through the process as shown in Fig. 7.

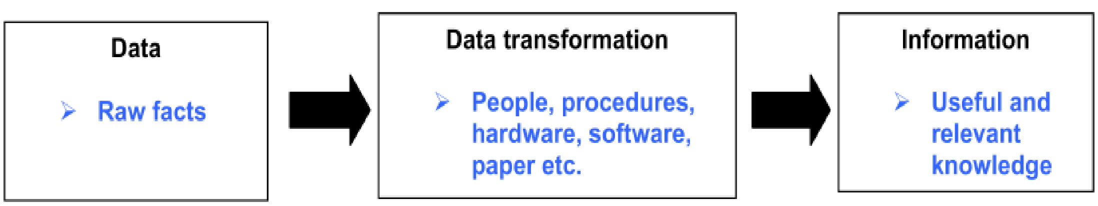

Figure 7. Transformation of Data to Information

Consider the communication between RTU and SCADA Server in Fig. 4. Raw data are retrieved by RTUs from field devices and facilities. Through this process, the electronic signal on the physical level is transformed into the digital form of data. The data at each RTU are transmitted to the MTU, and then collected and structured in a relational database system at the MTU server in which the raw data are transformed into information. The information is in turn transformed into visualized forms for the operators in the MTU. The data and information at MTUs are again transmitted to the SCADA server and used for the overall operation of the entire system.

3. Concept Design for Visualization

3.1 Concept Design for Visualization Area

There are several stages on the flow of processing data and information from field devices to the SCADA server. The data are made to be segmented and related to each other in the MTU server where the data become information. The data are filtered and organized as required by the regional operation and transmitted to the upper SCADA server.

The control system of MTUs exhibits two data-usage patterns. One is to use the data for the automated operation in the control system, and the other is to display the data with various visualized forms for human operators in the MTU. The hierarchical structure of data transformation process, shown in Fig.8, takes place for the inner control process and the visualized display. It is an example of the segmentation of data according to functional usage. The data could be segmented more by data type layers. The raw data are transformed into the processed information at each level which defines system environments and control purposes, as shown in Fig. 8.

Data segmentation increases the flexibility of data usage and transformation, by combining and organizing the segmented data sets in many different ways. Data are considered as information when a functional relationship could be induced from two variables which are mapped into two segmented datasets, as shown in Fig. 9. This kind of formulation could be applied to multiple with various forms of mathematical relationships.

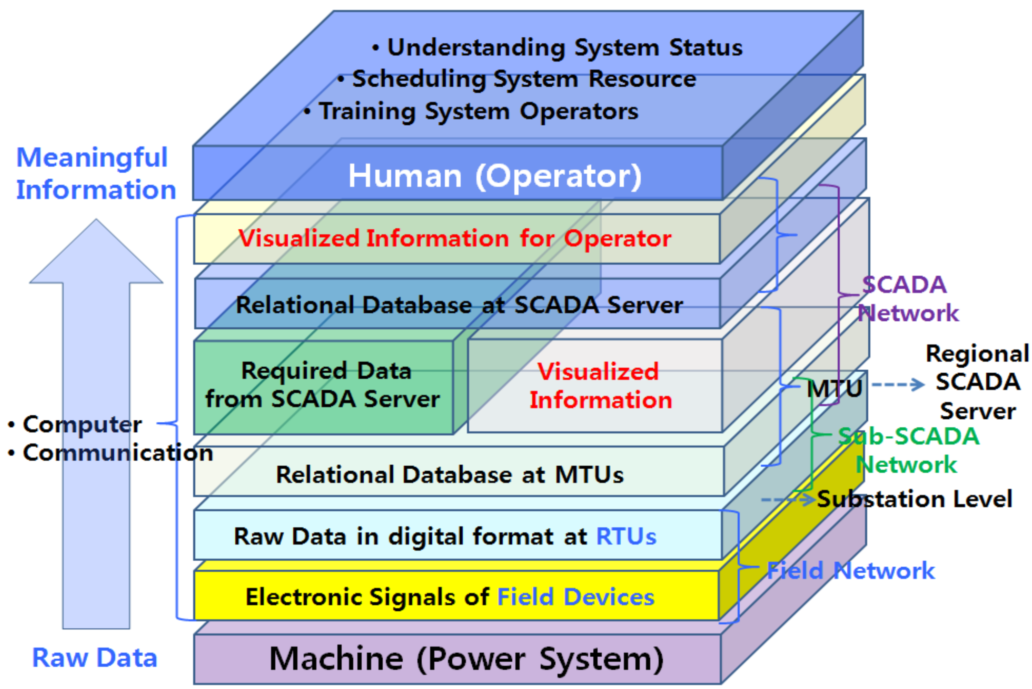

Figure 8. Concept Design for Hierarchical Data Segmentation

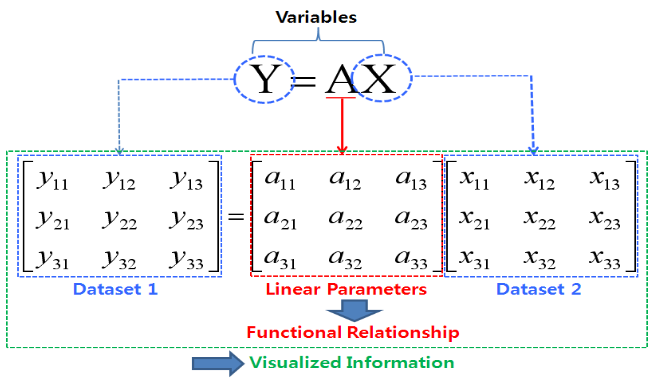

Figure 9. Mathematical Formulation of Information with Datasets

Information is produced from datasets, and higher level information is produced from multiple information sets from the lower level. The hierarchical structure from low-level data to high-level information is shown at y-axis in Fig. 10. Note that the higher level information is required by humans than by automated control processes on machine and computer levels. The intersection area indicated by the dotted square is considered to be preferred as the visualization area for the human operator. Of course, it is possible to change the visualization area depending on which information is needed and who wants the information in a visualized format. The power system is composed of several layers as shown in 'Multiple Layers of Power Industry [3]' in Fig. 11.

There are many system components and market participants in electricity market at each layer, so there exist many entities who need various types of information, both quantitative and qualitative. Fig. 11 illustrates the visualization area for variables dependent on different layers of the system and the information users.

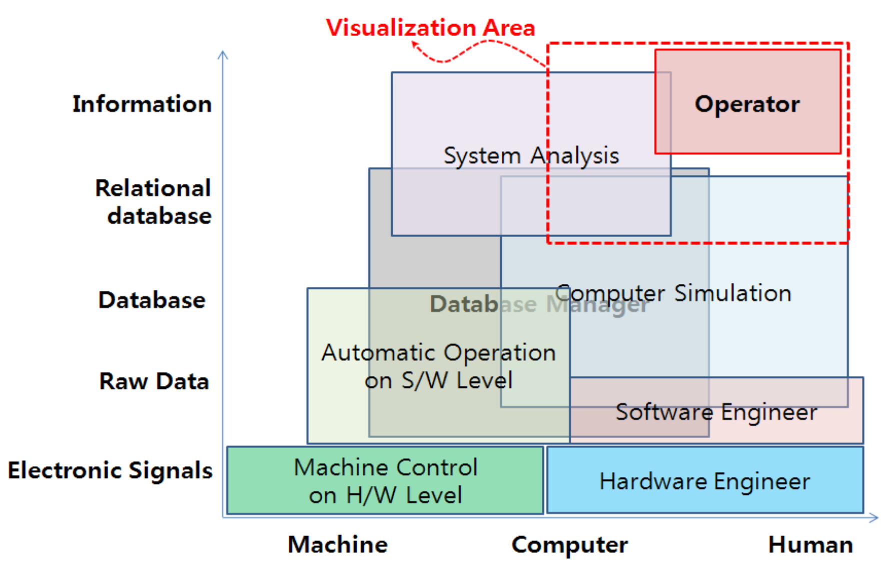

Figure 10. Concept of Visualization Matrix

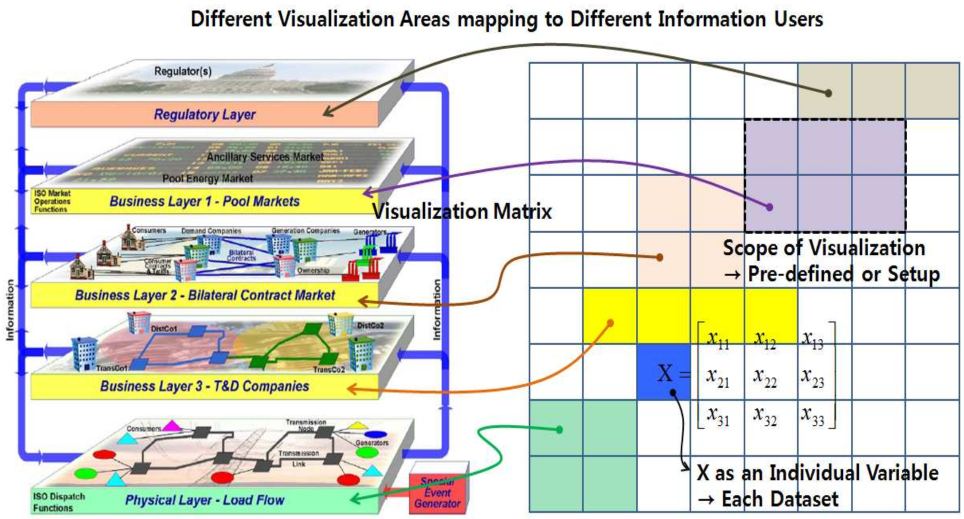

Figure 11. An Example of Variable Visualization Area

3.2 Concept Design for Visualization Process with Computerized Tools

The data components in the visualization matrix are determined in Fig. 12. The data measured in the form of analog and digital signals are acquired and then transformed into digital bits by field devices and sensors. The data are transmitted to RTUs and transformed to the raw data format. The data are stored in the database, and the relationships are built based on the functions provided by the database program. When it is required to build more complicated functional relationships after data segmentation process, the functions could be provided with other numerical analysis programs or statistical tools through an API (Application Program Interface).

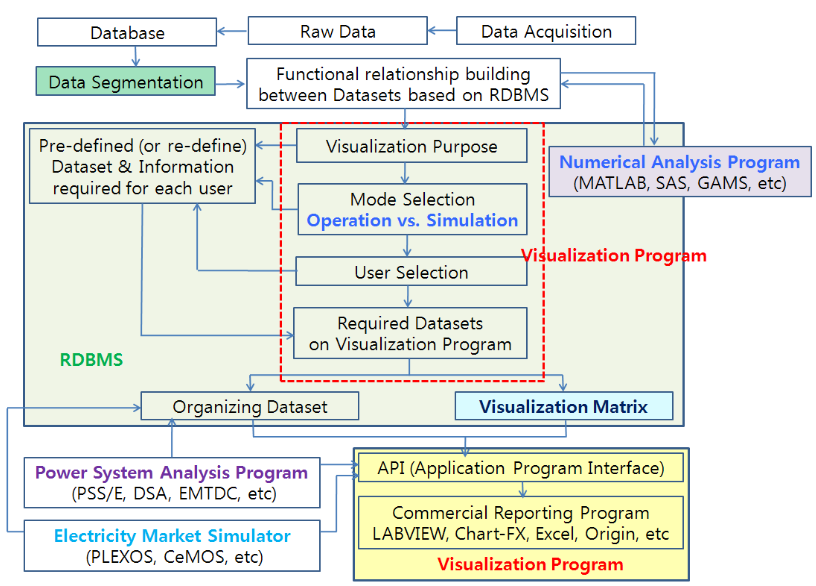

Figure 12. Procedure for Establishing Visualization Matrix

After the relationship-building process is finished, several options are recommended to create the dataset required for the visualization process, depending on the purpose, the user, and the mode of visualization. For example, in the power industry, the purpose could be to understand system dynamics, market simulation, generation dispatch, etc. The user could be system operators, market analysts, system engineers, etc. In terms of software engineering, the relation between the data is built by the Relational Data Base Management Systems (RDBMS) ORACLE and MS-ACCESS are commercial database programs widely used in many fields including the power industry. It is easy to establish simple relations in the RDBMS, but it is impossible to create a new set of information based on complicated calculations, which requires another application program. The application program creates more complicated and functional relationship between datasets, or producing higher-level information. The application program should be designed to interact with RDBMS and other visualization tools. The concept design of visualization program is illustrated in Fig. 13, with horizontal and vertical conceptual structures.

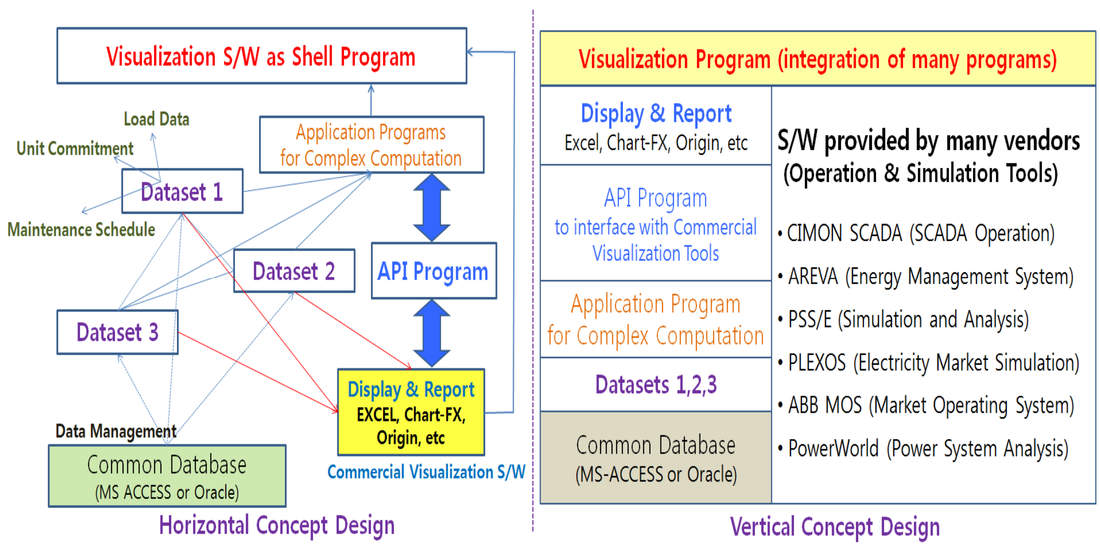

Figure 13. Horizontal and Vertical Concept Design of Visualization Program

In the electric power industry, many commercial tools are provided by vendors with different purposes and usages. Some are the on-line operation tools monitoring and controlling the power system on real-time basis, while others are off-line simulation tools to analyze the system characteristics with many contingent cases. Unfortunately, two classes of tools are incompatible with each other in spite of the fact that all these tools are needed to exchange the data and share the functionalities. We expect the visualization program take a role of interfacing different programs with one another, providing a shell program or an API above all the programs, as shown in Fig. 14.

4. Application of Visualization Matrix to Power Industry

Everything is connected to everything else. It is called the first of ecology, which is also applicable to information technology.

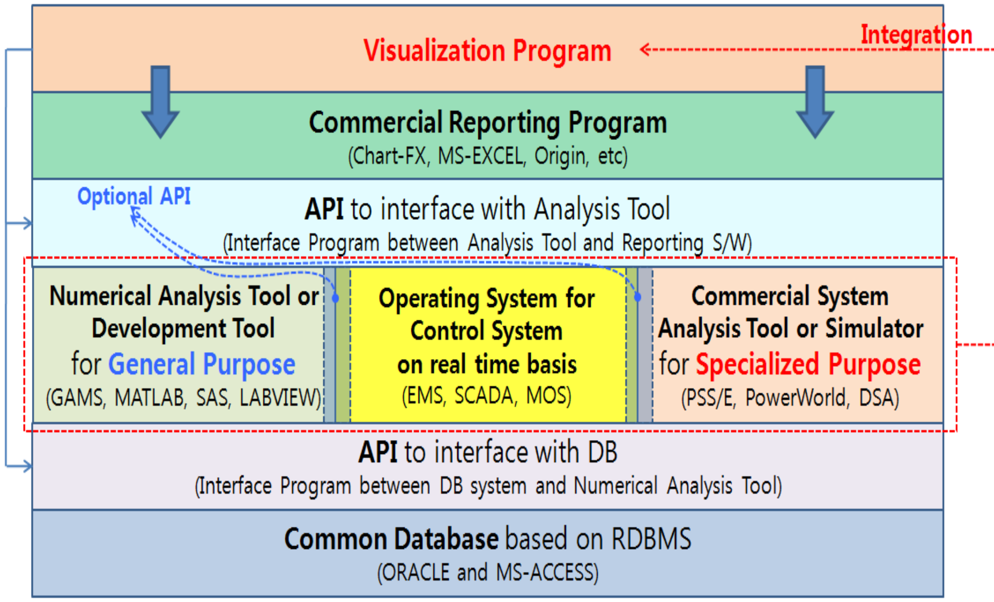

Figure 14. Visualization Program Hierarchy with API

Quoting John Donne, no data is an island, entire of itself, every data is a piece of a data source, a part of a larger business reality. It is the underlying philosophy of the visualization program concept proposed in this paper. It is required to integrate many different functions and information provided by many different applications into a business flow. The electric power industry works based on a large-scale power system with lots of physical facilities and market participants. There are many kinds of computerized tools to control, analyze and simulate the system and market. Although the tools provide various functions and produce a huge amount of information, they are not compatible with each other, which decreases the efficiency of overall understanding of the system and makes it hard to make decisions based on both aspects of physical system and business flow. If the tools could share the databases and exchange the functions, the flexibility of the application would be enhanced. The tools share the relational database at the lowest level as a common input system, and the visualization program at the highest level as a common output system, as illustrated in Fig.15.

Visualization matrix is a conceptual design of the visualization program as a common output system. When the database is shared, it is possible to integrate the visualization process in reporting programs. Otherwise the data are conveyed to the visualization program through the API and then made to be an output in a visualized format. In a sense, the visualization program is a common API for many different software tools that interface with common database systems. Using the visualization matrix, each tool can identify its functional position in the entire system and determine with which tools to interface. The vertically and horizontally hierarchical visualization process can be applied to various solutions and use based on a common database system. Especially on smart grid environments, many new services targeted to different users are being introduced as shown in Fig. 16. These services are based on common database system but require different user interfaces.

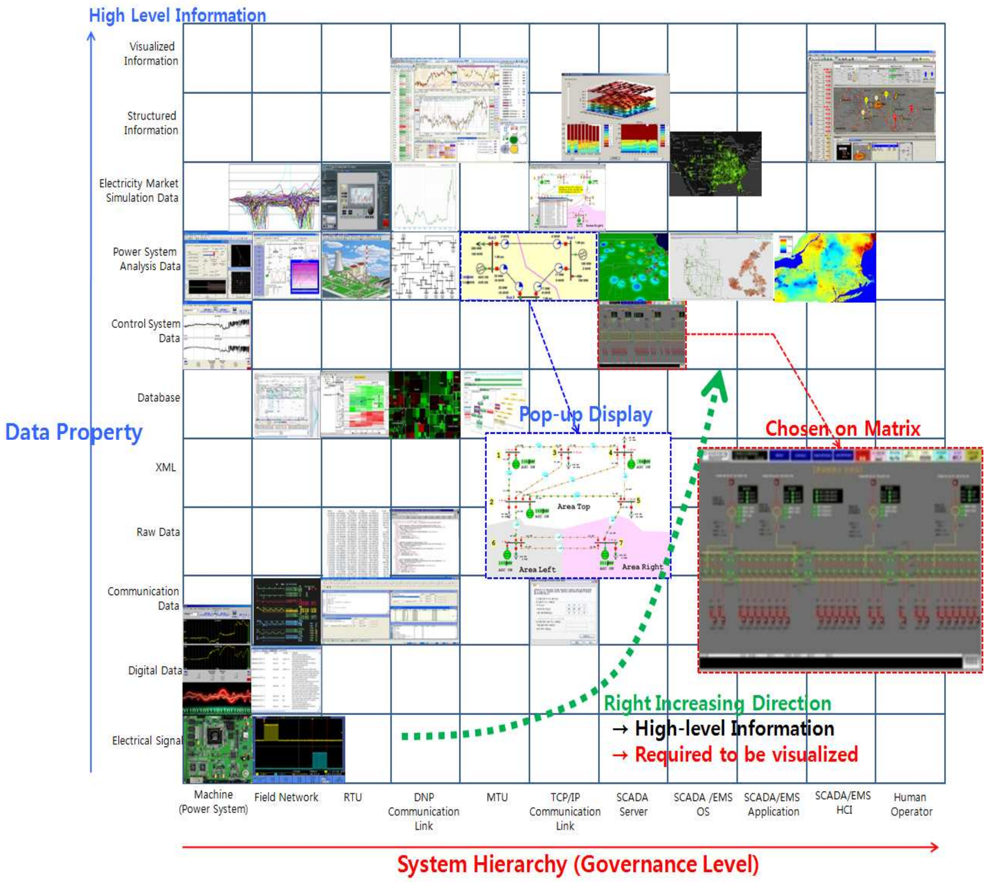

Figure 15. Application Example of Visualization Matrix in Power Industry

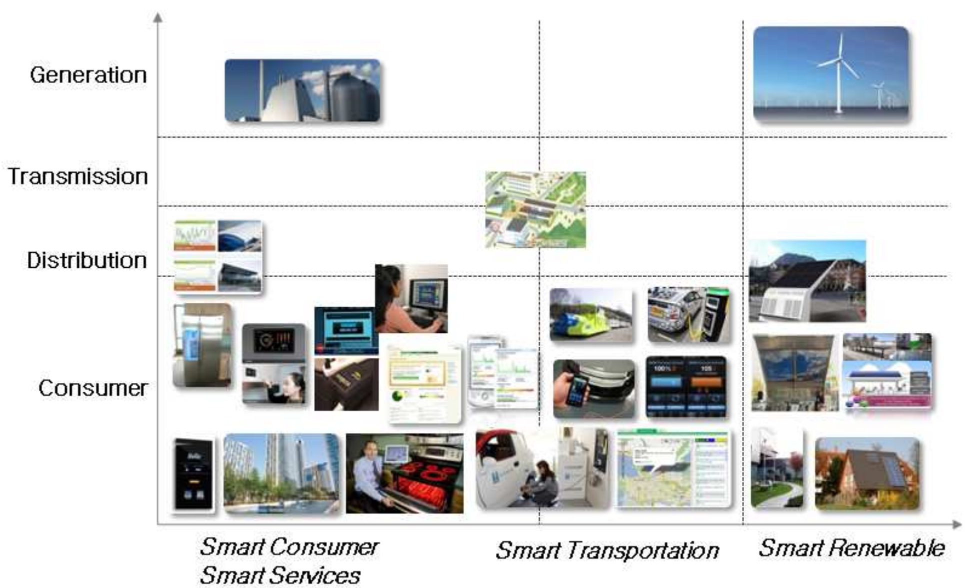

Figure 16. Application Example of Visualization Matrix in Smart Grid [6]

5. Conclusion

The main goal of data visualization is to communicate information clearly and effectively through graphical means. To convey ideas effectively, both aesthetic form and functionality need to go hand in hand, providing insights into a rather sparse and complex data set by communicating its key aspects in a more intuitive way [7]. We argue that the electric power system is in dire need of an effective way to communicate lots of abstract and complex information, such as reliability, adequacy, security, etc., many of which are described in numerical formats. As stated above, this need for an effective way of communicating complex information is getting important in smart grid environment, because the final consumers are often lacking the expertise on electrical engineering. To aid the consumer's understanding of the information is the key factor to the vitalization of smart grid industry. Visualized information is easier to understand, and this paper proposes a conceptual approach to visualize many different data from various solutions in electric power systems and smart grid environment. The proposed method can also be used as an integration tool for interfacing between different solutions.

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