A Web-based Dispatcher Information System for Electricity Transmission Grid Monitoring and Analysis

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Abstract

Adequate monitoring of the electricity transmission system through widespread installation of data acquisition modules is crucial for the effective monitoring and control of the electricity transmission grid. In this paper, we present the architecture and implementation details of a ubiquitous Web-based dispatcher information system deployed on the Turkish electricity transmission grid. By means of the described dispatcher system, the transmission system operator is able to dynamically monitor the transmission grid and hence to take the proper short-term and long-term operational decisions. Through the analysis facilities of the system, plausible outputs can be obtained such as load forecasts and timely information on the grid security. After the system description, we provide sample analysis results obtained through the system in addition to pointers to future research prospects.

1. Introduction

The operation of the electricity grid is an important task with nationwide and international implications. The transmission system operator (TSO) in every country is responsible for the management and planning of the transmission subsystem of the grid. In order to carry out this task, monitoring and controlling the operation of each and every component of the transmission grid is indispensable. To fulfill these needs, several large-scale software systems (with the underlying hardware infrastructure) need to be installed including wide area monitoring and control systems (such as [1]), supervisory control and data acquisition (SCADA) systems (as in [2]), power quality monitoring and analysis systems (such as [3]), forecast systems for the renewable energy plants (such as [4]), load forecast systems, energy management systems, and dispatcher information systems. These systems help decision makers, like the TSOs, take the appropriate actions during the times of seamless operation as well as during the times of interruptions or failures. But, it should be noted that these systems should possess the characteristics of widespread coverage, high reliability and availability, ease of use, and convenient presentation/visualization facilities, among the others, in order to help the operators during the course of the grid operation. The aforementioned systems are also significant as they stand as critical components within the much anticipated smart grids [5].

In this paper, we present a wide-coverage Web-based dispatcher information system that has been installed on the Turkish electricity transmission grid. Through this system, the energy production and other electrical quantities from about 1,000 power plants and 1,100 transformer substations all over the country are acquired and stored into a central database. These plants and substations correspond to almost 99% of all in the country, so the system has quite a high coverage. Online electrical quantities regarding the grid components like busbars, shunts, reactors, feeders, couplings, electricity transmission lines, transformers, and plant units are all acquired and included into the scope of the system, in addition to the qualitative information on these components. The presented dispatcher system has the necessary components for (i) information and data acquisition, (ii) storage of the acquired information and data, (iii) data visualization/reporting, and finally (iv) data analysis. Particularly through the analysis modules of this system, important facilities like load forecast can be performed and the results can be presented to the system operators. The main contributions of the study are listed below:

1. The presented dispatcher system is a quite wide-coverage information system genuinely installed on the Turkish electricity transmission grid with more than 2,100 active users.
2. The system's being Web-based facilitates gradual updates to add new features and contributes to its widespread employment.
3. The data acquired through the proposed system is being used by several on-line and off-line analysis applications, which are required by the national regulations and international contacts.
4. The system is in the process of being integrated with the other systems installed on the grid, such as the power quality monitoring system [3], to automate the data acquisition, whenever possible.

The rest of the paper is organized as follows: In Section 2, an overview of the Web-based dispatcher information system is provided with its main software components. Sample results from the system demonstrating its main monitoring facilities are given in Section 3 while sample analysis outputs of the system are presented in Section 4. Finally, Section 5 concludes the paper with a summary of main points and pointers to future research directions.

2. An Overview of the Web-based Dispatcher Information System

The dispatcher information system installed on the Turkish transmission grid is a Web-based system with centralized stor-

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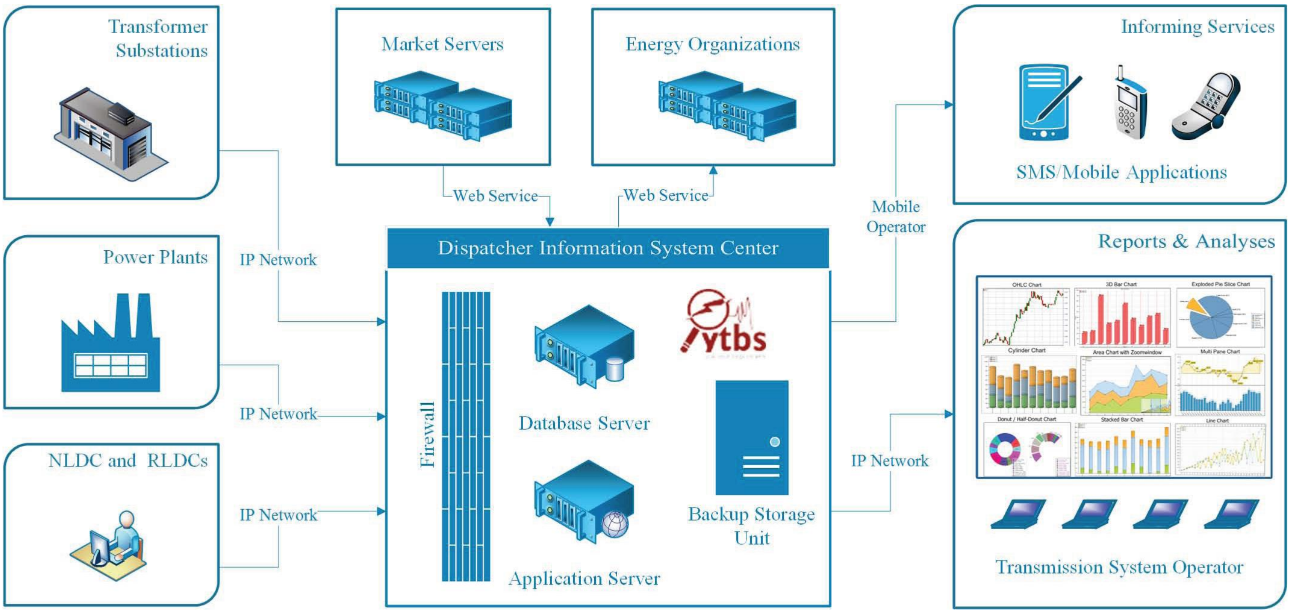

Fig. 1. The Architecture of the Web-based Dispatcher Information System

age. Hourly load and other electrical quantities are stored in the central database by the power plant and transformer substation operators through the data acquisition interfaces of the system and the acquired data is served to the TSO. In addition to the hourly data; up-to-date status, event, and maintenance information about the grid components are also stored into the database through the Web interfaces. These two sources of information, coupled with the widespread utilization of the system throughout the country, enables the TSO to take the necessary operational and security-related decisions. At the time of writing this paper, the system has been actively used by more than 2,100 users in about 1,000 power plants and 1,100 transformer substations in Turkey, amounting to a coverage of about 99% of the whole transmission grid.

The main grid components monitored through the dispatcher system include busbars, shunts, reactors, feeders, couplings, electricity transmission lines, transformers, and plant units.

The TSO organization in Turkey is TEİAŞ [6] and has got a department of load dispatch where this department, in turn, has got one national and 9 regional directorates of load dispatch. The proposed dispatcher information system is tailored to the particular needs of TSO's department of load dispatch (with its directorates) and the system basically has four user types where some of these have subtypes as well. Brief information about these user types is provided below:

1. *Administrators*: These users can be directorate-level administrators who are responsible for one of the 9 directorates of load dispatch or they can be general administrators responsible from the whole system. They carry out the necessary tasks to define new system users, control the overall pace of the data acquisition, and make use of the analyses outputs of the system.
2. *Operators*: This user group is responsible for defining the newly-added grid components, in addition to storing event, maintenance, and configuration information regarding these components, through the corresponding interfaces of the system.
3. *Plant or Substation Users*: These users, who can be responsible from a single plant/substation or multiple plants/substations, supplies daily load information regarding the monitored grid components.
4. *Observers*: These users can be authorized within a single plant, substation, directorate or over the whole system. The observers cannot make any modifications through the system but based on their authorization level, they have access to the reports and other analysis results automatically produced by the system.

The developed Web-based dispatcher information system has got several components, including a suite of Web user interfaces (for the definition of grid components, load data acquisition, and system operation in addition to the visualization of the system outputs), a data storage and service subsystem, i.e., a center, which hosts the database and application servers with other storage units, and finally the facilities for data visualization/reporting.

The architecture of the system is visually depicted in Fig. 1. The data is basically acquired from the users at the transformer substations, power plants, national load dispatch center (NLDC) and regional load dispatch centers (RLDCs). Additionally, market data is obtained from the corresponding organizations through the relevant Web services. The system also provides Web services of essential statistical information to energy organizations such as Energy Market Regulatory Authority and Ministry of Energy. The data stored in the center is served to authorized users through the data visualization, analysis, and reporting facilities of the system. The authorized users are also notified about the system events through automated SMSs in addition to customized mobile applications.

The interfaces of the Web-based dispatcher information system are based on JavaServer Faces (JSF) technology [7] and utilizes PrimeFaces JSF library [8]. The data acquired by the system is stored within a relational database installed on the database server. The main components of the system are further elaborated in the following subsections.

2.1. User Interfaces for Data Acquisition

2.1.1. Interfaces for the Definition of Grid Components

The dispatcher information system has individual pages for the defining new grid components of the following types: power plants, power plant units, transformer substations, transformers, busbars, busbar groups, feeders, couplings, transmission lines, shunts, and capacitors. The information about the components can also be updated and deleted through the system interfaces.

2.1.2. Interfaces for the System Operation

The system also has the necessary interfaces to supply information regarding the system operations, such as event and maintenance information regarding the grid components in addition to other configuration information such as up-to-date status (online/offline) information of the components and the connectivity information between different components.

2.1.3. Interfaces for the Load Data Acquisition

In order to obtain hourly load data from the plant and substation users, the system has the necessary data acquisition page which is dynamically formed based on the components associated with the plant(s) or substation(s) on which the users have been authorized. Additionally, the users of hydroelectricity plants use another data acquisition page to supply the system with information related to the water levels at different times of each day.

2.2. Data Storage and Service Subsystem (Dispatcher Information System Center)

The data storage and service subsystem of the dispatcher information system comprises a database server, an application server, and a storage unit. The database servers acts as the main data storage server and contains a relational database holding all of the data acquired through the system. A backup server contains an online backup of this database so that in case of a failure of the main database server, this database server will seamlessly replace it and the system operation will not be interrupted. This synchronous backup strategy is enabled with a facility provided by the database management system. The storage unit holds additional daily cold backups of the database as a further precaution for possible failures. These daily backups are created by a daily running script on the main database server.

2.3. Data Visualization/Reporting Facilities

In order to provide the system operators with information in appropriate granularity and in appropriate forms, the system has a dashboard page, several map-based visualization pages, and provides several options for automatic report generation. The dashboard page provide summary information regarding the overall energy generation in dynamic bar, pie, and time-series charts where generation information with respect to the energy source can be examined (See Section 3). Detailed information can be obtained from the system through reports automatically generated by the system in different formats following the preferences of the users.

3. Sample Results from the System

The system has a wide-range of reporting facilities regarding inventories, installed capacities, load curves, resource based generations, water information of hydroelectricity plants, operational reports, peak demand and regional consumption reports etc. in daily, monthly, yearly ranges. Dynamic graphics are implemented via amCharts Library [9] and static reports are created using Jaspersoft Studio library [10]. In this section, prominent examples of reporting facilities will be introduced.

In Fig. 2, an image of daily load curve of Turkey is presented. With this dashboard, hourly national and regional consumption can be observed online with the distribution of resources that met the demand.

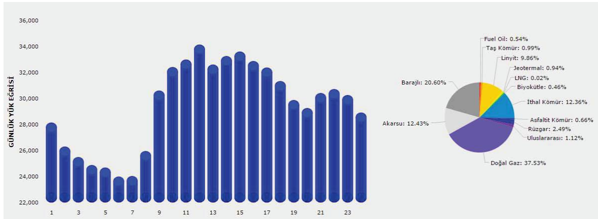

Fig. 2. Daily Load Curve and Distribution of Resources.

In Fig. 3, an image of daily generation mix is given. In this dynamic graph, the users can monitor distribution of generation and its numerical values. They can also edit the graph with the hide-show controller of resources.

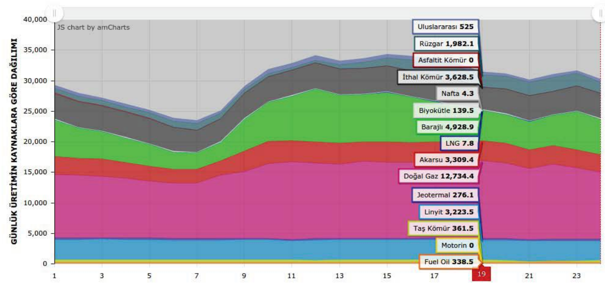

Fig. 3. Distribution of Generation Based on Resources

The system can visualize distribution of consumption and supply centers geographically on region, province and substation base so that losses and loadings of transmission network can be controlled quickly. In Fig. 4, the distribution of supply and demand based on provinces is presented.

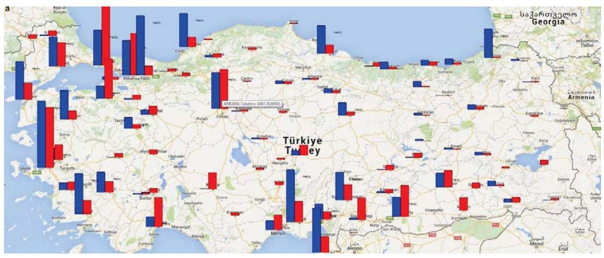

Fig. 4. Distribution of Supply - Demand Based on Provinces

The system has a daily short-term substation-based load forecasting module, and presents forecast results in line chart format. In Fig. 5, weekly results of forecasted and observed load is given. The users may track and download historical load and Mean Absolute Percent Error (MAPE) of the forecasts.

Fig. 5. Display of Forecasted and Observed Regional Load

The system has various interfaces for definition of substations, power plants, transmission equipment, and electrical events. In Fig. 6, the interface for the definition of transmission substations is presented.

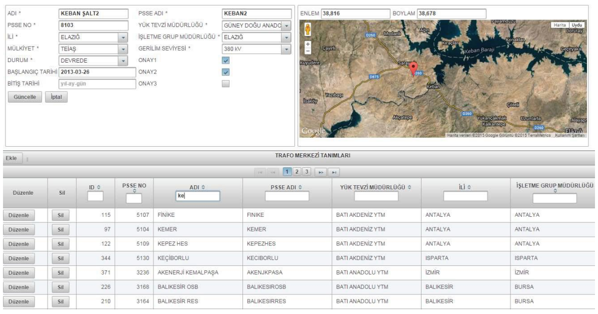

Fig. 6. Interface for the Definition of Grid Components

Finally, grid components can be drawn together automatically in a single line diagram format via the developed algorithm with the topological and load flow measurement results (Fig. 7).

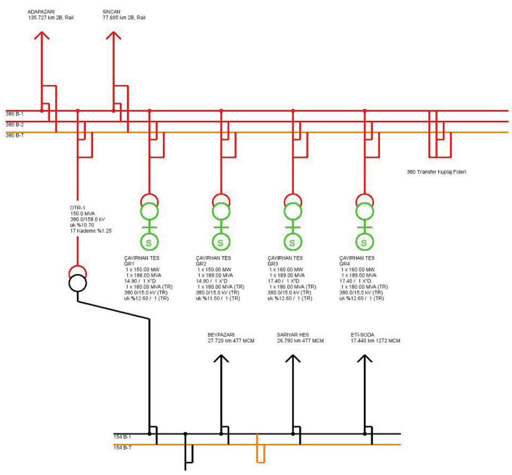

Fig. 7. Single Line Diagram of a Substation

4. Electricity Transmission Grid Analyses

Transmission grid analysis is one of the important tasks of the TSOs, as security and reliability of the network can be monitored mainly through the power system analyses. In this chapter, analysis applications of the system are presented in three categories according to time period; network day-ahead analysis, intra-day analysis, and bygone-day analysis.

4.1. Network Day-Ahead Analysis

Network day-ahead analyses are an obligatory task for ENTSO-E members [11]. The system offers its users a service for the preparation network day-ahead congestion forecast (DACF) files. The DACF files comprise short term substation based load forecast, network configuration forecast (considering maintenance schedules in transmission lines etc.), and generation forecast (via web services with electricity markets to obtain next day dispatch and international trade information). The system constructs the network data model in Siemens PTI PSS/E [12] environment, and optionally analyzes voltage and loading condition of the network and reports the results. Necessary user interfaces are deployed to ease the access to the network analyses files (Fig. 8).

Fig. 8. Network Data Downloading Interface

4.2. Network Intra-Day Analysis

Network real-time security analysis is one of the obligation of Turkish TSO for full membership to ENTSO-E. Within this framework, the system has a pseudo-real time security analysis module installed at the National Load Dispatch Control Center of TSO. The module automatically monitors system states and equipment status, carries out the necessary load flow and contingency and stability calculations, and reports the outputs to the operators hourly. The module constructs detailed node-breaker network model in DIgSILENT PowerFactory [13] environment, and reports critical up-to-date information of the network, so that the operators can take the necessary switching and scheduling decisions. In Fig. 9, line loading and contingency result outputs of the module are presented.

Fig. 9. Intra-Day Security Software Display

4.3. Network Bygone-Day Analysis

Dispatcher information system is designed with a database of grid component information and hourly measurement information to allow the construction of network static model of any hour and day in the past. The data can be downloaded in Siemens PTI PSS/E or DIgSILENT PowerFactory environments, with full detailed (containing medium, high and extra high voltage levels) and reduced (containing only extra high voltage level) modeling option. The necessary user interfaces are deployed to ease the access of network analyses files. Thereby, manual data preparation process, which is time-consuming and less reliable, was eliminated.

The system also has the auxiliary interfaces to increase the efficiency of network analyses. The users can visualize well-defined network data in geographical plane using Python codes and Google Maps libraries. Thus, the calculation and interpretation of results are facilitated. The first visualization given in Fig. 10 is the example of geographic projection of line loadings and bus voltages. The second visualization given in Fig. 11 is the example of geographic projection of transformer loadings.

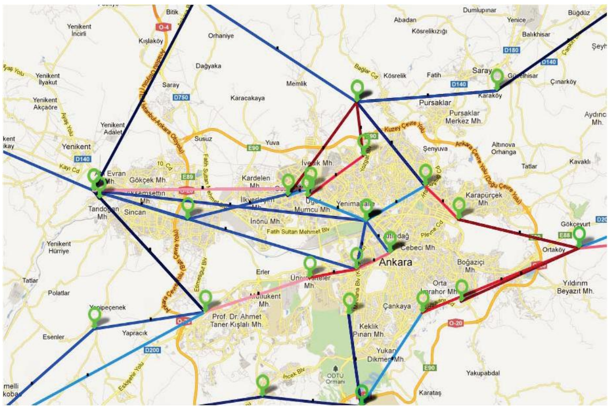

Fig. 10. Geographic Projection of Line Loadings & Bus Voltages

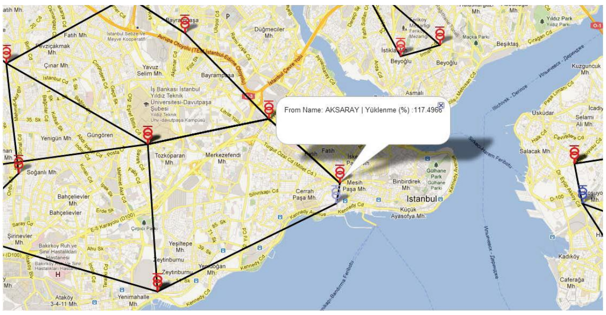

Fig. 11. Geographic Projection of Transformer Loadings

In network bygone-day security category, there are several off-line network analyses. On a monthly basis, network activity reports (consisting of load flow, contingency, short circuit, relative angle, network loss analyses etc.) are generated so that the statistics of medium term network conditions provide convenience for the transmission planning studies.

5. Conclusion

Monitoring the electricity transmission grid is one of the important tasks of the TSOs and the systems facilitating this task enables these operators to take timely and appropriate decisions for seamless grid operation. In this paper, we present a Web-based dispatcher information system which is developed for the Turkish electricity transmission system. The system is being used by more than 2,100 active users and serves the needs of the TSO of Turkey.

One of the important directions of future work is the online integration with the other systems installed on the transmission grid. Thereby, for the transformer substations and plants covered by these latter systems, manual data acquisition will be replaced with automatic acquisition. Other significant directions of future work include in-depth analysis of the accumulated data with diverse algorithms to improve the accuracies and spans of the forecasts currently produced by the system.

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