An Ai-Based Scalable and Integrated Monitoring System for the Electrical Grid

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SUMMARY

Monitoring systems for the electrical grid have diverse benefits from the aspects of system management, planning, and prevention of faults, particularly for national transmission system operators. In this paper, we present a scalable and integrated monitoring system (TEKİS) for Turkish electricity transmission grid, where the system is equipped with AI-based capabilities for event and fault classification. The presented monitoring system encompasses tailor-made modules for real-time and retrospective data monitoring, data analysis, detection, and classification tasks. The system also possesses the capability to act as phasor measurement unit as it calculates and transmits phasor data, complying with the related international standards. As part of future work, the system will be automatically integrated with renewable data forecast systems and will utilize and present renewable forecasts conveniently.

KEYWORDS

Power quality, grid monitoring, smart grid, artificial intelligence, wide area monitoring, phasor measurement unit

1. INTRODUCTION

Effective monitoring of electrical power and power quality (PQ) parameters of the electrical grid is known to be useful for early identification of important problems, planning and preventive maintenance purposes as well as for retrospective analysis of significant incidents in the grid. Therefore, several power quality monitoring systems or wide area monitoring systems have been presented in the related literature [1-6], with different capabilities and using different software/hardware technologies. Some of these systems have been implemented for a subset of power and PQ parameters while some other systems have been applied on electricity distribution systems only.

In this study, we present an integrated large-scale monitoring system that facilitates measurement, storage, online monitoring, retrospective analysis, and automatic reporting of the power and PQ parameters, and PQ events and faults in Turkish electricity transmission grid. This current system is the successor of the nationwide power and PQ monitoring system presented in [2] and includes new modules such as its sag directivity detection and load dispatch modules, and Artificial Intelligence (AI)-based ones such as its event/fault classification module. The current system also encompasses integrated user interface modules implemented using modern Web technologies.

The rest of the paper is organized as follows: a general description of the proposed system is given in the upcoming section, then the modules of the TEKİS system are presented in the following section, next, important future research directions are listed, and finally, the paper is concluded by summarizing the main points.

2. SYSTEM DESCRIPTION

The proposed system is abbreviated as TEKİS from its open form in Turkish which can be translated as TEİAŞ Electric Power Quality and Grid Monitoring System, where TEİAŞ is Turkish Transmission System Operator (TSO). A preliminary description of TEKİS has been previously presented in [7].

TEKİS is a scalable and integrated system that has a modular structure and hence comprises different software modules performing the following system capabilities in an automated manner:

- Online measurement of PQ parameters and detection of PQ events (in compliance with IEC 61000-4-30:2015+A1:2021 PQ standard)
- Online phasor data measurement (in compliance with IEEE/IEC 60255-118-1:2018 phasor data measurement (PMU) standard)
- Classification of the PQ events with respect to their causes using AI-based learning algorithms with high performance rates
- Online detection and presentation of non-standard user-defined power and PQ events
- Collection and storage of the all measurements together with analysis and classification results in centralized databases
- Real-time graph-based and tabular monitoring of continuously-measured PQ parameters, phasors, and raw voltage and current waveforms corresponding to PQ events
- Map-based visualization of phase angles, PQ events, and user-defined alarms detected on the transmission grid
- Retrospective analysis of the collected PQ parameters and PQ events
- Calculation and presentation of PQ event indices (including voltage sag indices in IEEE Std. 1564-2014)
- Detection of sag directivity using different algorithms and settings (including the methods given in [8])
- Detection of the locations of events in the electricity transmission grid
- Automatic generation of PQ reports according to related standards including EN 50160:2010+A3:2019 and EN 61000-2-4:2002
- Visualization of summary PQ information in the form of convenient dashboards
- Data integration facilities from different devices using various related standards and protocols such as Modbus
- Data exporting facilities in various formats such as CSV, PDF, etc., through its user interfaces
- Data integration facilities to import data from and export data to other energy information/management systems through Web services.

With its capabilities listed above, the proposed TEKİS system can be considered as a significant wide-area monitoring system and as a large-scale smart grid application. Besides, this AI-based modular power quality and grid monitoring system is highly scalable since it can be enriched with new capabilities that can be conveniently implemented and integrated into the system.

3. SYSTEM MODULES

The modules of the system can be grouped the following three categories based on their characteristics:

1. Device and communication modules
2. Data storage, processing, and integration modules
3. User interface modules

The modules are hence briefly described in the following subsections corresponding to their category names.

3.1. Device and Communication Modules

First of the modules under this category is an analysis software that performs the actual power, PQ, and phasor measurements, complying with the related standards including IEC 61000-4-30:2015+A1:2021 and IEEE/IEC 60255-118-1:2018, with time synchronization. This module also detects PQ events and saves the raw voltage and current waveforms during these events as COMTRADE files, complying with the related IEEE/IEC Std. C37.111-2013 standard. The analysis software continuously runs on the system's PQ analysis devices installed at the transformer substations of the Turkish electricity transmission grid.

Secondly, communication modules (under this category) continuously run on the PQ devices and the system server in order to transmit the measurements and detected events to the system center. Upon receiving the measurement and event data from the communication module running on the device, the communication module running on the server stores the measurement data on the system's database server and the event files on the system's file server.

3.2. Data Storage, Processing, and Integration Modules

TEKİS has a centralized database (at the system center) that is used to store all of the related measurements including the data from its PQ analysis devices, the data obtained from other PQ devices, and from other energy systems through the data integration modules of the system.

The sag directivity detection module aims to identify the sources of voltage sag events detected and sent to the system servers by the device and communication modules presented in the previous subsection. The module utilizes state-of-the-art techniques and its operation is triggered by the system users through one of the user interface modules, namely, fault analysis and reporting module to be introduced in the next subsection.

Event/fault classification module makes use of different machine learning and deep learning models to identify the root causes of these events/faults. Various machine learning models including SVM, decision trees, random forest, k-nearest neighbors, logistic regression and other modified versions of these models have been tested so far. Hence, this module is based on AI techniques and best performing models after initial experiments will be integrated into this module.

TEKİS also receives relevant information and data from the other energy information and management systems in addition to other PQ devices through its data integration modules. The means of data transfer from these systems and devices are mainly Web services and protocols such as Modbus.

3.3. User Interface Modules

TEKİS has an integrated user interface system that is based on modern Web technologies. The main user interface modules are summarized below and they are made available to the system users based on the user privileges.

1. Real-time trend monitoring module presents power and PQ measurements in addition to the phasor data to the system users as convenient dynamic and synchronized graphs. All of the graphs and tables in this module (and their corresponding data) and those in other modules can be exported in different formats.
2. PQ analysis and reporting module facilitates retrospective analysis of the measurements through its querying interfaces and also encompasses automatic reporting interfaces that produce reports according to related standards such as EN

50160:2010+A3:2019 and EN 61000-2-4:2002. A snapshot of the querying interface of the module is presented in Figure 1. Similarly, a snapshot of the reporting interface of this module is displayed in Figure 2 where an EN 50160-compliant report has been generated.

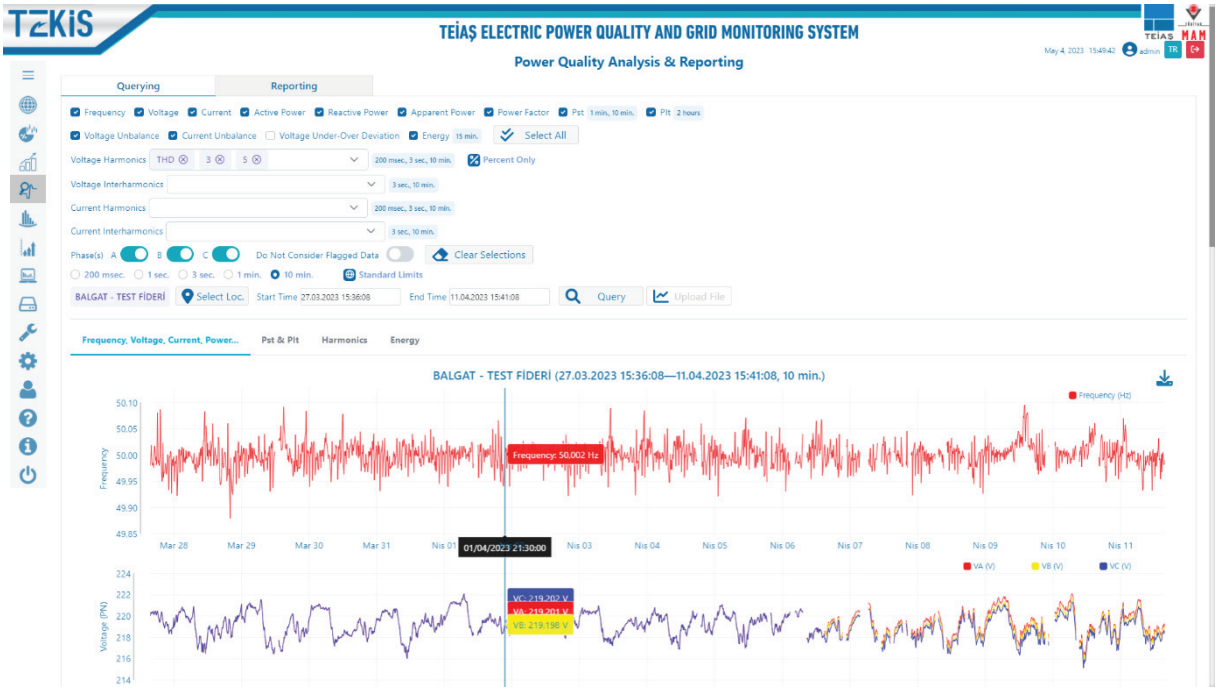

Figure 1. *TEKİS Power Quality Analysis and Reporting Module (Querying Interface)*

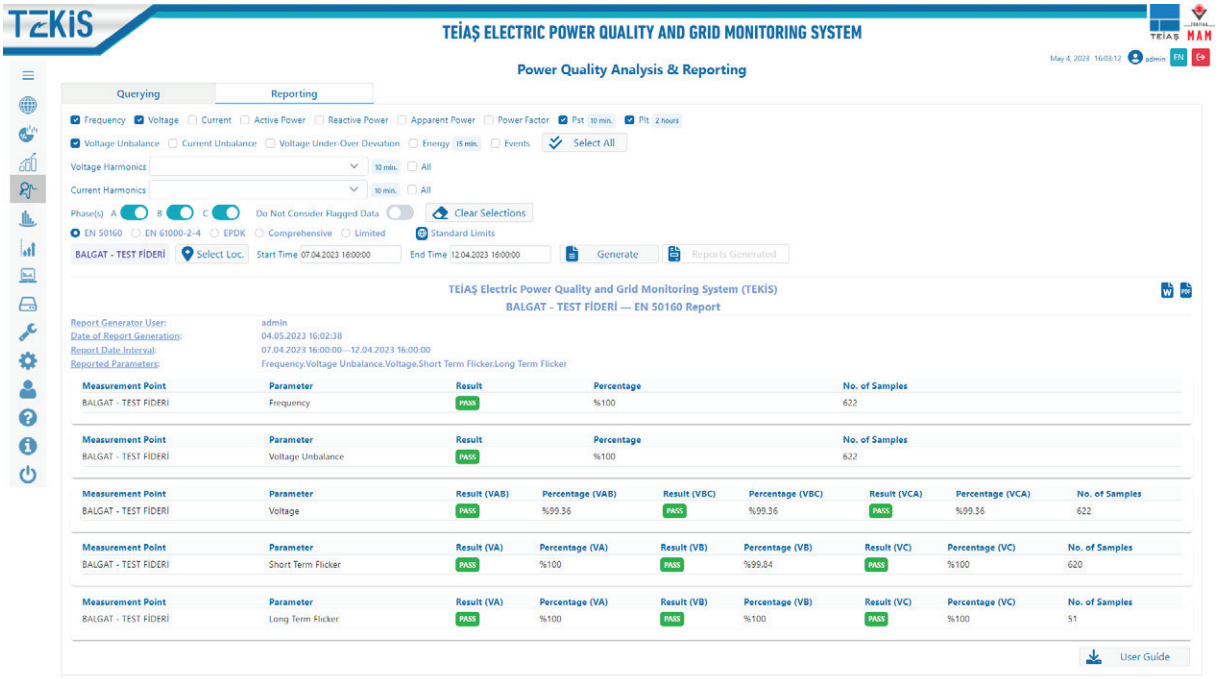

Figure 2. *TEKİS Power Quality Analysis and Reporting Module (Reporting Interface)*

3. Fault analysis and reporting module is used to inspect various PQ events/faults and generate reports based on the event data. The outputs of the aforementioned sag directivity detection and event/fault classification modules are also presented through this user interface module.

4. Map-based monitoring module aims to visualize the collected PQ measurements and events on the map of the Turkish electricity transmission grid.
5. Load dispatcher monitoring module is implemented to present the collected high-resolution phasor data in various convenient forms, to be utilized by the load dispatcher users. A snapshot of this module is given in Figure 3.

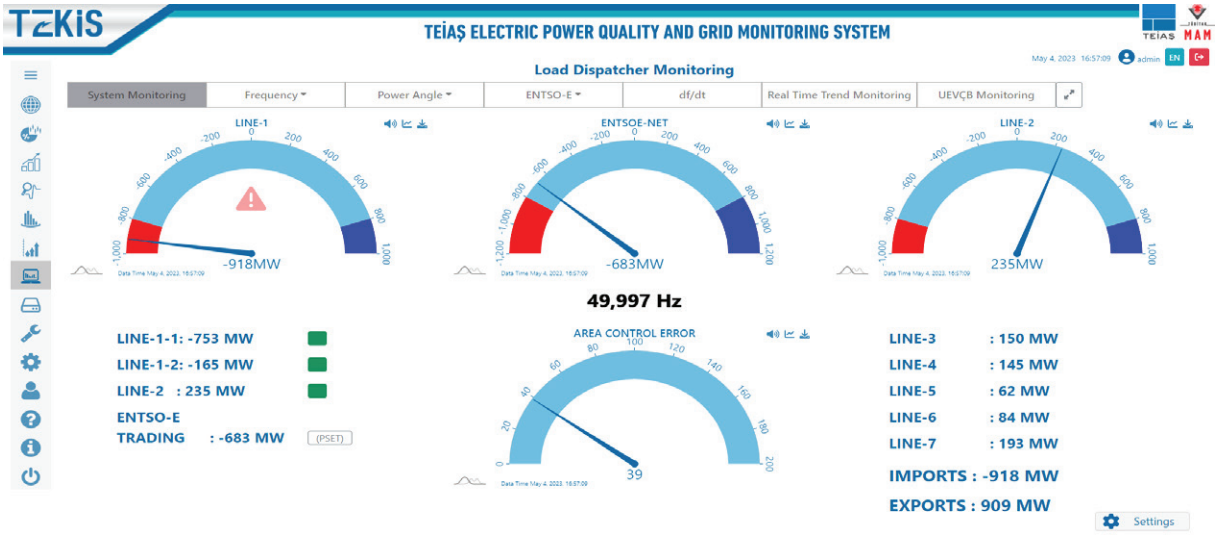

Figure 3. *TEKİS Load Dispatcher Monitoring Module*

6. Device status tracking module aims to the present the connection and other related status data of the PQ devices to the system administrators. A snapshot corresponding to this module is shown in Figure 4.

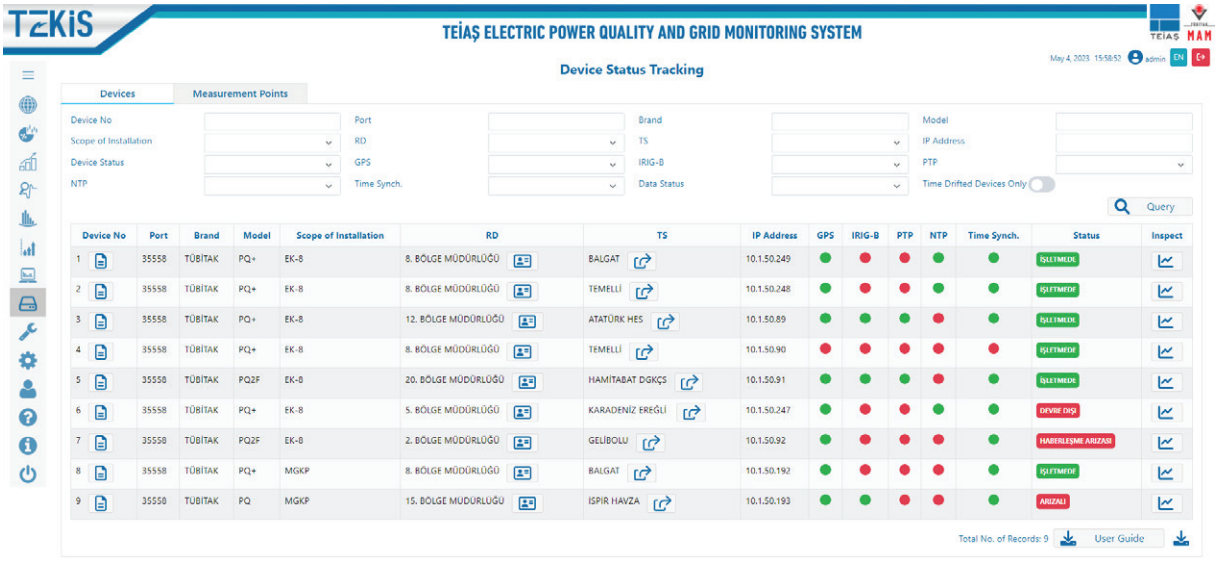

Figure 4. *TEKİS Device Status Tracking Module*

7. Device configuration and calibration module is built in order to carry out the configuration and calibration processes of the PQ devices.

4. FUTURE WORK

As part of future work, new features that can be integrated into the TEKİS system (as new system modules) include the following:

- Detection and storage of inter-area power oscillations together with online monitoring and retrospective analysis interfaces for these oscillations

- Online monitoring of renewable energy forecasts and corresponding generations for different renewable power plants including wind, solar, and hydropower plants.

Particularly considering the second item above, RİTM is a national wind power monitoring and forecast system for wind power plants [9], similarly ATHOM is a national river flow forecast and optimization system for hydropower plants [10], and these two systems can be integrated with TEKİS so that renewable energy forecasts generated by the former two systems can be served to the Turkish TSO through TEKİS system.

5. CONCLUSION

In this paper, TEİAŞ Electric Power Quality and Grid Monitoring System (TEKİS) is presented. TEKİS is scalable and integrated system covering a diverse set of modules and including modules based on artificial intelligence techniques. We present the significant capabilities of the system in addition to the descriptions of its individual modules seamlessly integrated into the system. TEKİS is built in order to monitor Turkish electricity transmission system to be used by TEİAŞ (Turkish transmission system operator). The system has various facilities for real-time and map-based monitoring, retrospective analysis, and automatic reporting of power and PQ parameters of the transmission grid, in addition to modules for sag directivity detection and event/fault classification. An important future work based on the current study is the integration of TEKİS with existing national renewable energy monitoring and forecast systems.

6. ACKNOWLEDGMENT

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