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# **Egyptian Wide Area Monitoring System (EWAMS) Based on Smart Grid System Solution**

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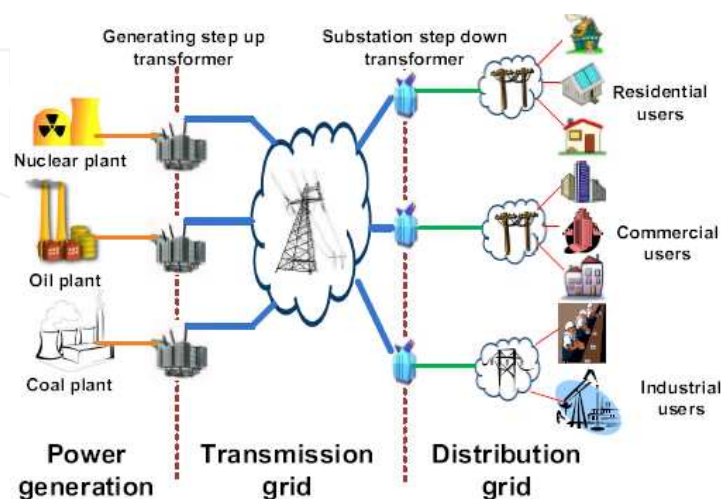
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## **1. Introduction**

Wide-area measurement systems (WAMS) in smart grid can be defined as a system that captures measurements in the power grid over a wide area and across traditional control boundaries, and then uses those measurements to improve grid stability and events through wide-area situational awareness and advanced analysis. Authors have achieved Wide Area Monitoring System (WAMS) based on Frequency Disturbance Recorders (FDRs) as a family of the PMUs deployed on Egyptian Power grid for mapping and visualization of all system parameters. The FDRs are deployed on live 220kV/500kV Egyptian grid system in cooperation with the Egyptian Electricity Transmission Company (EETC). The project is funded from the National Telecommunication Regulatory Authority (NTRA). The Egyptian Wide Area Monitoring System (EWAMS) achieved at the Helwan University can gather information from many FDR units geographically dispersed throughout the boundary of the Egyptian power grid and data manipulated at a data center contains many servers at Helwan University. The Synchrophasor system with wide deployment of using (FDRs) phasor measurement units and high-speed communications to deliver and collect synchronized high-speed grid operating data, along with analytics and other advanced on-line applications will improve real-time situational awareness and decision support tools to enhance system stability. The EWMS is a good environment for many applications that can help the EETC to enhance the Egyptian Grid. This manual Guide explains the remote access for the EWAMS established at Faculty of Engineering through the EETC. The access will be for displaying the FDRs' parameters with different configuration through web service.

The growing global population is driving an even greater increase in the demand for electricity. Added to this, governments around the world are focusing on reducing carbon dioxide (CO<sub>2</sub>) emissions by increasing the utilization of renewable energy sources in the power chain. Today, existing grids are under pressure to deliver the growing demand for power, as well as provide a stable and sustainable supply of electricity. These complex challenges are driving the evolution of smart grid technologies. The greatest future challenge is the integration with the renewable energy resources and controlling of it to reflect the best impact on the massive energy production [1].

Optimal use of ageing assets strategy is as much determined by economic factors as it is by technical issues. Factors such as obsolescence need to be considered when determining future needs. Increasingly companies are turning to risk based assessments to provide a holistic approach. Any Asset Strategy should be implemented and supported by a range of policies covering process safety, maintenance and inspection, renewal, and competence. The smart power transmission networks are conceptually built on the existing electric transmission infrastructure. However, the emergence of new technologies (e.g new materials, electronics, sensing, communication, computing, and signal processing) can help improve the power utilization, power quality, and system security and reliability, thus drive the development of a new framework architecture for transmission networks [2]. The traditional power grid is unidirectional in nature. Electricity is often generated at a few central power plants by electromechanical generators, primarily driven by the force of flowing water or heat engines fueled by chemical combustion or nuclear power. In order to take advantage of the economies of scale, the generating plants are usually quite large and located away from heavily populated areas. The generated electric power is stepped up to a higher voltage for transmission on the transmission grid. The transmission grid moves the power over long distances to substations. Upon arrival at a substation, the power will be stepped down from the transmission level voltage to a distribution level voltage. As the power exits the substation, it enters the distribution grid. Finally, upon arrival at the service location, the power is stepped down again from the distribution voltage to the required service voltage(s) [3]. Fig. 1 shows an example of the traditional power grid [4].



**Figure 1.** Traditional power grid [4].

The future grids can be regarded as an electric system that uses information, two-way, cyber-secure communication technologies, and computational intelligence in an integrated fashion across electricity generation, transmission, substations, distribution and consumption to achieve a system that is clean, safe, secure, reliable, resilient, efficient, and sustainable. This description covers the entire spectrum of the energy system from the generation to the end points of consumption of the electricity [5]-[6]. Fig. 2 shows a typical configuration for the future grid.



Figure 2. Future power grid [7].

The following Table 1 shows a comparison between the traditional and future power grid from different point of view.

Traditional power grid	Future power grid
Electromechanically	Digital
One way power flow	Multi-way power flow
One way communications	Multi-way communications
Few sensors	A lot of IED sensors
Low power quality	High power quality
Limited power flow control	Full power flow control (FACTS)
Manual monitoring	Self-wide area monitoring
Manual restoration	Self-Healing
Failures and blackouts	Adaptive and Islanding
Few consumer choice	Demand side management
No interconnected Renewable resources	Accept Renewable resources

Table 1. Comparison between Traditional and future power grid

## 2. EWAMS architecture

Egyptian Wide Area Monitoring System (EWAMS) is a 3G based wide area sensor network consisting of a special type of high precision family of the phasor measurement units (PMUs) and a central data management and processing system. EWAMS is a smart grid system designed to collect real-time synchronized frequency, voltage, and phase angle measurements at the transmission level 220kV/500kV of the power grid.

The structure of the EWAMS can be classified into five levels. The first level represents the placements of power stations on the power grid in which the sensors are installed. The second level contains the GPS enabled sensors that provide frequency, voltage magnitude, and voltage angle measurements. The third level is the communication infrastructure that provides the integrated wide area communication media for data measurements transmission. The fourth level is the remote data management and processing center that provides data gathering, storage, web service, post-disturbance analysis and other information management functions. The last level is the secure remote access connection for different EETC sectors and other remote clients. The following Figure shows the EWAMS architecture deployed for the Egyptian power grid. In order to discuss the unique characteristics of the EWAMS, the main building blocks of the EWAMS are discussed in more details in the following subsections.

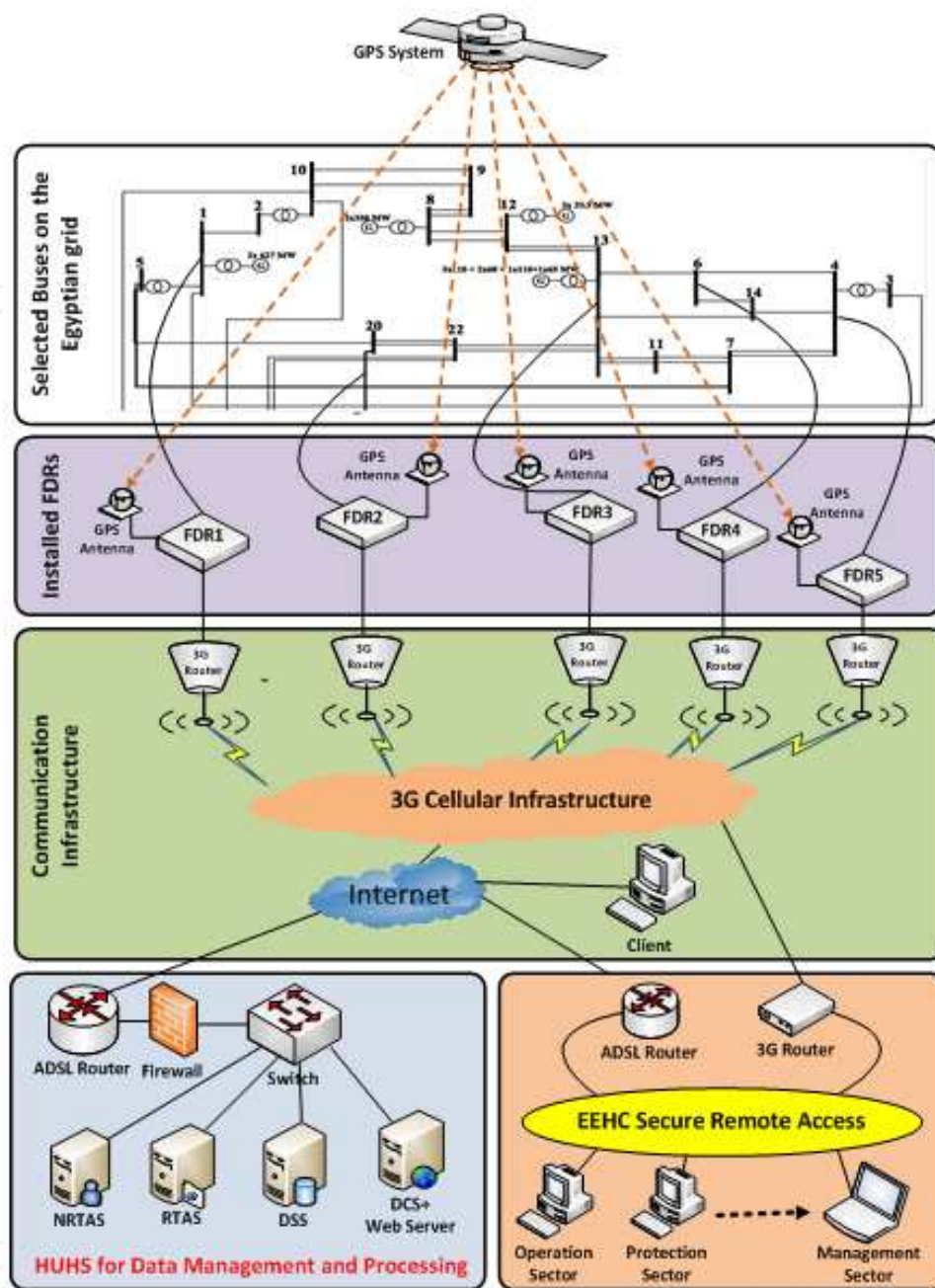
The TCP and IP headers have numerous fields that are used to support the intended TCP and IP functionality as shown in Figure 6(a). In the proposed wide area measurement system, IP is used for delivering the different measurements collected by FDRs distributed over a wide area to the correct Data Concentrator Server (DCS) located at DMS while TCP is used to provide a reliable communication channels between FDR devices and the DCS.

The TCP connection between each FDR and the DCS is established through a three-way handshake process, ensuring that both FDR and DCS have an unambiguous understanding of the sequence number space. The operation of the connection is as follows:

- a. The FDR sends the DCS an initial sequence number to the predefined destination port, using a SYN packet.
- b. The DCS responds with an ACK of the initial sequence number and the initial sequence number of the FDR in a response SYN packet.
- c. The FDR responds with an ACK of this DCS sequence number.
- d. The connection is opened.

The operation of this algorithm is shown in following Figure. The performance implication of this protocol exchange is that it takes one and a half round-trip times (RTTs) for each FDR and DCS to synchronize state before any data can be sent. After the connection has been established, the TCP protocol manages the reliable exchange of data between FDRs and DCS. The existing UMTS mobile communication infrastructure is used to provide Internet access connection for FDRs. High speed packet access (HSPA) USB modems connected to 3G routers are used to provide the Internet access connection. Client server model is used to provide the communi-



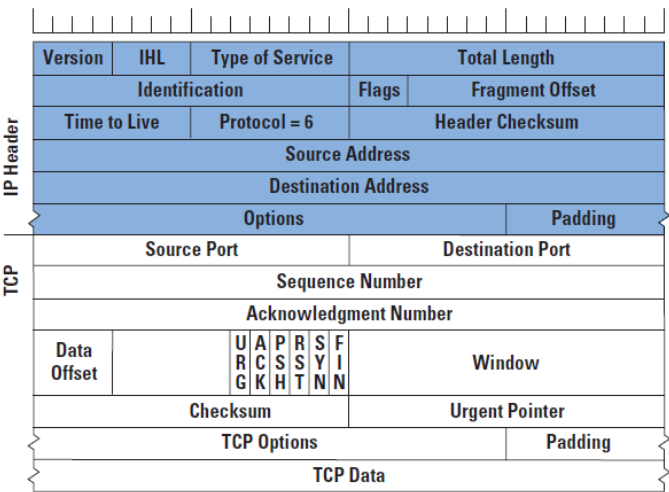


Scheme 1. EWAMS Architecture.

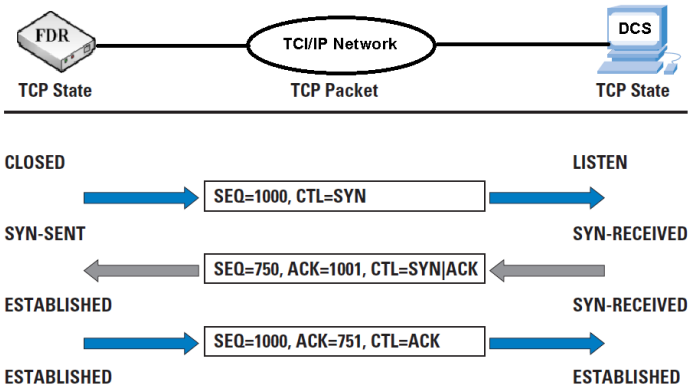
cation between FDRs devices and DCS server. Each FDR device is act as a client and requesting to make a connection with the DCS server. The measurements data is transmitted from FDRs devices to the DCS server using a standard network protocols, Transmission Control Protocol (TCP)/Internet Protocol (IP).

#### a. EWAMS Sensors (FDRs)

In EWAMS, the FDR is especially designed and implemented to have two power inputs. The first one is the single phase voltage (57.73VAC) which is taken from the 220/500 kV voltage



Scheme 2. The TCP/IP Datagram.



Scheme 3. TCP Connection establishment between FDR and DCS.

transformer output in each power station and is used for estimating the three required parameters (frequency, voltage magnitude, and voltage angle). The other input is 220 VAC from power outlet which is used to supply the FDR device with the required power for its electronic circuit operation.

**b. Communication Infrastructure for EWAMS**

In EWAMS, FDR devices are distributed over a wide area, covering various locations within the boundary of the power system. The FDR devices are then connected to the remote data center through communication network. Public telecommunication infrastructure (Internet) will be used to provide the communication channels between FDRs and the data concentrator server (DCS) in the data center. The Data Concentrator Server (DCS) located at the Egyptian Wide Area Monitoring System "EWAMS" hosted at Helwan University. Transmission Control Protocol/Internet Protocol (TCP/IP) is used in building the system. The TCP connection between each FDR and the DSC is established through a three-way handshake process, ensuring that both FDR and DSC have an unambiguous understanding of the sequence

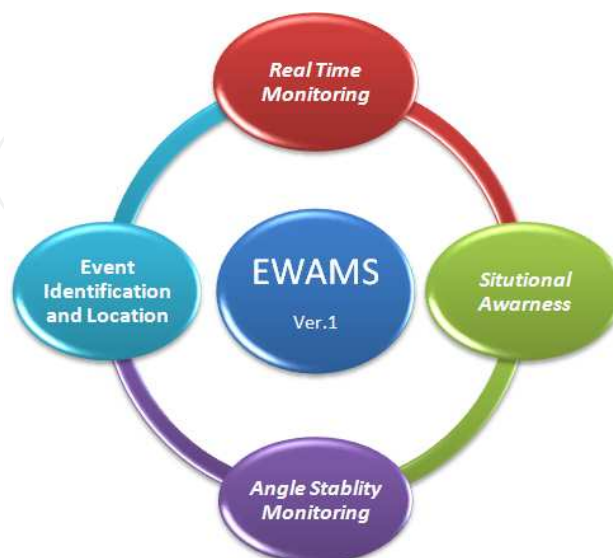
number space. The FDR sends the DSC an initial sequence number to the predefined destination port, using a SYN packet. The FDRs transmits their measurements over the Internet to the DCS using the standard Internet Protocol suite TCP/IP. Since, the Internet Protocol doesn't guarantee any quality of service which it provides best effort delivery for data packets. The missed data at the DCS is expected as a result of a number of factors including packet drop due to network congestion, buffer overflow at the FDR or DCS, and corrupted packets rejected in-transit or faulty networking hardware.

### 3. Helwan University Host Servers (HUHS)

The HUHS is data management and processing center operated by several dedicated servers. The logic behind decomposing the HUHS to several numbers of servers is to distribute the computation power which had the advantage of increasing the systems redundancy and reliability. The HUHS consists of four servers connected together through local area Network (LAN). HUHS can divided in terms of functionality to four servers, the data concentrator server (DCS), the real-time application server (RTAS), the Non-Real-time application server (NRTAS), the web server, and the data storage server (DSS). The main functions of each server are described below.

### 4. EWAMS capabilities

EWAMS includes many applications in real time mode. The system includes real time situational awareness in different mode for displaying different parameters. The EWAMS system includes also many vital applications. The different software EWAMS capabilities are summarized in four main applications, see Figure 3.



**Figure 3.** The four different applications in the EWAMS.



#### **a. Real Time Monitoring**

In this application, the system introduces the features of the real time monitoring. In this step, the EWAMS system displays many measurements as trends. All measurements are synchronized at same time using GPS timing system.

#### **b. Real Time Situational Awareness**

In this application, the system introduces the features of the real time situational awareness. The situational awareness application will display many measurements in color mapping way on the Single Line Diagram of the Egyptian power grid that help the operator in taking decisions in real time in case of situational awareness issued from one screen.

#### **c. Real Time Stability Monitoring**

The most effect way to predict the grid operating state is “the real time angle stability monitoring”. In this application, the angles of the monitored buses reflect the state of the areas of the angles on the Egyptian grid to indicate any alerts during the angle divergence. This application will give the operator complete image about the state of the system to take fast actions.

#### **d. Event Identification**

The EWAMS system has the ability to detect events and define its type either generator tripping or load shedding. It also estimates the mismatch power amount that rejected from the grid and defines the area of the event. The measurements during this event could be visualized at any time and date for current event or any another historical events. This study partially completed and under construction now for remote access.

#### **e. Historical Data**

One feature of the EWAMS system is the possibility to access at any time and date for getting historical data. This data facility introduces transient analysis for any historical events on the grid, planning for future work on the grid through parameters monitoring, forecasting analysis, etc. This features as a remote access is under the construction but it is available on the EWAMS.

### **4.1. Main Features of the Real time monitoring and situational awareness**

- The frequency mapping will define the islanded areas and how it effects on the rest of the grid.
- The angle mapping will define the oscillated areas and also shows the weakness area on the grid.
- The voltage mapping will define the most loaded area to help in load shedding selection criteria.

## 4.2. Procedures Steps for EWAMS Accessing

This part explains in more details an explanation for the operator about the possibility of EWAMS access.

In the welcome page the user will first go to the main menu through the following page

1. Open your internet browser using Internet Explorer, Chrome or Firefox...etc.
2. Enter the main webpage has following Internet Link in the browser
3. Write the Username and Password in space fields.
4. Press Login Button and then the program webpage is displayed

Figure 4 shows the main menu.

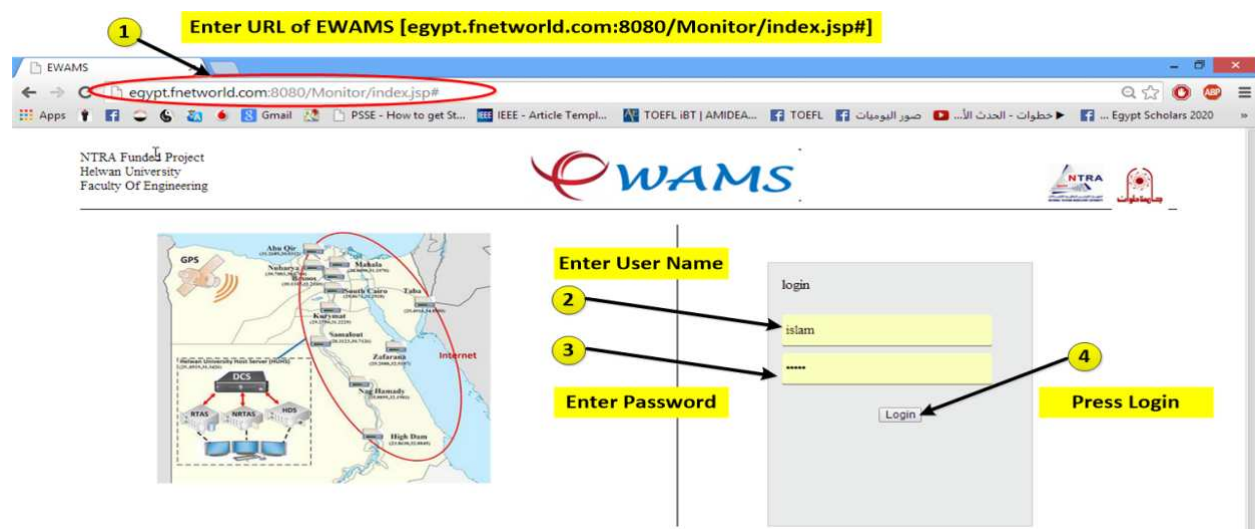


Figure 4. Main menu.

### a. Accessing the “MAIN MENU” of the EWAMS

After logging in, the system will go to the monitoring menu. Figure 5 shows the EWAMS software system. As shown in the figure the menu contains:

Vertical Menu that contains:

- Trends
- Maps
- SLD
- Applications

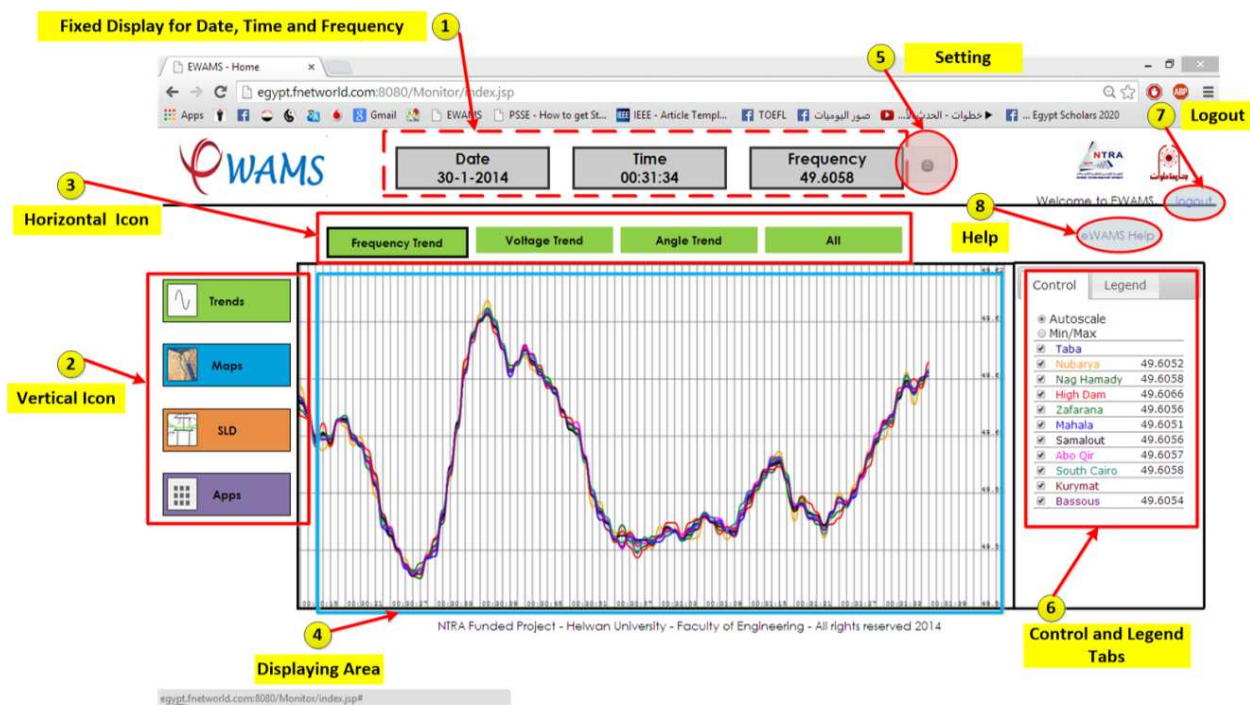


Figure 5. The main menu of the EWAMS system.

**Trends:** are used for displaying the frequency, voltage, phase angles and all trends of the system in trends mode.

**Maps:** are used to display the mapping of the system parameters on the Egyptian map in MAP MODE

**SLD:** is used to display the system parameters on a single line diagram of the Egyptian grid

**Applications:** are used for displaying the “real time stability monitoring”.

Figure 5 shows the horizontal menu. This menu appears based on the vertical menu.

Figure 5 shows also the three displaying menu for the Date, Time and Frequency of the HIGH dam that taken as the reference for the system.

In Figure 5, the right hand side of the main menu there are two tabs; “control” and “legend”. The control tab displays a list of the FDR stations, and the corresponding frequency readings. There is the option to select the FDR stations and their readings. Also, there is a tab with “legend” that displays the color bar ranges of the frequency or angle. This tab will appear only in the “SLD” and “MAPs” on the vertical menu. Figure 5 shows also the “setting icon” that uses for selecting the reference frequency for displaying it on the vertical icons. It also used for determine the max and min frequency thresholds.

### b. Accessing “TRENDS”

This part will deal with “real time monitoring”. Figure 6 shows the EWAMS system, when the operator wants to access the “Trends”, he just clicks on the “Trends” icon”. After clicking, a

horizontal menu will be appeared that displays four icons “Frequency Trends”, “Voltage Trends”, “Angle Trends”, and “All”. Every icon will display the trends of the parameters located. Figure 6 shows also the frequency trends that will come from “Frequency Trends” icon in the horizontal mode.

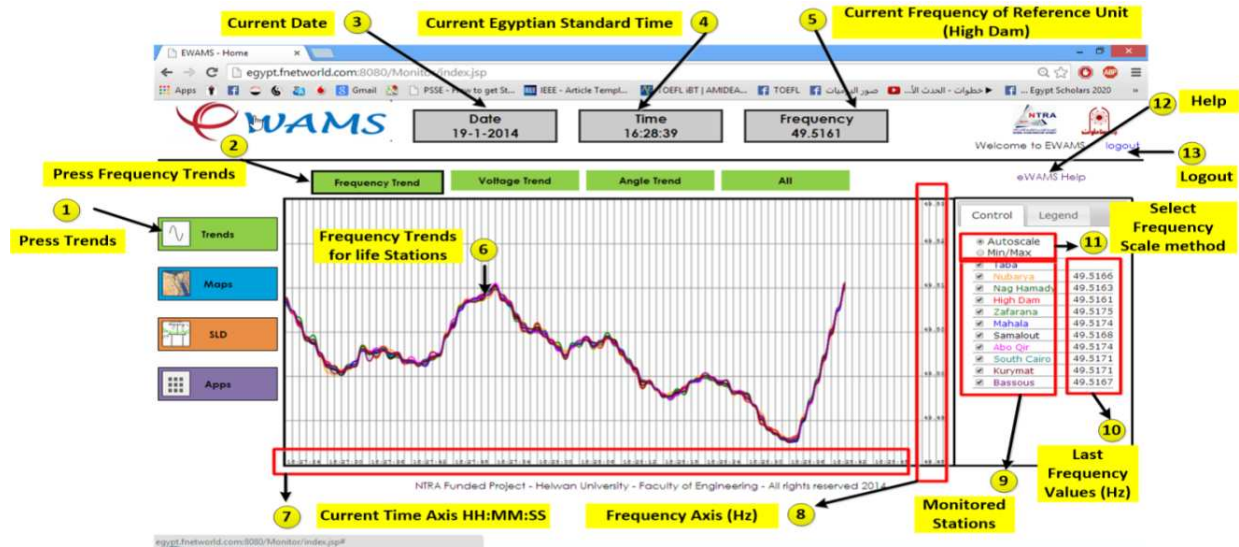


Figure 6. Accessing trends through EWAMS.

Figure 7 shows the voltage trends, which will come after clicking the “Voltage Trend” in the horizontal menu. Figure 8 shows the angle trends that come from the clicking on the “Voltage Trends” in the horizontal menu. Figure 9 shows the all trends that come by pressing on “all” tab.

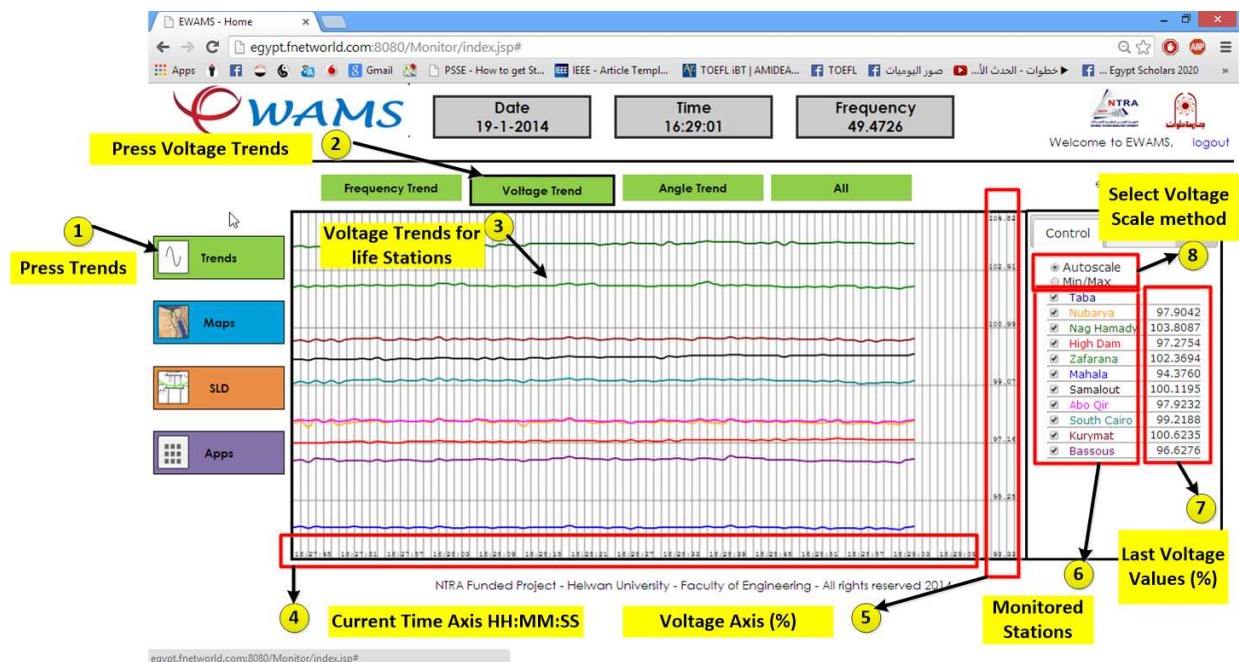


Figure 7. The voltage trends.



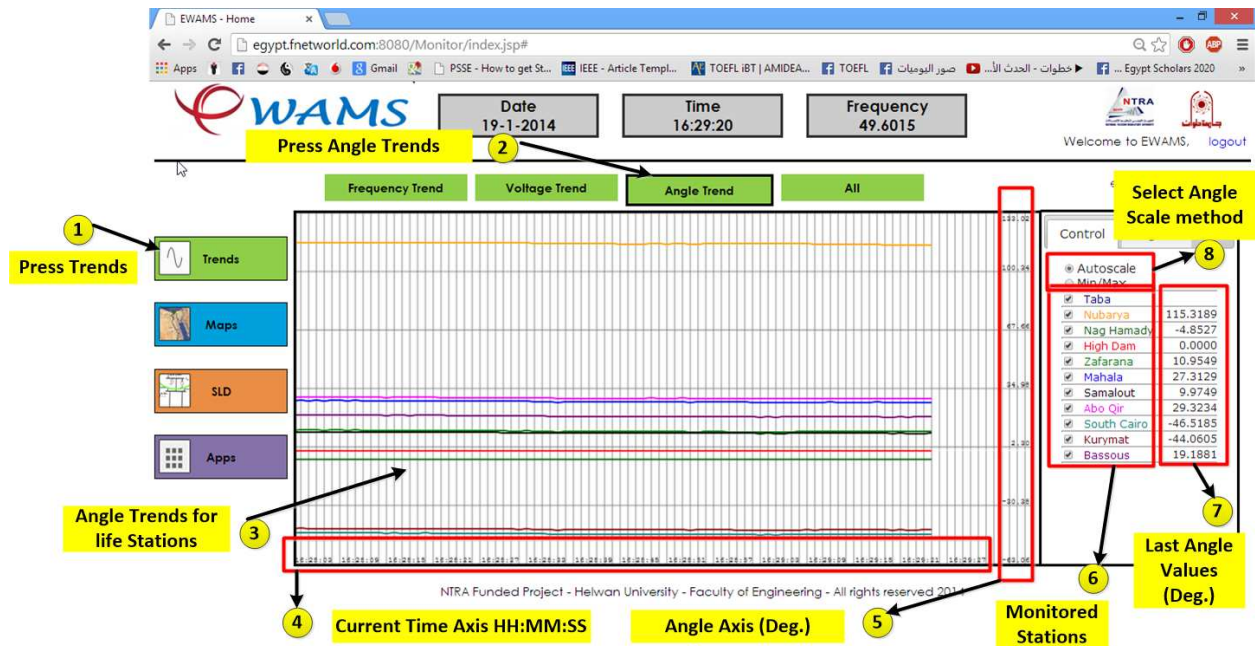


Figure 8. The voltage trends.

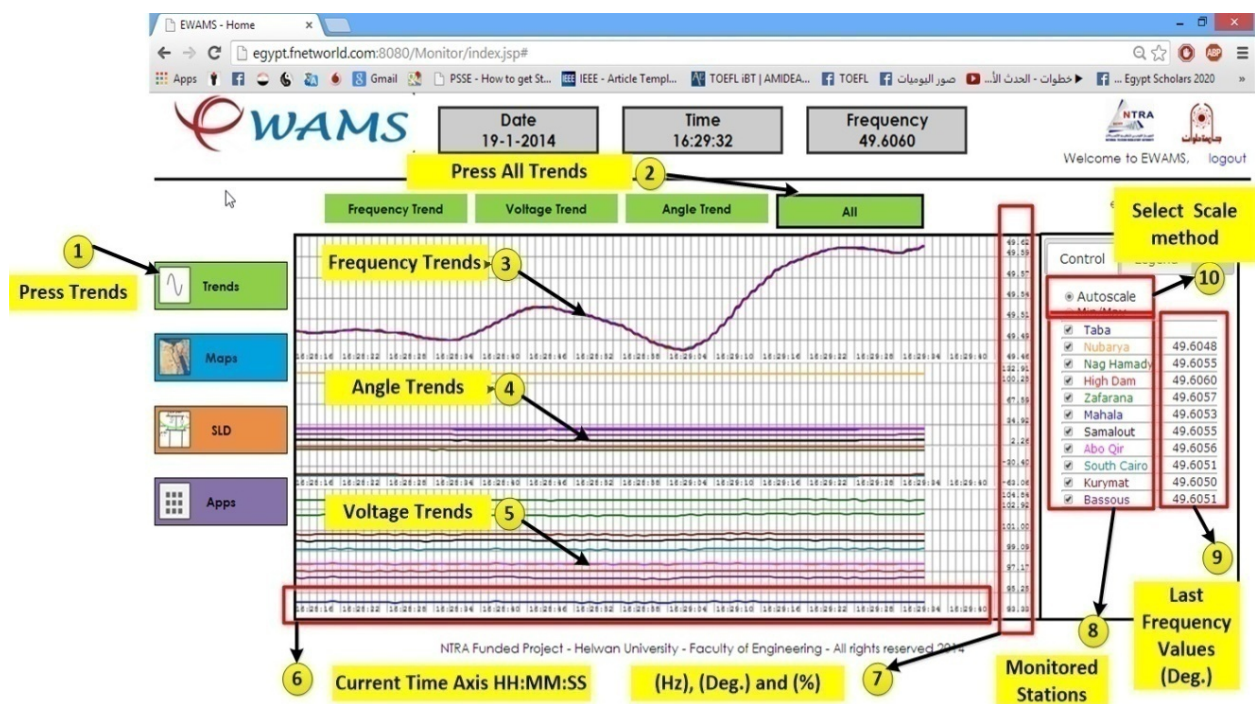


Figure 9. All trends.

Figure 8 shows the right hand list of the control icon. In this list all FDR with their values will be appeared. There is the option to select the displayed FDR stations.



Control	
Legend	
<input type="radio"/> Autoscale	
<input type="radio"/> Min/Max	
<input checked="" type="checkbox"/> Taba	
<input checked="" type="checkbox"/> Nubarya	49.9991
<input checked="" type="checkbox"/> Nag Hamady	49.9992
<input checked="" type="checkbox"/> High Dam	49.9990
<input checked="" type="checkbox"/> Zafarana	50.0003
<input checked="" type="checkbox"/> Mahala	49.9995
<input checked="" type="checkbox"/> Samalout	49.9996
<input checked="" type="checkbox"/> Abo Qir	50.0019
<input checked="" type="checkbox"/> South Cairo	49.9999
<input checked="" type="checkbox"/> Kurymat	
<input checked="" type="checkbox"/> Bassous	49.9992

Figure 10. Control legend.

### c. Accessing "MAPS"

This part will deal with "Real Time Awareness". In this tab the frequency, angle and voltage will be displayed on a Map. To access this application the user must follow these steps:

To display Situational awareness by frequency, press "Maps" Tab, then press "Frequency Map" Tab given on the horizontal bar. Figure 13 shows the "Maps" and "Frequency map" for the frequency displaying. And so on for the "Voltage Map" and "Angle Map". On the right hand side a color code for the frequency readings that corresponding FDRs.

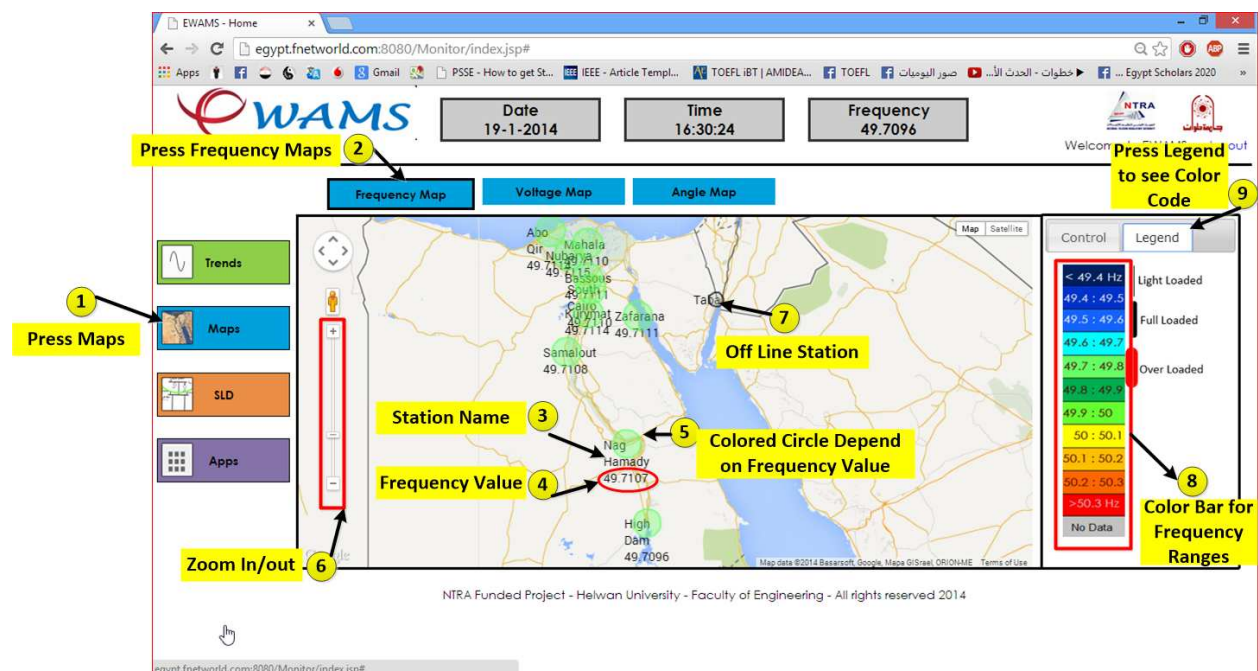


Figure 11. MAPS menu for the frequency displaying.

The FDR data can be used to enhance grid reliability for both real-time operations and offline planning applications [11]-[14], as listed below; the benefits of achieving such system will assist in:

- Wide-area situational awareness
- Real-time operations applications
- Frequency stability monitoring and trending
- Power oscillation monitoring
- Voltage monitoring and trending
- Alarming and setting system operating limits, event detection and avoidance
- Resource integration
- State estimation
- Dynamic line ratings and congestion management
- Outage restoration
- Operations planning

## 5. Conclusion

Wide Area Monitoring System on real 220kV/500kV Egyptian grid is achieved in cooperation with the Egyptian Electricity Holding Company in installing the devices. The EWAMS concerns the pioneers in the field of the smart grid wide area monitoring system. This system is a part of Smart grid system through transmission levels. On-line monitoring for different parameters is achieved. Many of new applications such as EWAMS Mapping and Visualization, Real time event detection and identification, Angle stability monitoring are applied based on remote access at the EETC. The system can satisfy many of the features for the Egyptian grid as Improved power system operation, Better use of existing equipment, Increased power transmission capacity, Lowered risks of power system instabilities, Improved power system planning, Less outage power and time, capability of integration renewable recourses, analysis and investigating many post-events.

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