



# Smart Grid Frequency Monitoring Architecture and Applications



**Speaker: Prof. M. M. Eissa**

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Smart Energy Grid Engineering (SEGE'13)  
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UOIT, Oshawa, Canada"**



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**Project PI, Helwan University**



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**IT Team Leader, Helwan**  
**University**





# Project Team

## Faculty of Engineering at Helwan Project Team



**Principle Investigator**  
**Prof. Moustafa M Eissa**



**Egyptian Electricity  
Holding Company  
(End User)**

### Project Board



**Team Leader  
Power System  
Prof. W.M. Fayek**



**Senior Team Leader  
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Prof. H. Gabar**



**Team Leader  
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**Project Coordinator  
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PHD Researcher**

#### Power System Team



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PHD Researcher**



**Eng. Hadeer  
MSc Researcher**

#### Communication Team



# *Summary*





# Tutorial Outlines

**1- Wide Area Monitoring System (WAMS)**

**2- Egyptian Wide Area Monitoring System (EWAMS)**

**3- EWAMS Architecture**

**3-1 EWAMS layout**

**3-2 FDR Deployment for EWAMS**

**3-3 FDR design for EWAMS**

**3-4 Communication Infrastructure for EWAMS**

**3-5 HUHS Data management and Analysis**

**4- EWAMS (device installation and software)**

**4-1 FDRs setup in power station**

**4-2 Network configuration for FDRs devices**

**4-3 Snapshots for FDR and Router installation process**


**4-4 EWAMS Software Installation**

**4-5 Logical structure of Egyptian WAMS**

**5- EWAMS Applications**



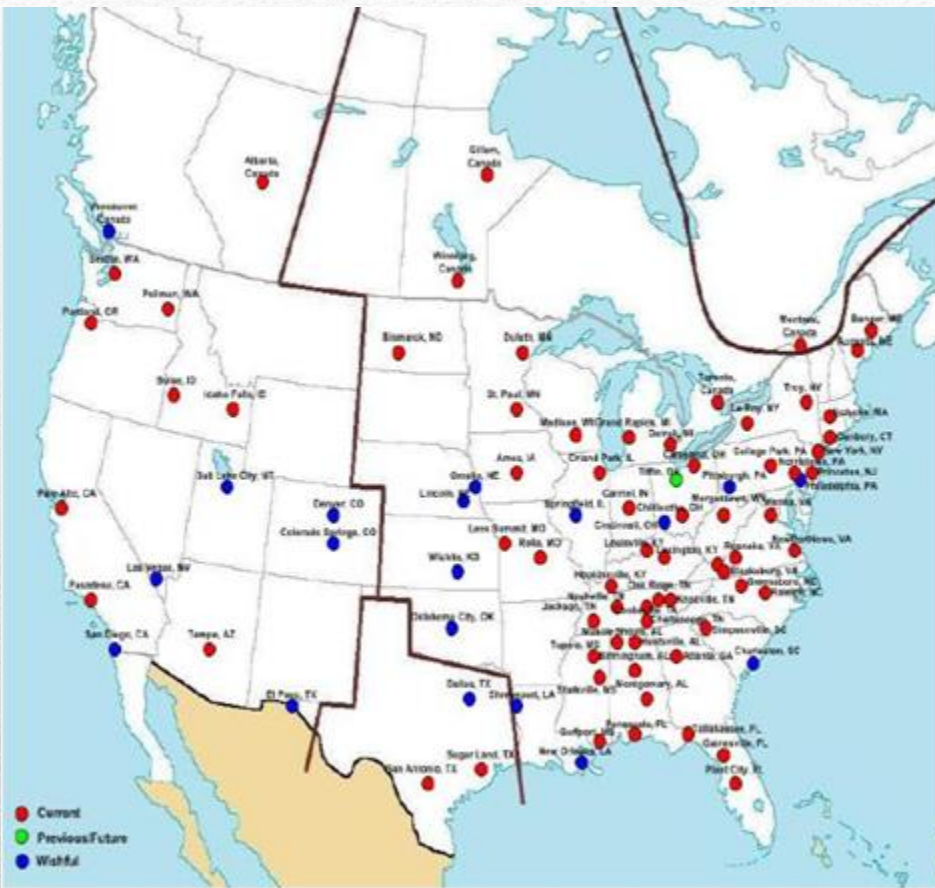
# 1-Wide Area Monitoring System (WAMS)

- ❑ Wide Area Monitoring System (WAMS) is an integral part of power system operation today.
  - ❑ WAMS Utilizing synchrophasor measurements enable the monitoring of power systems and provide critical information for understanding, forecasting, or even controlling the status of power grid stability in real-time.
- 
- ❑ In recent years, more and more WAMSs have been built around the world to meet the growing needs for all kinds of system-stability-related applications.
  - ❑ A wide-area Frequency Monitoring Network (FNET) utilizing a family of PMU called FDR was developed by Virginia Tech in North America.

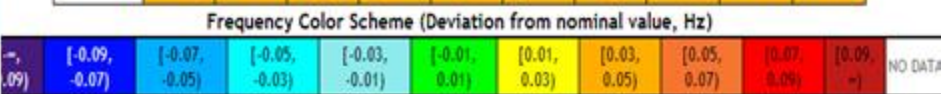


# Wide Area Monitoring System (WAMS)

More than 80 FDRs are installed in the United States and about 40 installed worldwide.



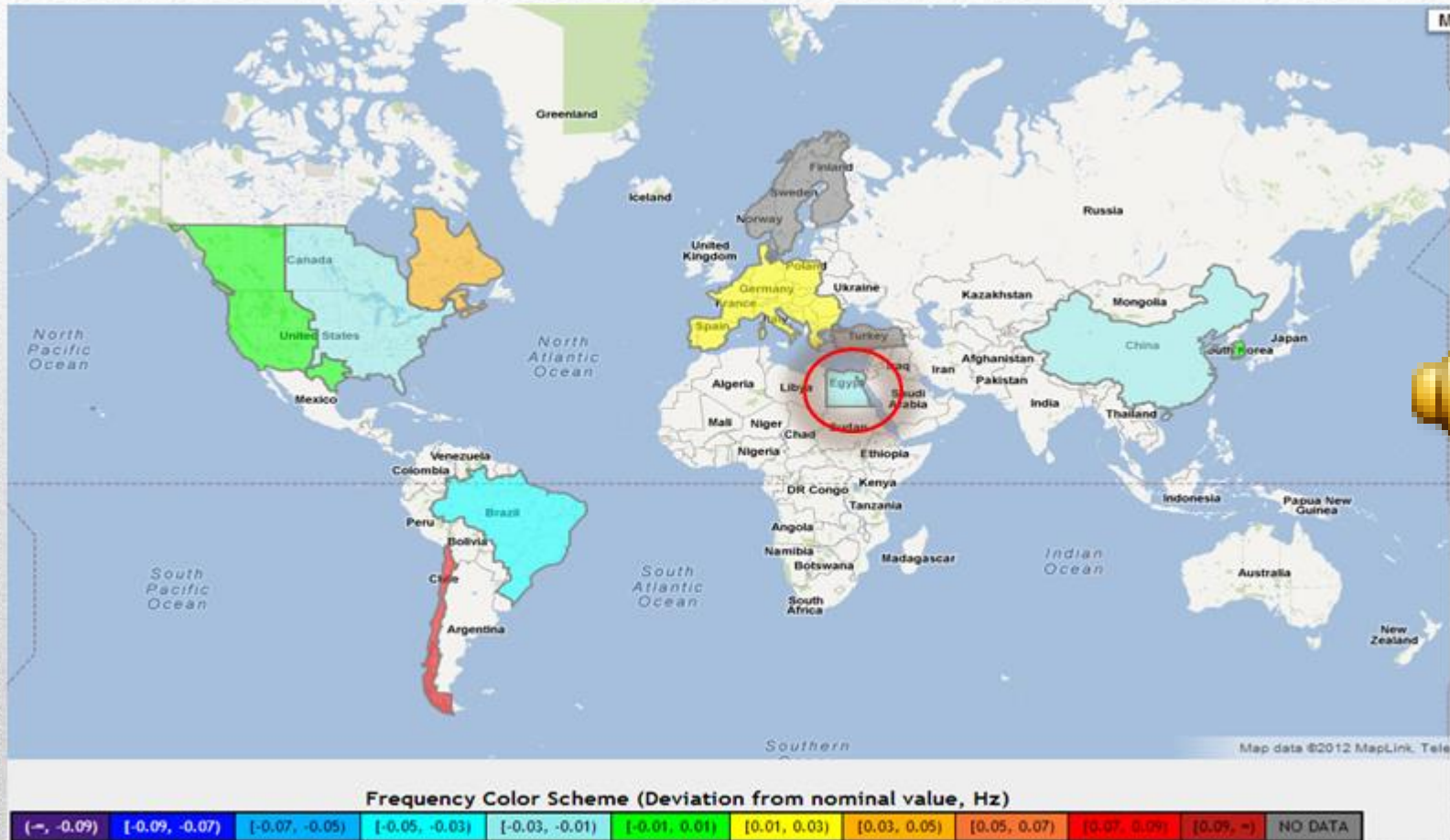
Big Island, Hawaii										
UTC Time	22:14:57	22:14:53	22:14:49	22:14:45	22:14:41	22:14:37	22:14:33	22:14:29	22:14:25	22:14:21
Unit #711	59.9894	59.9954	59.9949	59.9912	59.9944	59.9900	59.9924	59.9983	59.9870	59.9883
Oahu, Hawaii										
Unit #699	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Unit #700	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Grand Bahama										
Unit #1026	60.0654	60.0680	60.0441	60.0165	60.0172	60.0386	60.1180	60.0778	60.1250	60.1391
Brazil										
Unit #802	59.9901	59.9794	59.9692	59.9657	59.9640	59.9647	59.9667	59.9769	59.9813	59.9758
Japan - West										
Unit #1091	59.9518	No Data	No Data	59.9495	59.9492	No Data	No Data	59.9617	No Data	No Data
Quebec Interconnection										
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Unit #870	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Unit #917	60.0073	60.0184	60.0264	60.0232	60.0110	60.0016	59.9963	59.9862	59.9882	59.9932
South Korea										
Unit #927	60.0422	60.0433	60.0340	60.0356	60.0433	60.0488	60.0408	60.0435	60.0438	60.0423





# Wide Area Monitoring System (WAMS)

- Egypt is one of the recognized nations in the WAMS world





## 2- Egyptian Wide Area Monitoring System (EWAMS)

EWAMS was constructed through our project “Smart Grid Frequency Monitoring Network Architecture and Applications” by installing 10 FDRs in various power stations in Egyptian Electric power grid.



❑ EWAMS is an Internet based wide area monitoring system that is constructed using 10 FDRs connected to the VT output in 10 power stations distributed over the Egyptian power grid. 

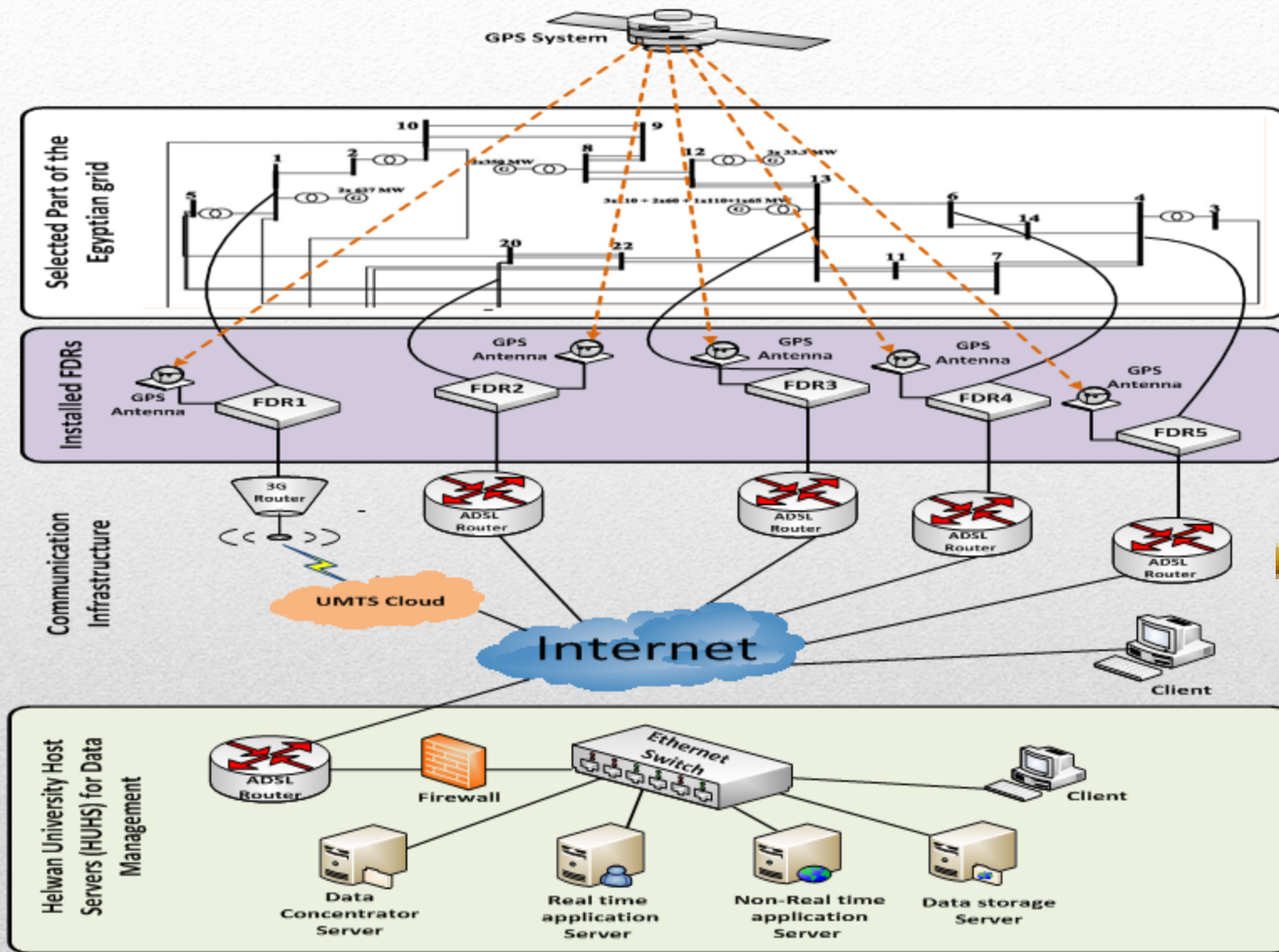
❑ EWAFMS is a power grid situational awareness tool that collects real-time, Global Positioning System (GPS) time-stamped measurements with high precision at the transmission level.

❑ EWAMS made the synchronized frequency, voltage angle, and voltage magnitude observation of the entire Egyptian power grid possible with reasonable cost for the first time.

❑ The following figure shows the developed Internet-based WAMS architecture for the Egyptian power grid.



# 3- EWAMS Architecture



## 3-1 EWAMS layout



The developed EWAMS architecture consists of **four** main parts:



**The Selected Power Stations from the Egyptian Electrical Grid for FDR deployment**



**The Frequency Disturbance Recorders (FDRs)**



**The Communication Infrastructure (Internet)**

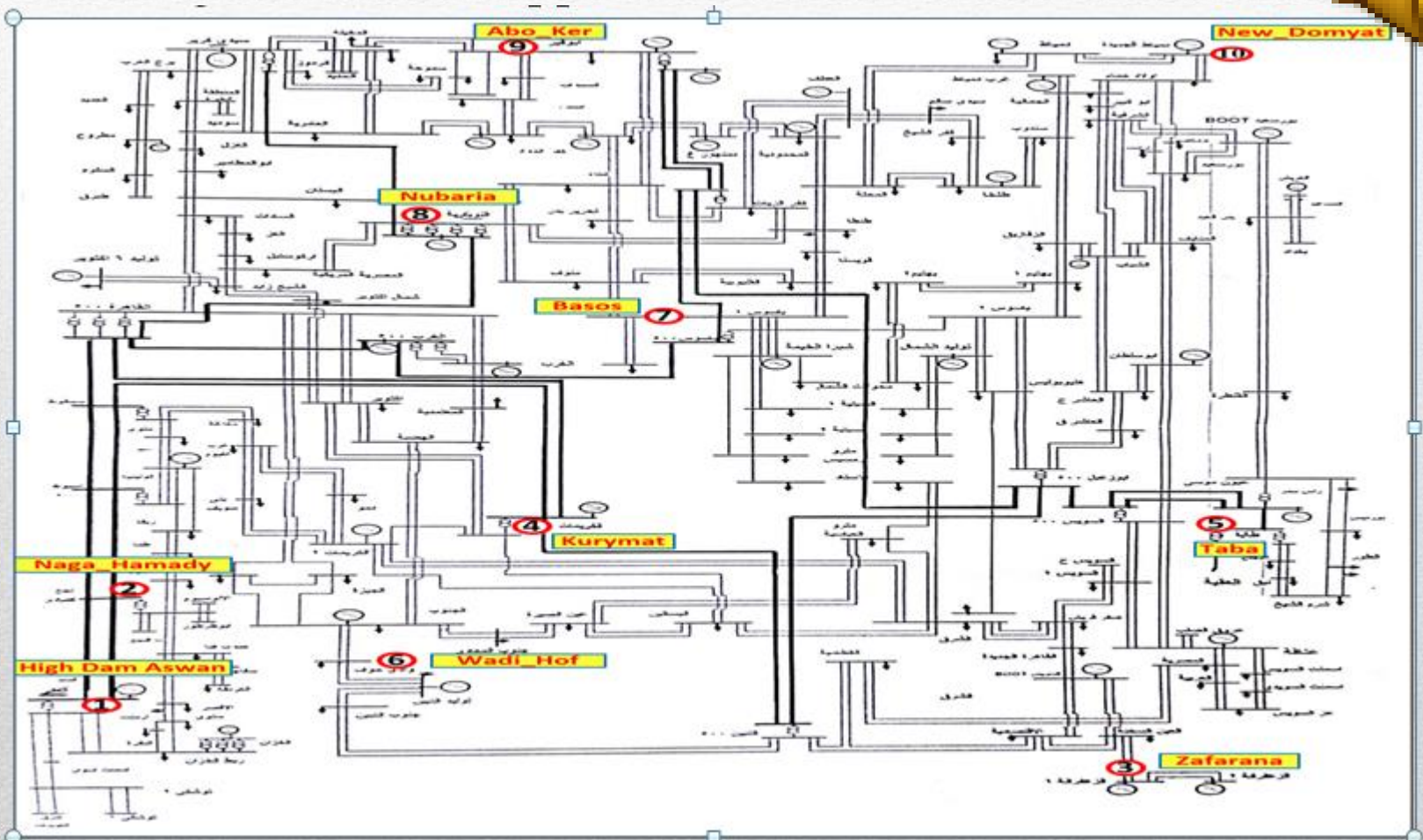


**Helwan University Host Servers (HUHS) for Data Management and Analysis**

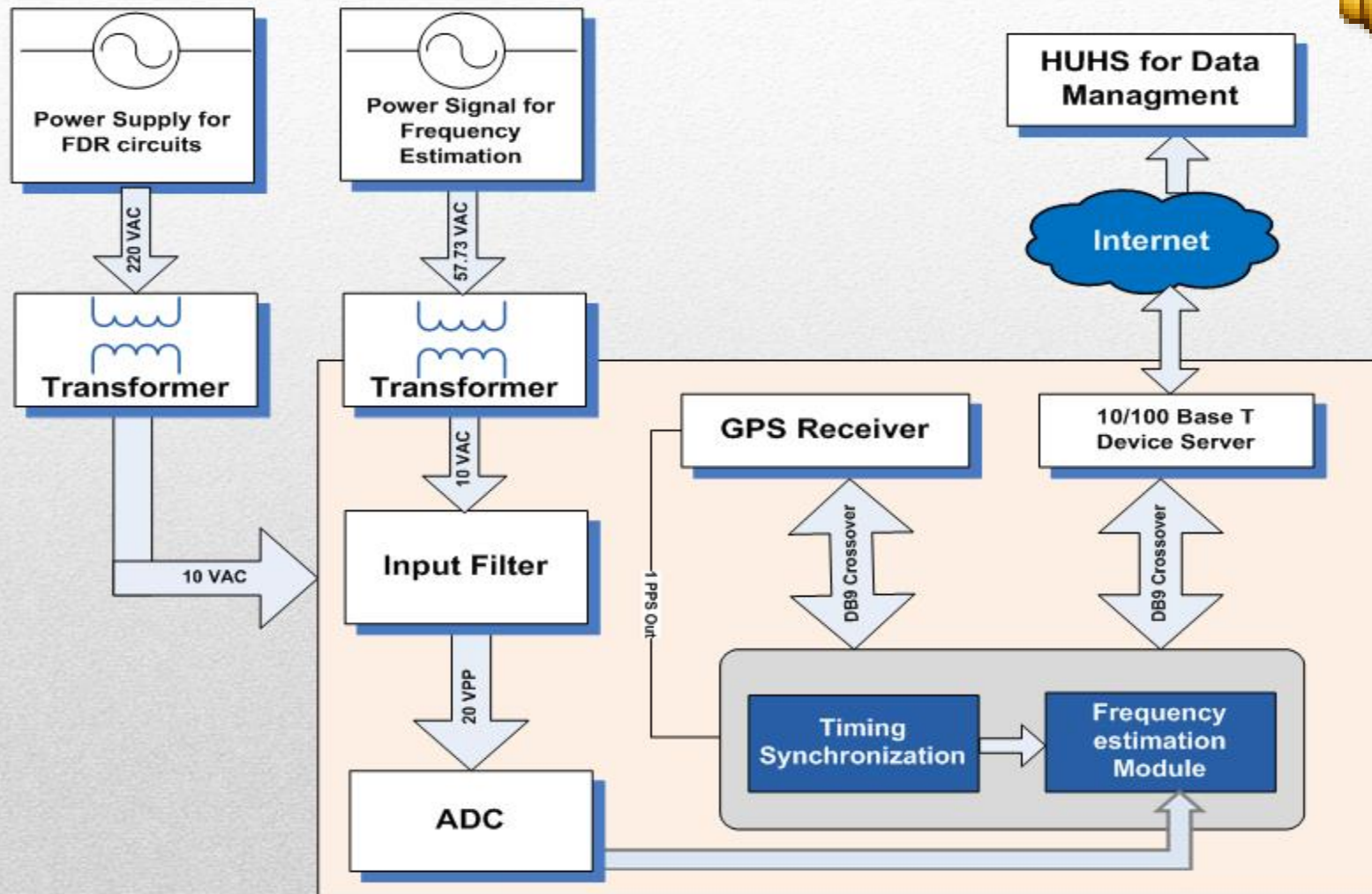


## 3-2 FDR Deployment for EWAMS

□ The locations of the 10 FDRs are decided to provide full observability of the Egyptian electric power grid for different monitoring and control applications.



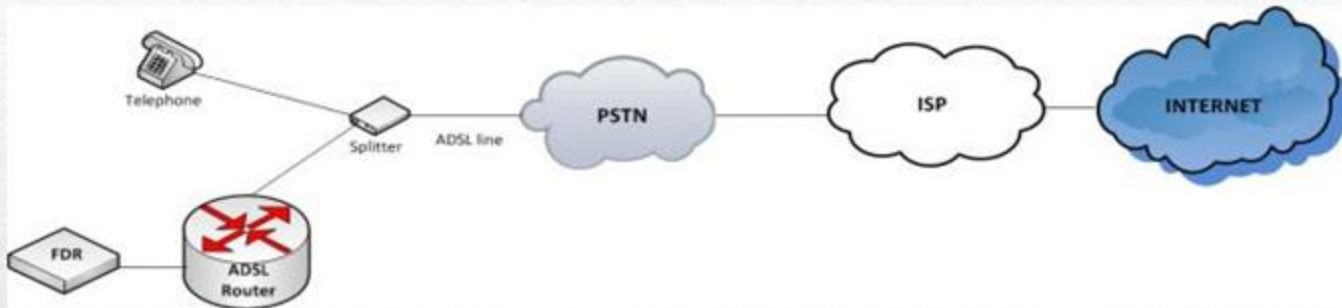
## Special design for Egyptian power grid





## Communication Infrastructure (Internet)

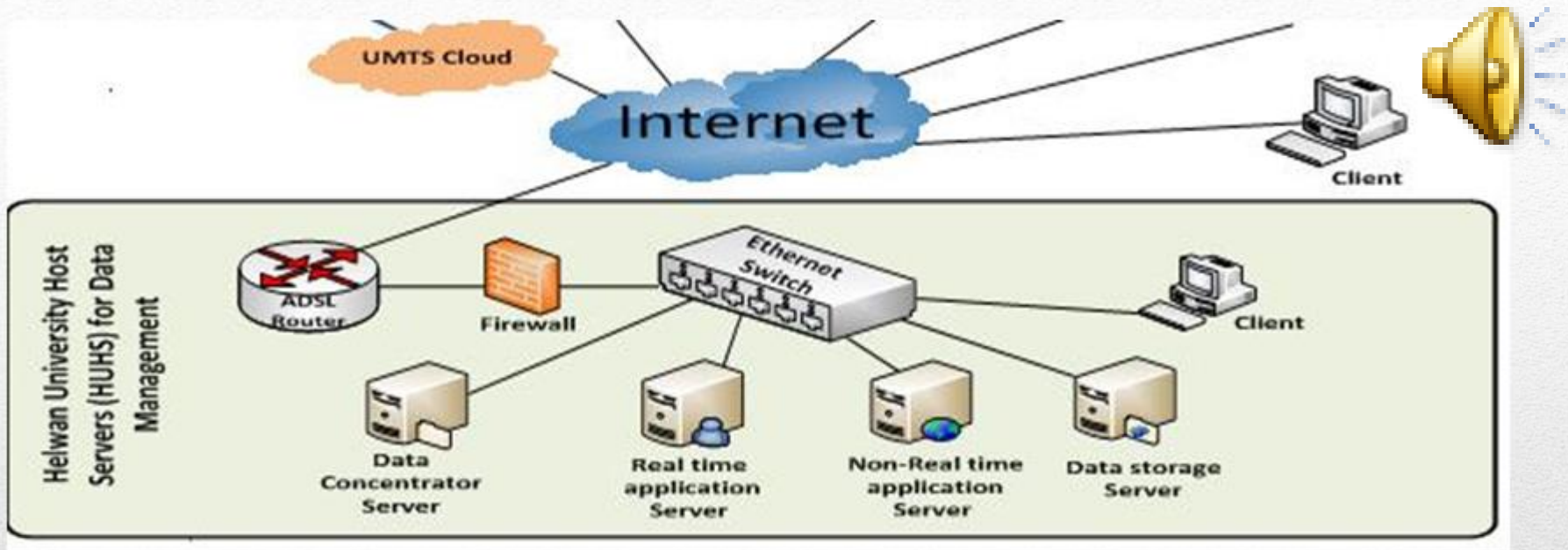
### □ ADSL Internet access connections



### □ UMTS Internet access connection



# 3-5 HUHS for Data Management and Analysis



## ❑ Data Concentrator Server (DCS)

- Collect data from FDRs
- Align the data by time stamps
- provide synchronized outputs for application software
- Database Operation Service



## ❑ Real Time Application Server (RTAS)

- Frequency monitoring application
- Phase angle monitoring application
- Event detection
- Event type diagnosis
- Event location
- Oscillation trigger

## ❑ Non-Real Time Application Server (NRTAS)

- Event visualization
- Oscillation modal analysis
- Web service

## ❑ Data Storage Server (DSS)

- Store all historical data

# **EWAMS**

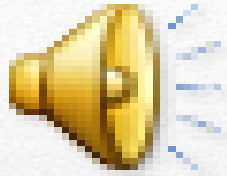
## **(device installation and software**



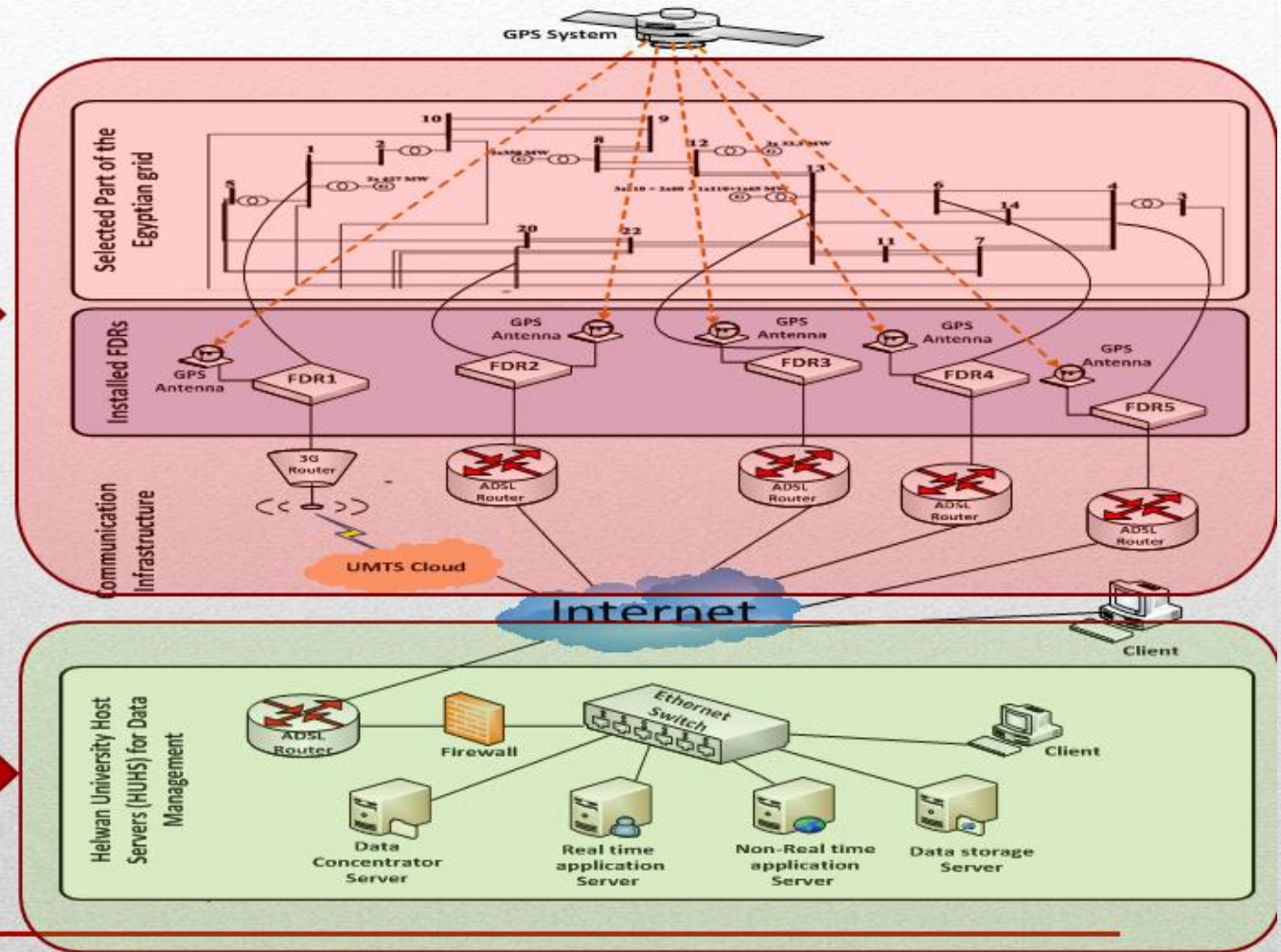


# 4- EWAMS Device and Software Installation

## Two levels for EWAMS installation



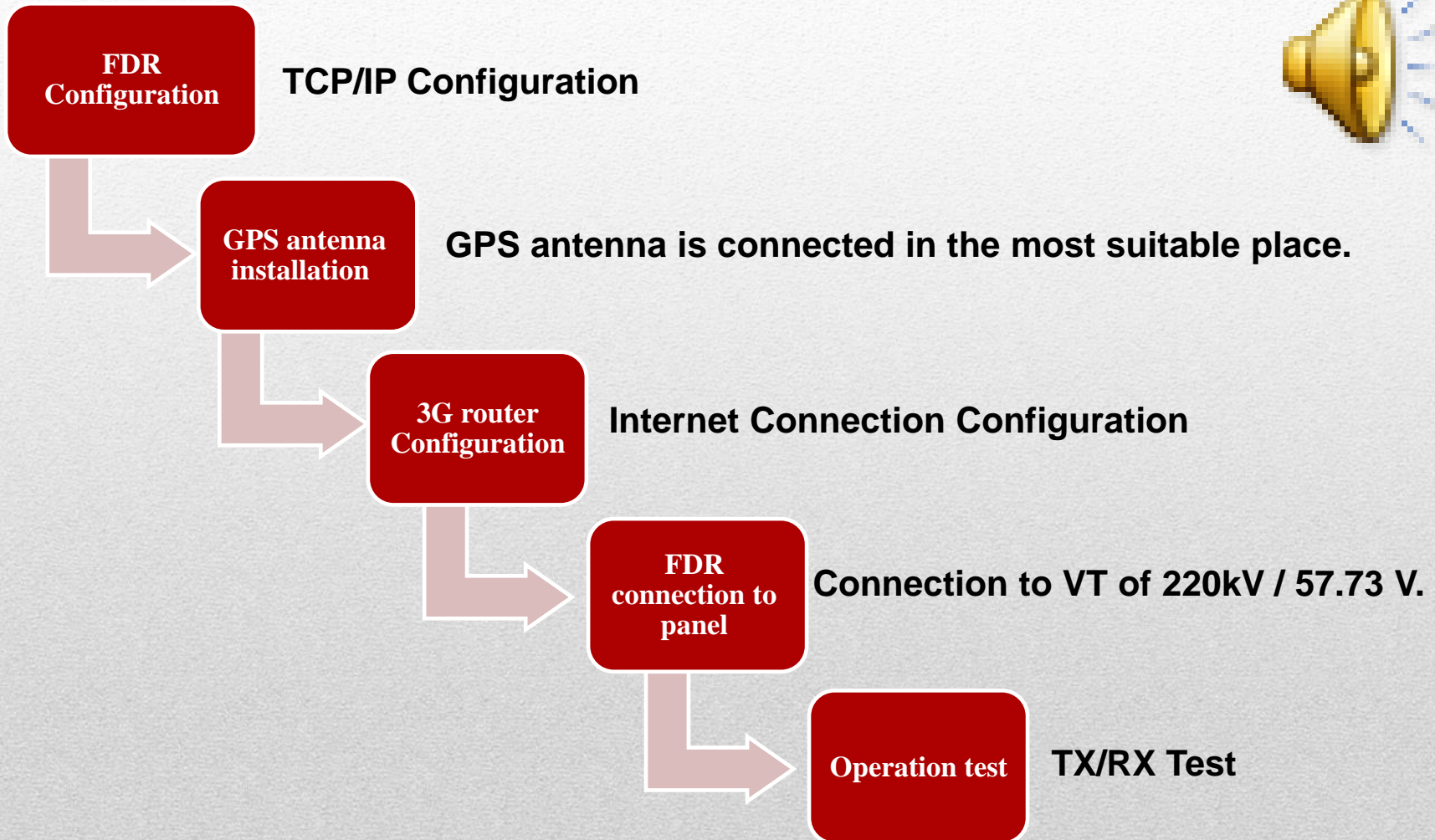
**Level # 1**



**Level #2**

# 4-1 FDRs setup in power station

## Five steps for installing FDR and Router in power station





# 4-2 Network configuration for FDRs devices

## FDR Transmission Protocol: **TCP/IP**



### Network Enabler Administrator

Moxa NE-4100T



FDR



Operating Mode

1 Port(s) Selected. 1st port is Port 1

Operating Mode: TCP Client Mode

TCP Client

TCP Client Mode Settings

Connect Mode	Startup
1	192.168.1.38 9426
2	192.168.1.50 4001
3	www.fnetworld.com 9426
4	www.fnet2020.com 9426

Miscellaneous (Optional)

TCP Alive Check Timeout: 1 (0-99 min)

Inactivity Timeout: 0 (0-65535 ms)

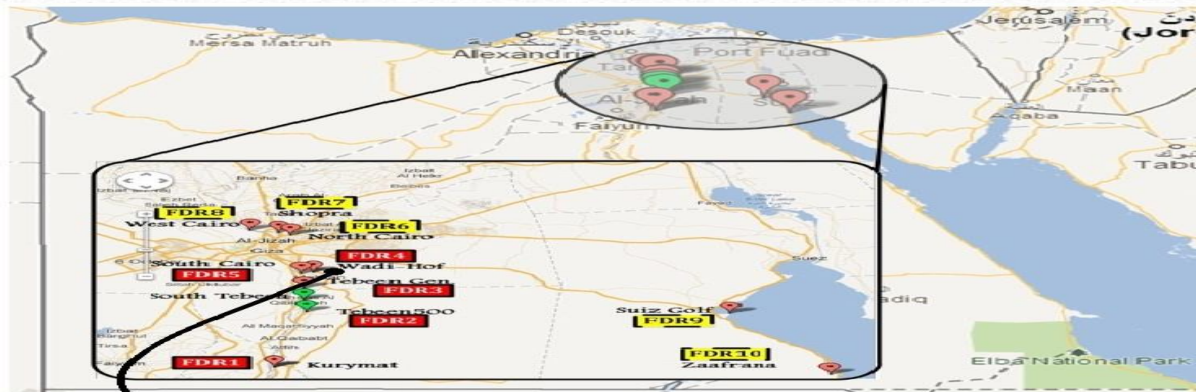
Data Packing (Optional)

Delimiter 1: 00 (0-ff, Hex)

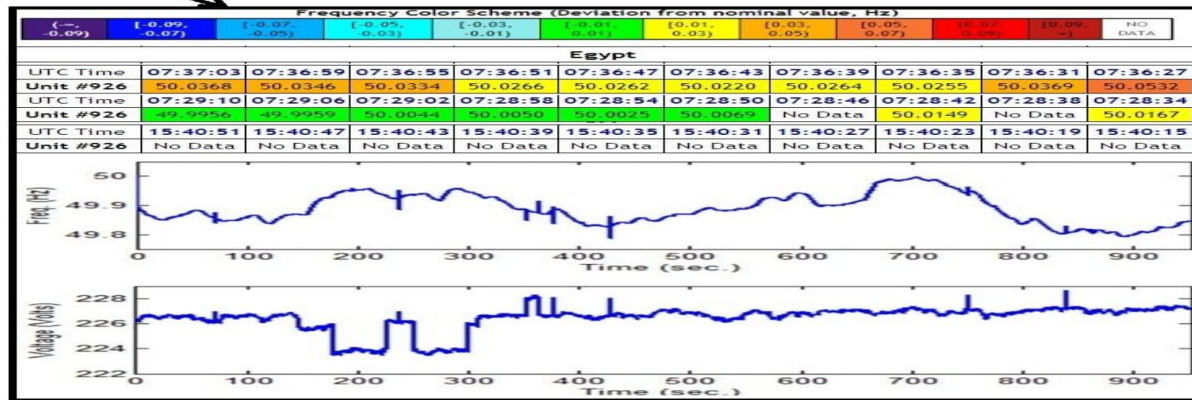
Delimiter 2: 00 (0-ff, Hex)

Force Tx Timeout: 0 (0-65535 ms)

OK Cancel



Data Recorded at Faculty of Engineering Helwan University



# FDR installation on 220kV/500kV Cairo Zone



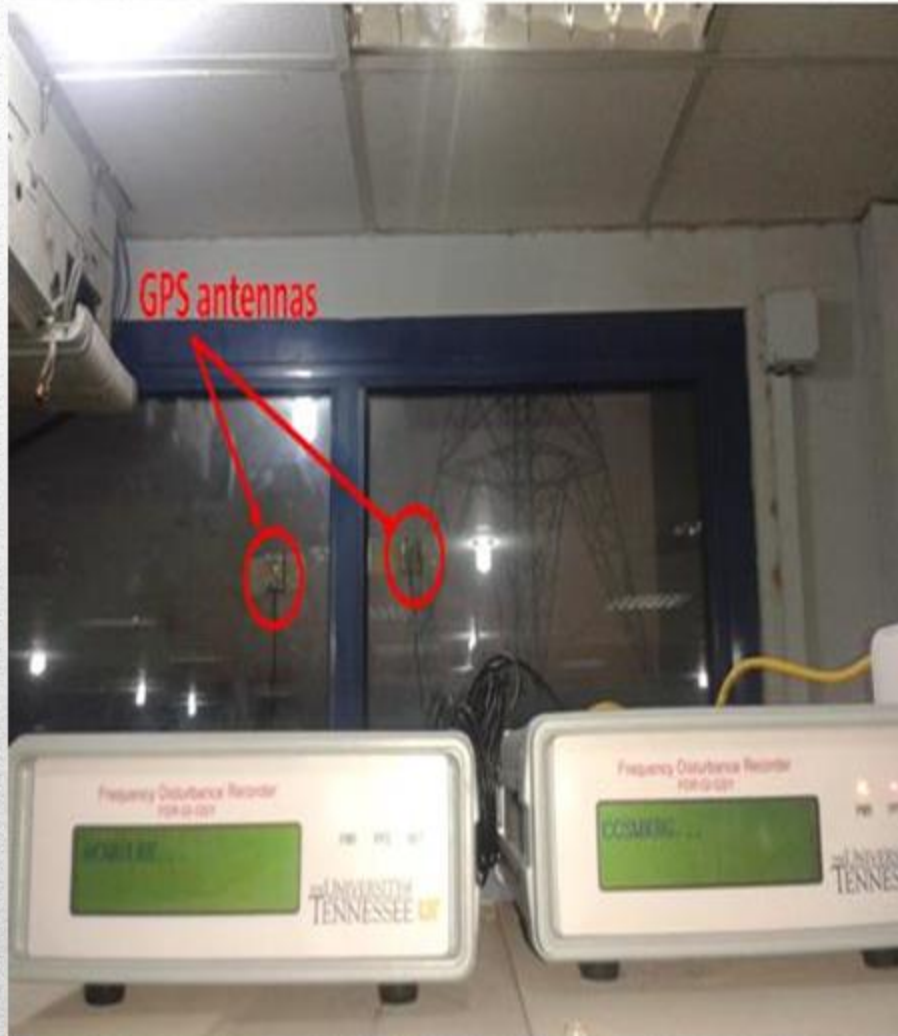
## 4-3 Snapshots for FDR and Router installation process

Wadi-Hof Installation (500kV/ 220kV Cairo Zone Grid)



# Snapshots for FDR and Router installation process

Wadi-Hof Installation (500kV/ 220kV Cairo Zone Grid)





# Snapshots for FDR and Router installation process

Wadi-Hof Installation (500kV/ 220kV Cairo Zone Grid)



# Snapshots for FDR and Router installation process

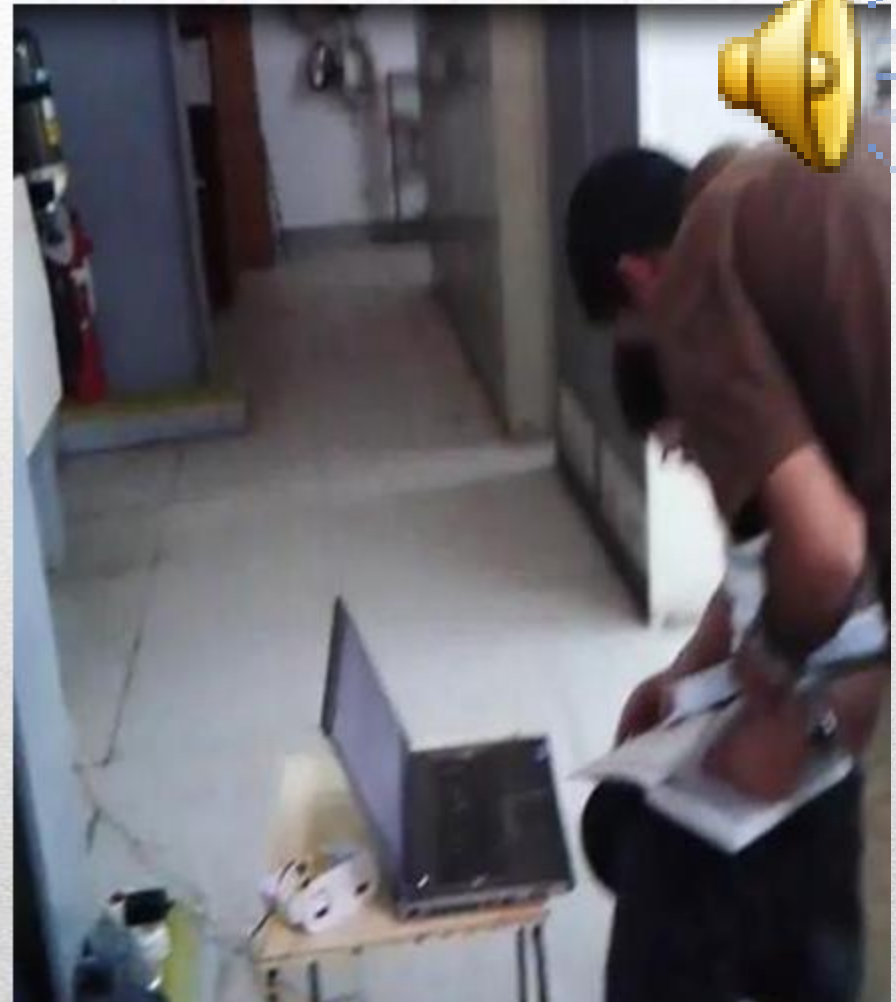
South-Cairo Installation (500kV/ 220kV Cairo Zone Grid)





# Snapshots for FDR and Router installation process

South-Cairo Installation (500kV/ 220kV Cairo Zone Grid)



# Snapshots for FDR and Router installation process

South-Cairo Installation (500kV/ 220kV Cairo Zone Grid)





# Snapshots for FDR and Router installation process

220kV /500kV board FDR installation



# Snapshots for FDR and Router installation process

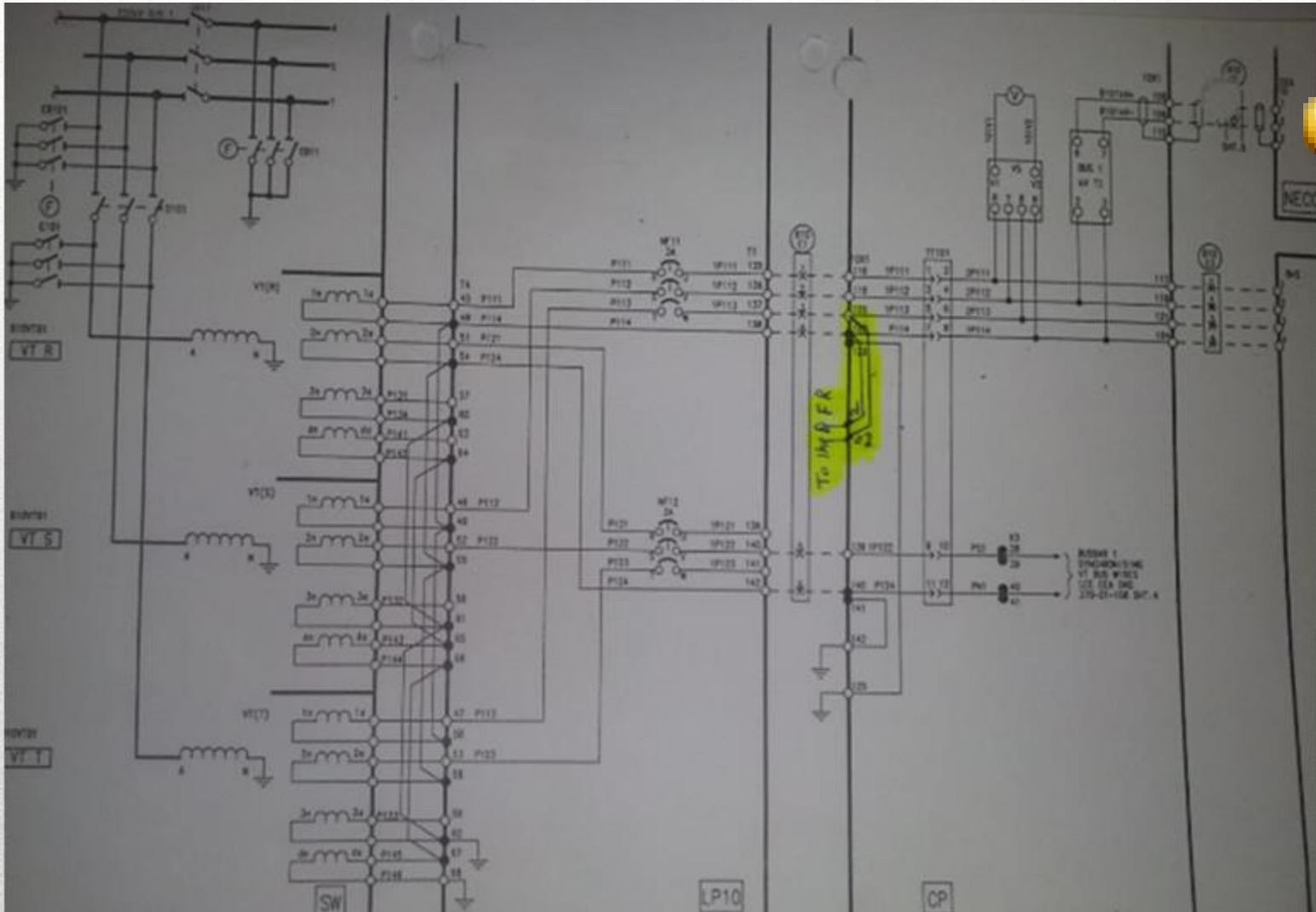
## Part of the wiring connection





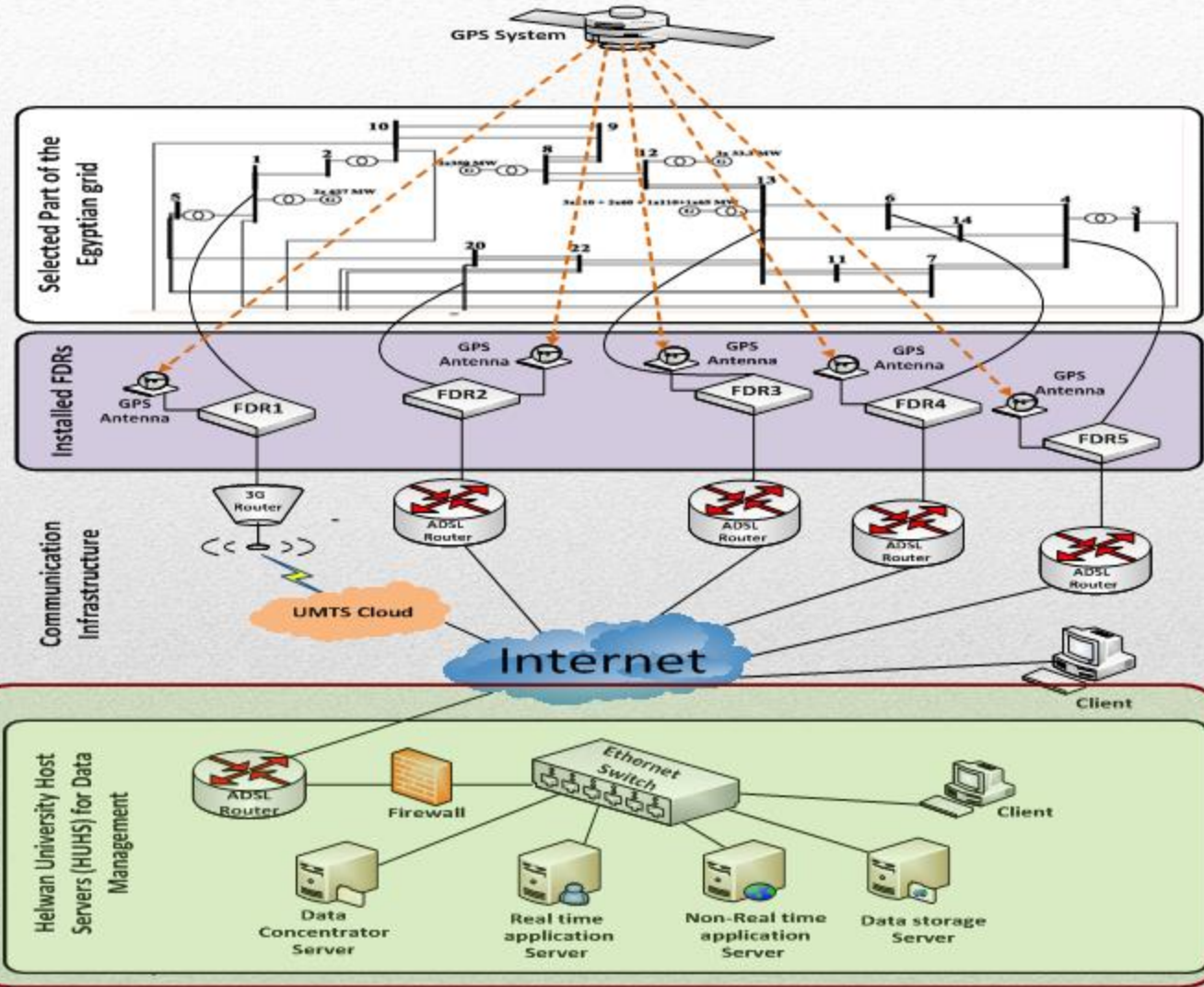
# Snapshots for FDR and Router installation process

## Wiring Diagram layout



# 4-4 EWAMS Software Installation

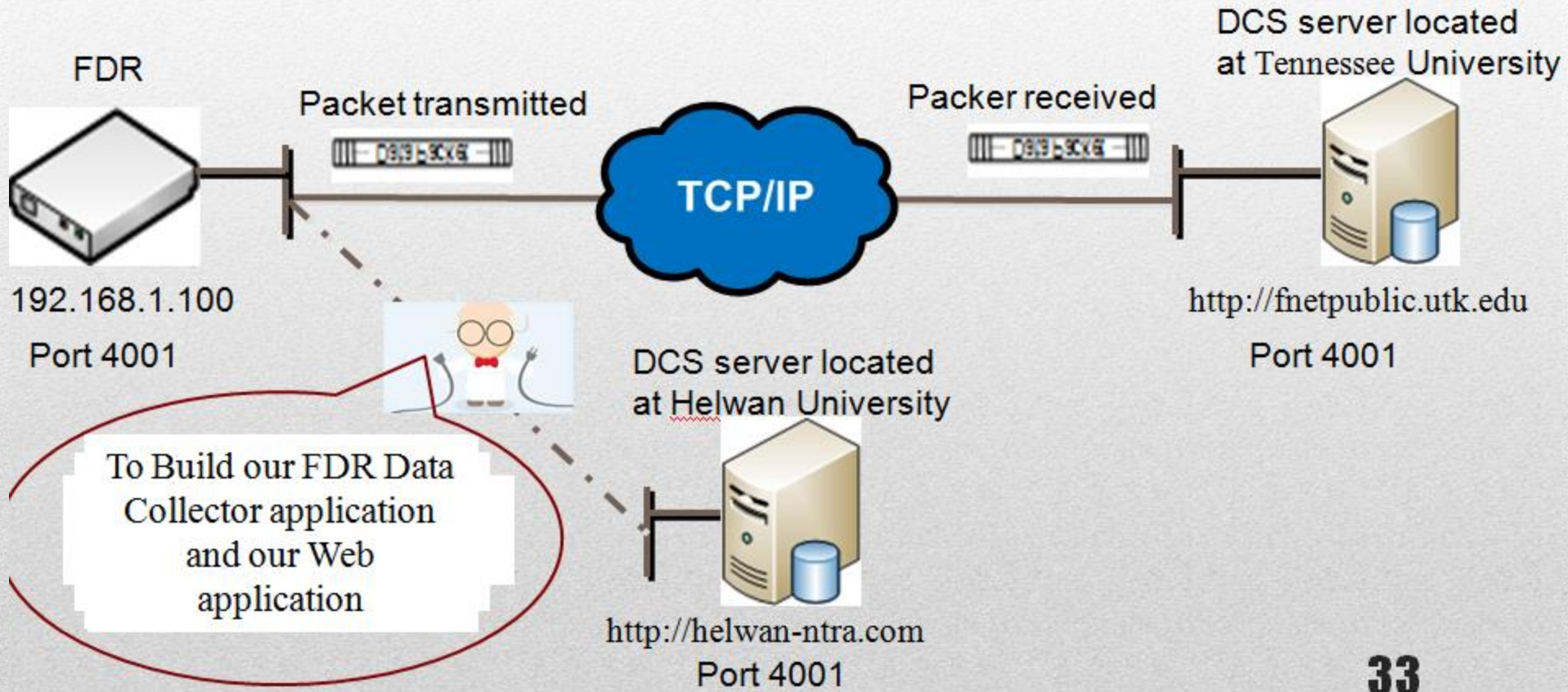
## EWAMS Architecture



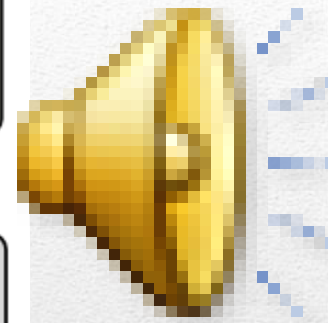
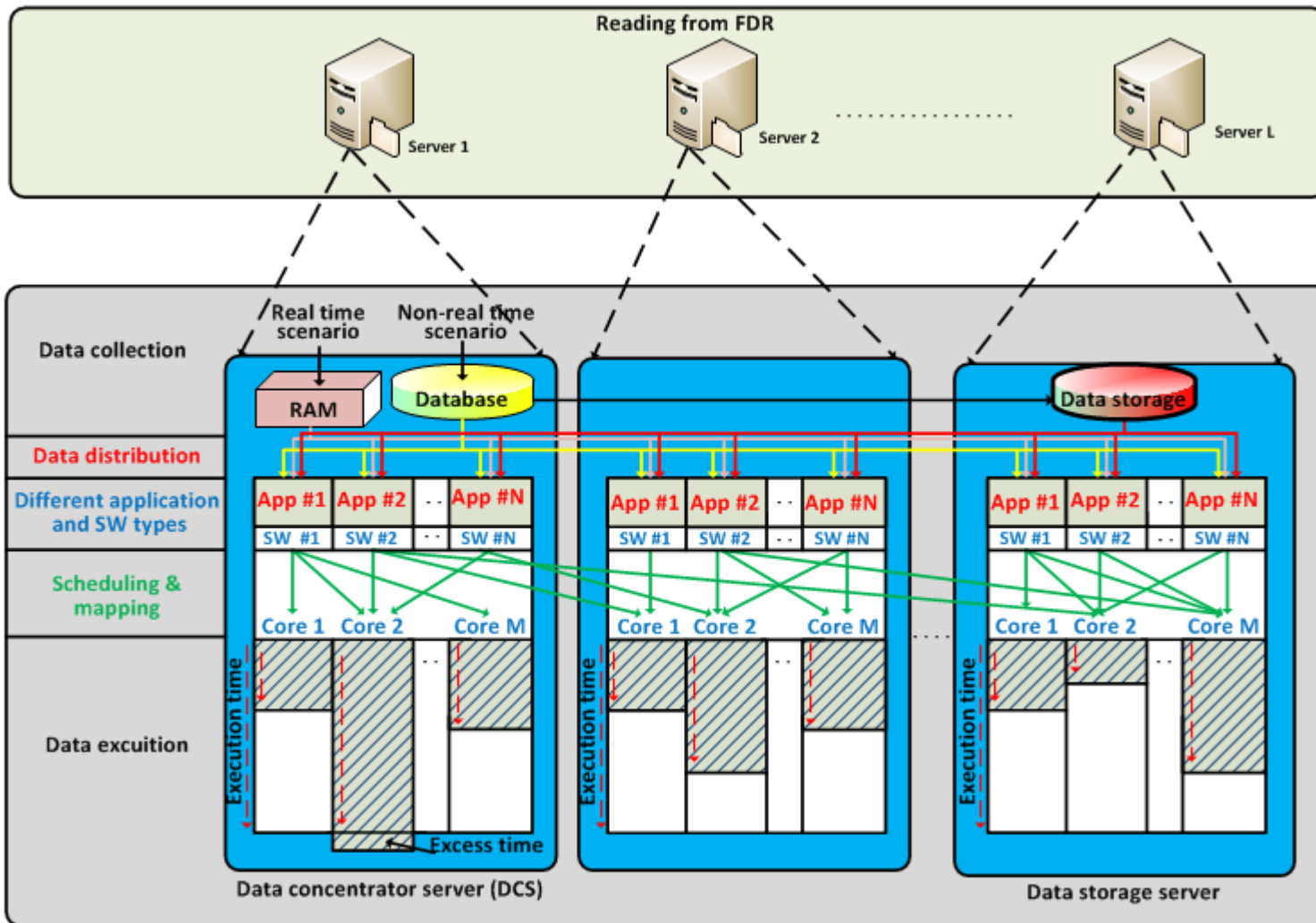
**Level #2 Installation**







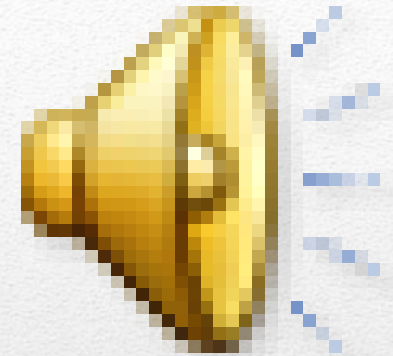
# 4-5 Logical structure of Egyptian WAMS





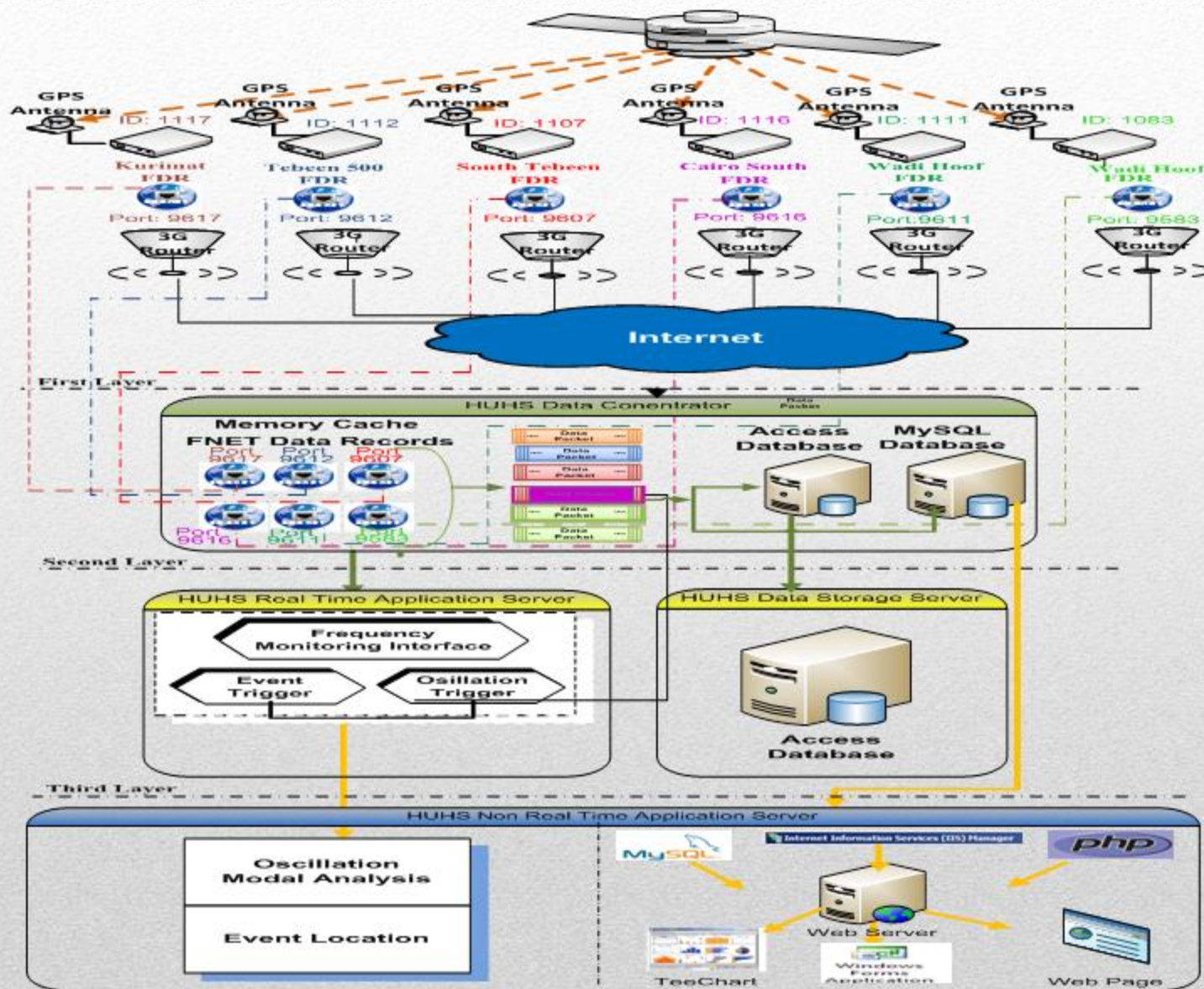
## ❑ HUHS Software components

- Window Server 2008 R2
- Nova Backup Server
- Microsoft Forefront Endpoint Protection
- TeeChart: Charting and graphing library
- MYSQL Server
- MySQL Workbench
- Microsoft Access
- PHP "Personal Home Page"
- IIS "Internet information services"
- FNET Server Application
- Applications: Event trigger, Oscillation Trigger, ...



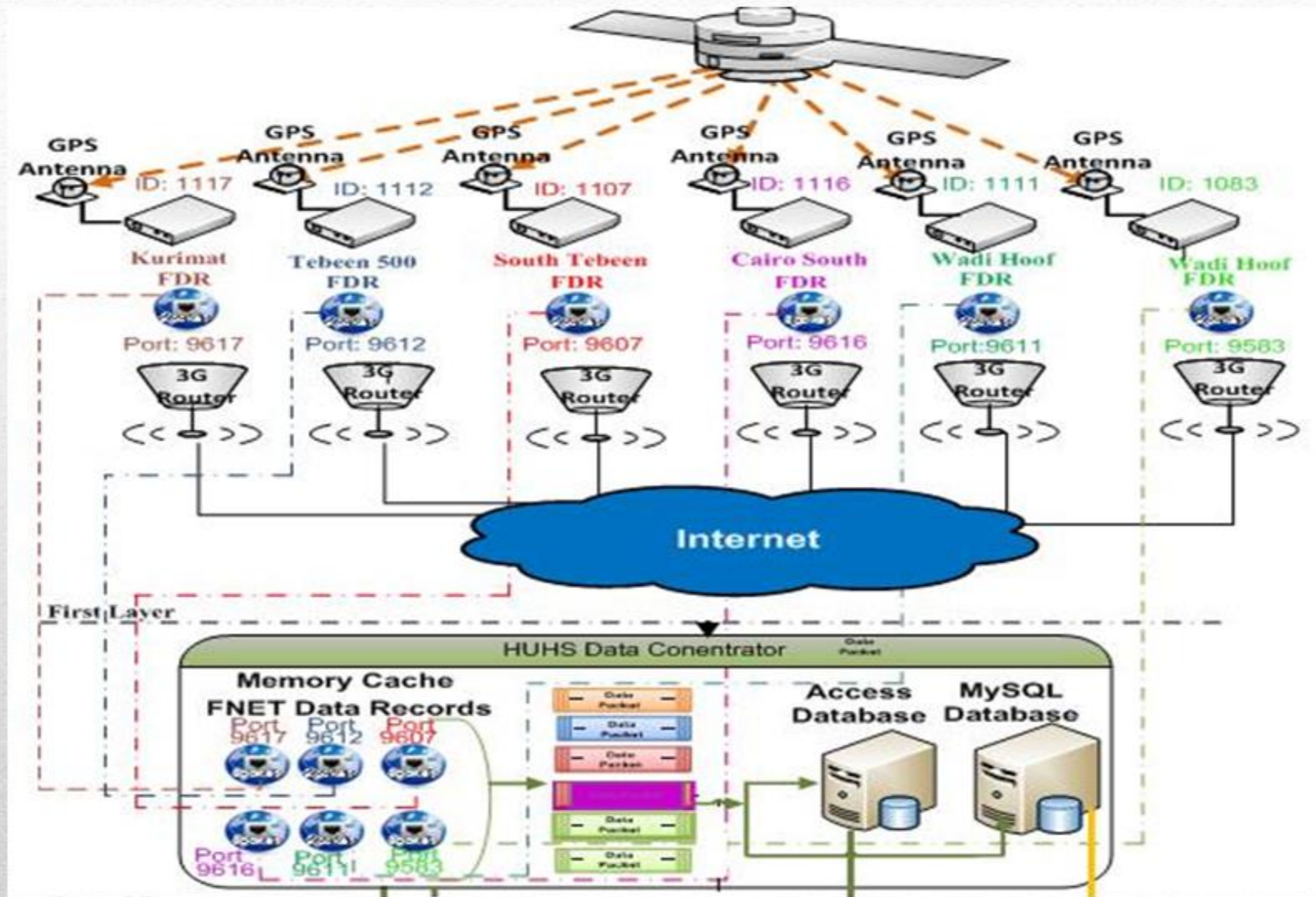


# Data Flow Paths and Application Hierarchy

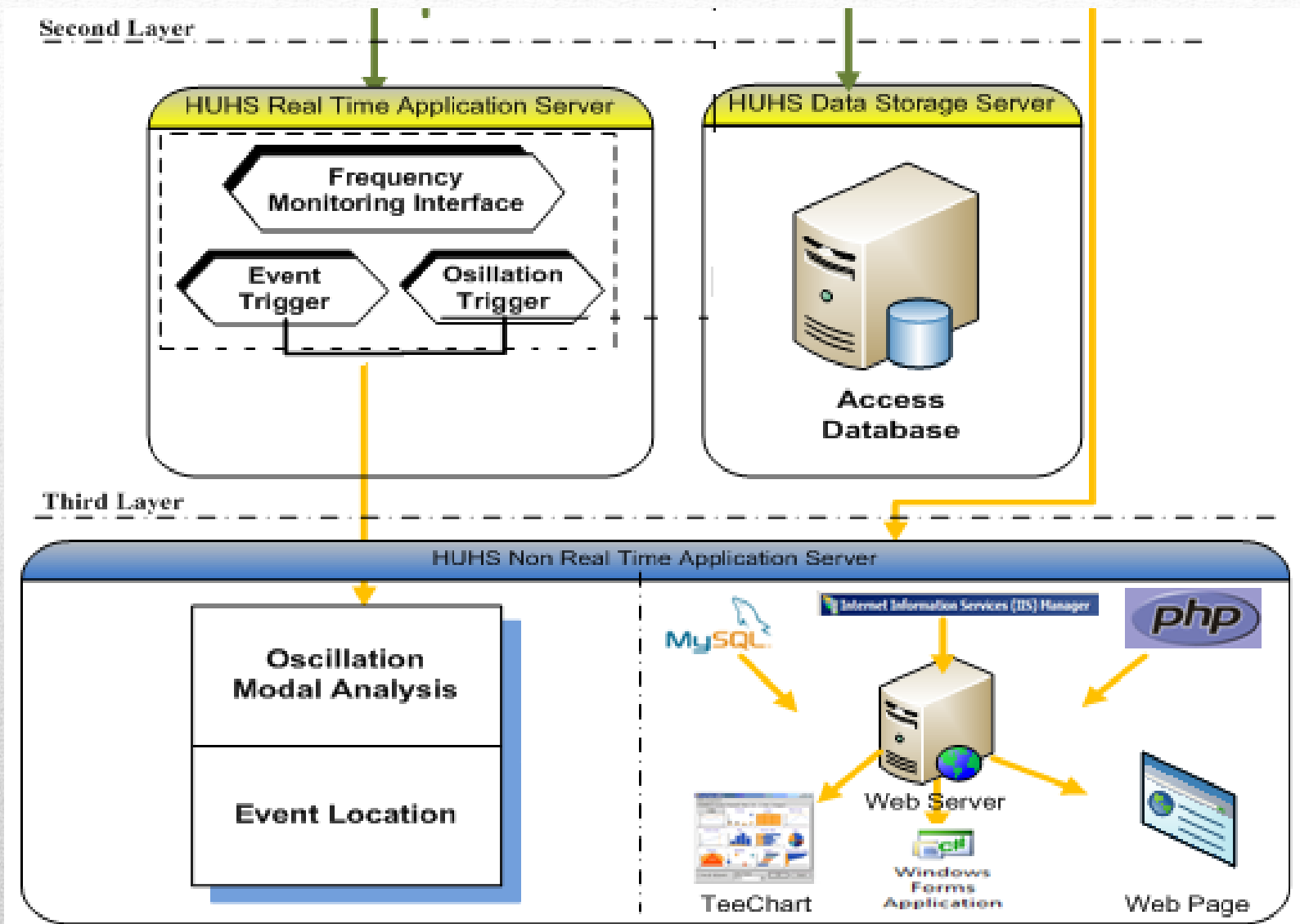




# Data Flow Paths and Application Hierarchy

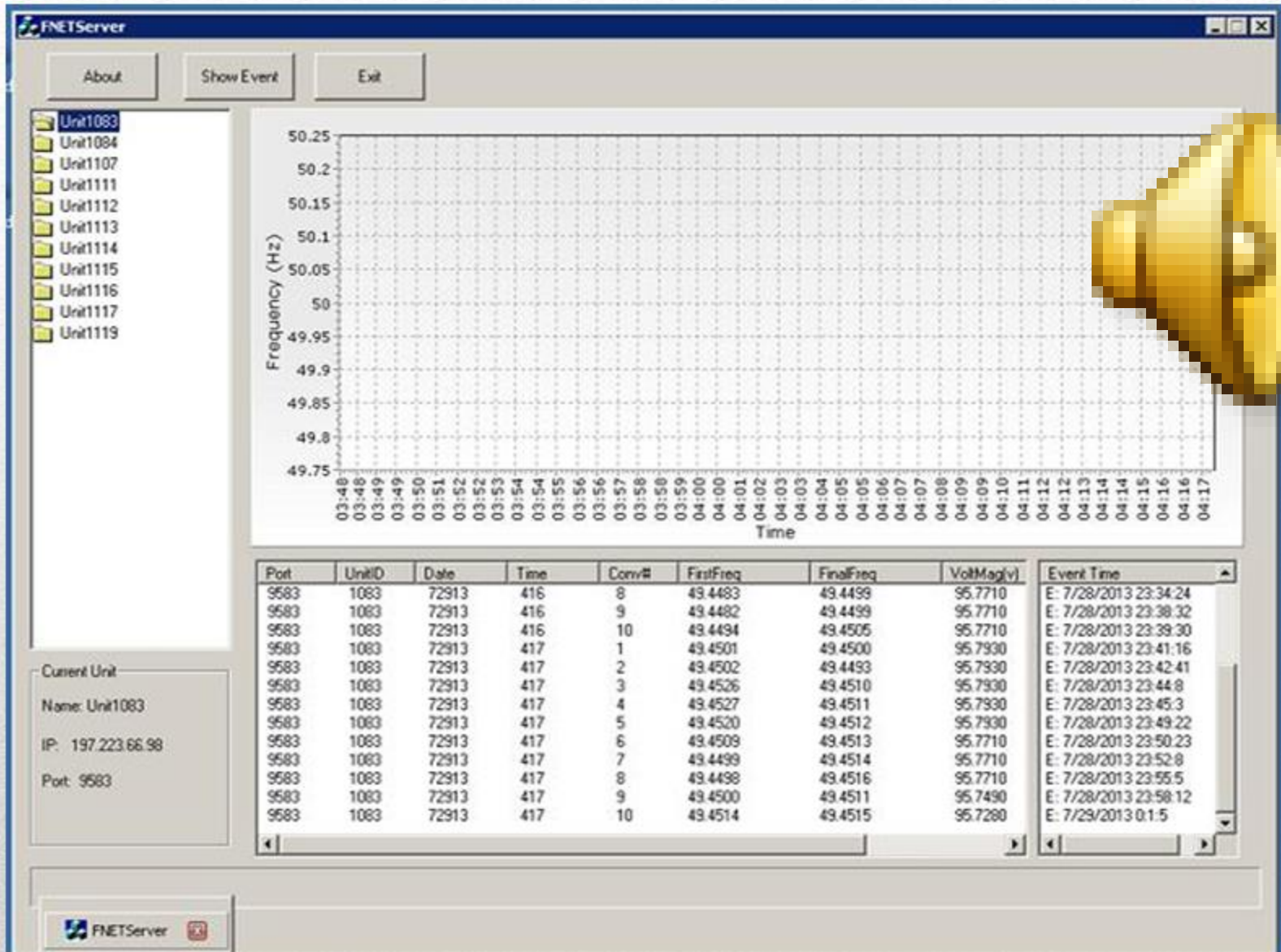


# Data Flow Paths and Application Hierarchy





# EWAMS Server Application



# Snapshot from the EWAMS Database



Microsoft Access - Table Tools

Home Create External Data Database Tools Datasheet

View Paste Copy Format Painter Views Clipboard Font Rich Text Refresh All New Save Delete Records Totals Spelling More Filter Selection Advanced Toggle Filter Size to Fit Form Switch Windows Window Find Replace Go To Select Find

Security Warning Certain content in the database has been disabled Options...

Tables

- FDRInfo
- FRURawData1083
- FRURawData1084
- FRURawData1107
- FRURawData1111
- FRURawData1112
- FRURawData1113
- FRURawData1114
- FRURawData1115
- FRURawData1116
- FRURawData1117
- FRURawData1119

FRURawData1107

Index	Unit	Sample_Date&Time	ConvNu	FirstFre	FinalFri	VoltageAi	VoltageM	DateCreated	TimeIndex
1	1107	7/27/2013 4:10:52 PM	10	49.7585	49.7577	2.8474	56.785	7/27/2013 9:12:41 AM	582530
2	1107	7/27/2013 4:10:53 PM	1	49.7586	49.7577	2.6944	56.785	7/27/2013 9:12:41 AM	582531
3	1107	7/27/2013 4:10:53 PM	2	49.7584	49.7577	2.5427	56.796	7/27/2013 9:12:41 AM	582532
4	1107	7/27/2013 4:10:53 PM	3	49.7585	49.7579	2.3907	56.785	7/27/2013 9:12:41 AM	582533

FRURawData1116

Index	Unit	Sample_Date&Time	ConvNu	FirstFre	FinalFri	VoltageAi	VoltageM	DateCreated	TimeIndex
1	1116	7/27/2013 4:10:52 PM	9	49.7577	49.7571	2.9441	56.39	7/27/2013 9:12:41 AM	582529
2	1116	7/27/2013 4:10:52 PM	10	49.7578	49.757	2.7915	56.39	7/27/2013 9:12:41 AM	582530
3	1116	7/27/2013 4:10:53 PM	1	49.7595	49.7586	2.6393	56.401	7/27/2013 9:12:41 AM	582531
4	1116	7/27/2013 4:10:53 PM	2	49.7584	49.7576	2.4874	56.401	7/27/2013 9:12:41 AM	582532
5	1116	7/27/2013 4:10:53 PM	3	49.7587	49.7581	2.3354	56.401	7/27/2013 9:12:41 AM	582533
6	1116	7/27/2013 4:10:53 PM	4	49.7589	49.7585	2.1839	56.39	7/27/2013 9:12:41 AM	582534
7	1116	7/27/2013 4:10:53 PM	5	49.7585	49.7583	2.0319	56.39	7/27/2013 9:12:41 AM	582535
8	1116	7/27/2013 4:10:53 PM	6	49.7591	49.7591	1.8807	56.401	7/27/2013 9:12:41 AM	582536
9	1116	7/27/2013 4:10:53 PM	7	49.7576	49.7578	1.7287	56.39	7/27/2013 9:12:41 AM	582537
10	1116	7/27/2013 4:10:53 PM	8	49.759	49.7594	1.5773	56.401	7/27/2013 9:12:41 AM	582538
11	1116	7/27/2013 4:10:53 PM	9	49.7569	49.7575	1.4252	56.401	7/27/2013 9:12:41 AM	582539
12	1116	7/27/2013 4:10:53 PM	10	49.7589	49.7595	1.2739	56.401	7/27/2013 9:12:41 AM	582540
13	1116	7/27/2013 4:10:54 PM	1	49.7569	49.7577	1.1214	56.401	7/27/2013 9:12:41 AM	582541
14	1116	7/27/2013 4:10:54 PM	2	49.7566	49.7575	0.9692	56.39	7/27/2013 9:12:41 AM	582542
15	1116	7/27/2013 4:10:54 PM	3	49.7581	49.7588	0.8179	56.39	7/27/2013 9:12:41 AM	582543
16	1116	7/27/2013 4:10:54 PM	4	49.7569	49.7575	0.6654	56.39	7/27/2013 9:12:41 AM	582544

Datasheet View

Start Database FNETServer MATLAB R2013a mappingtrendsgui Microsoft Access - ...

2:36 PM 7/29/2013



## Synchronized Frequency Measurements



Frequency Color Scheme (Deviation from nominal value, Hz)



\*\* The frequency values displayed here on the public website are fed from a set of sample data and do not represent the current system frequency.

Egypt										
UTC Time	03:52:31	03:52:27	03:52:23	03:52:19	03:52:15	03:52:11	03:52:07	03:52:03	03:51:59	03:51:55
Unit #1083	50.0817	50.0580	50.0205	50.0155	50.0152	50.0194	50.0213	50.0197	50.0165	50.0187
Unit #1084	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Unit #1107	50.0213	50.0197	50.0165	50.0187	50.0193	50.0181	50.0146	50.0092	50.0028	49.9969
Unit #1111	50.0943	50.0956	50.0911	50.0817	50.0580	50.0204	50.0155	50.0152	50.0194	50.0213
Unit #1112	50.0896	50.0774	50.0516	50.0157	50.0158	50.0165	50.0197	50.0218	50.0192	50.0164
Unit #1113	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Unit #1114	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Unit #1115	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Unit #1116	50.0194	50.0213	50.0197	50.0165	50.0187	No Data	50.0148	50.0145	50.0092	50.0027
Unit #1117	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Unit #1119	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data

WadiHof (57.7v)

SouthCairo (57.7v)

WadiHof (100v)

Tebeen500 (57.7v)

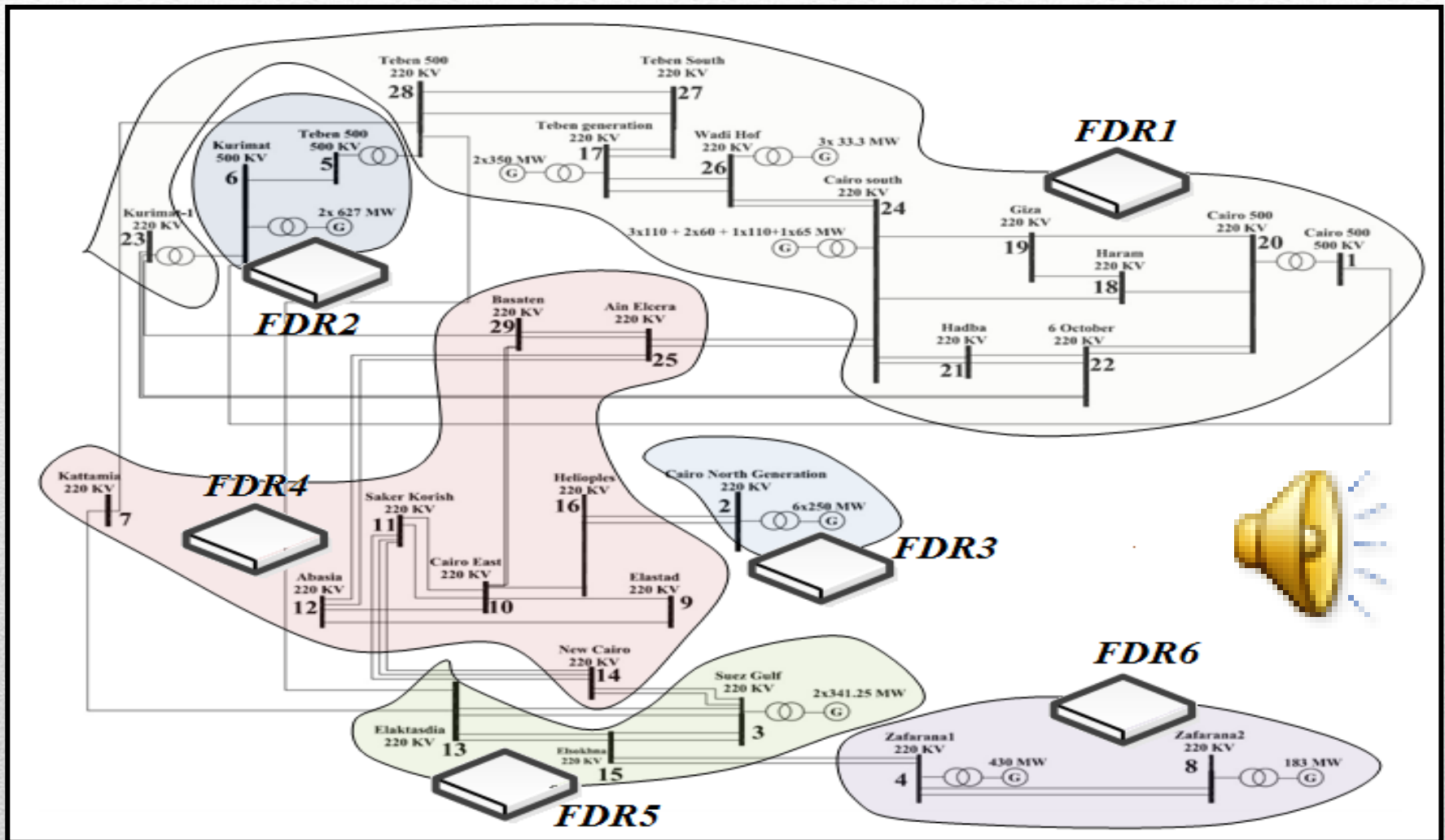
SouthTebeen(57.7v)

# 5- EWAMS Applications





# FDR Deployment using novel idea



## Real Time Applications

**Online Visualization**

**Instability  
Detection**

**Event Identification**

## Non-Real Time Applications

**Event Location  
Estimation**

**Smart Load Shedding**

**Adaptive Dynamic  
Modeling**



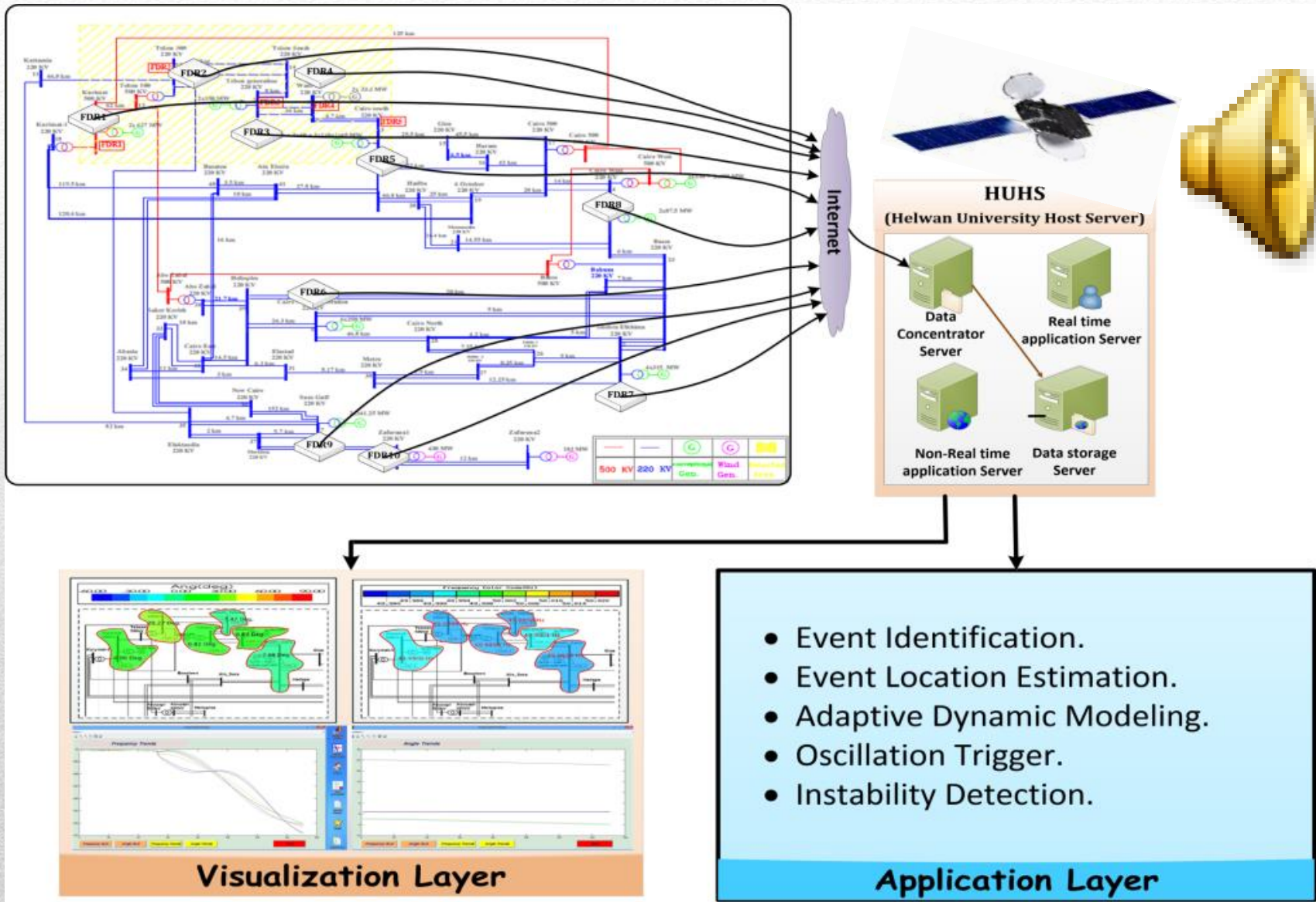


## Application-1



- ON-line Visualization based diagnosis

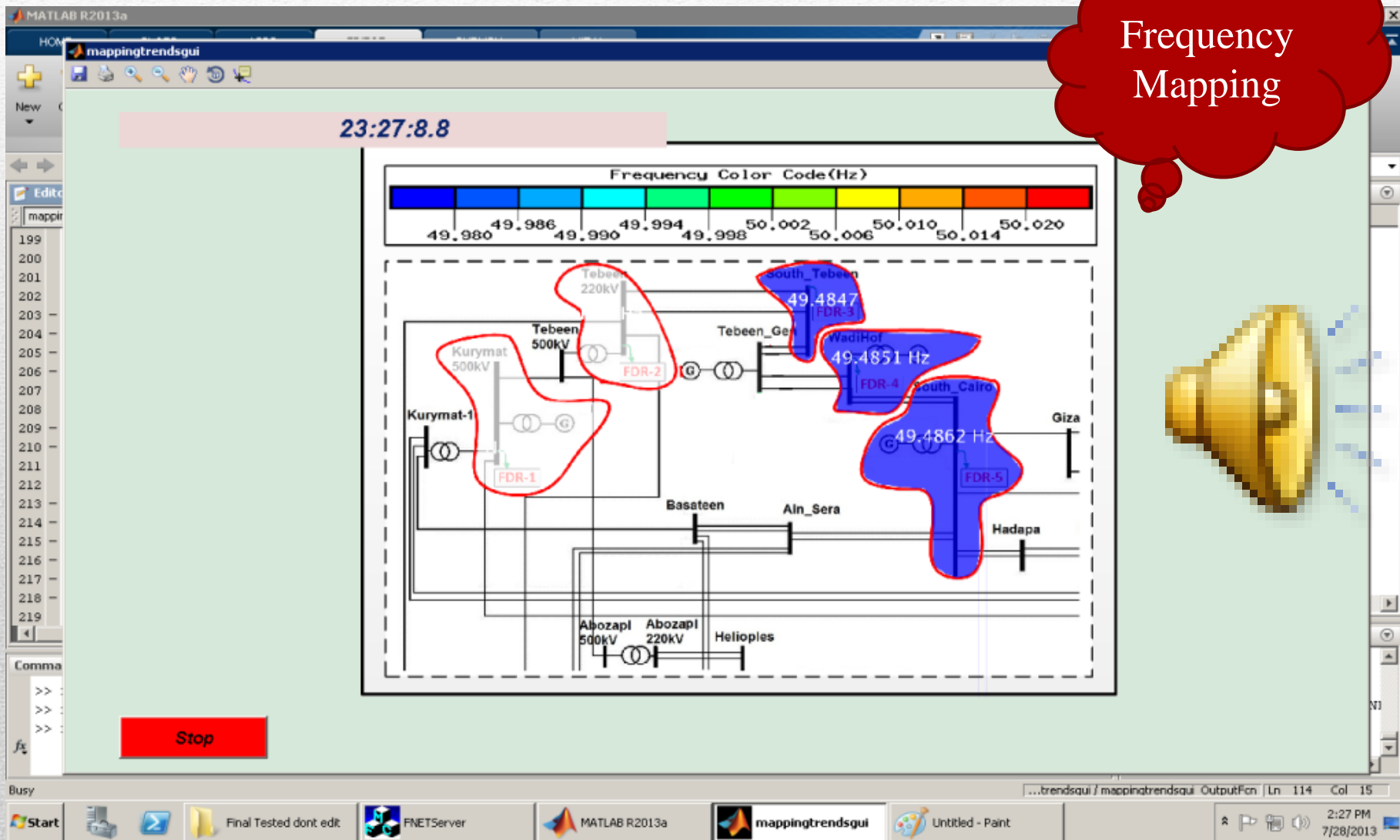
# Online Visualization of Synchronized Measurements



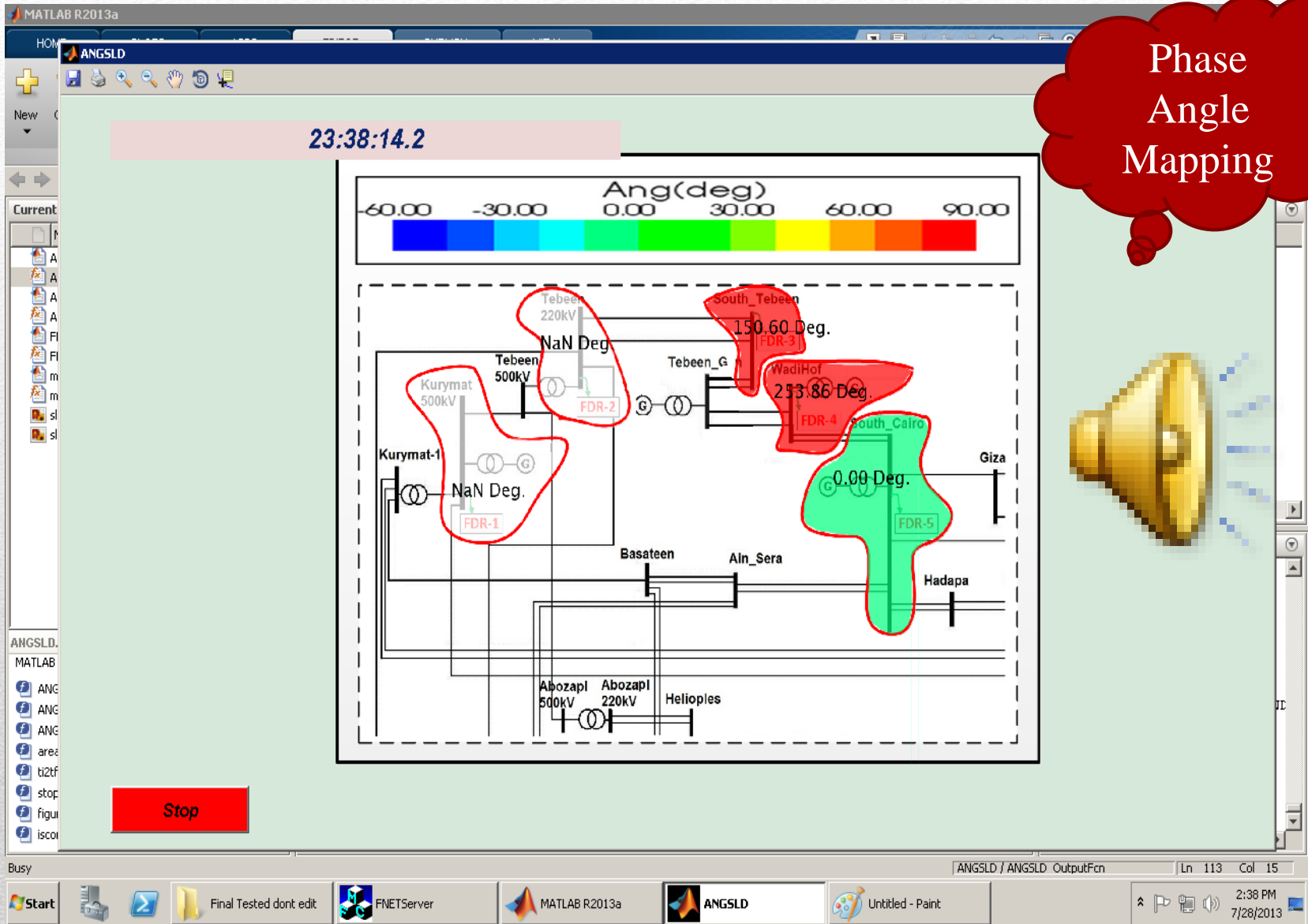


# Online Visualization of Synchronized Measurements

Effective visualization helps viewers to **understand** and interpret power system dynamic situation more easily and rapidly to **improve situational awareness**. The visualization tool will receive measurements from FDRs and visualize it online as shown.

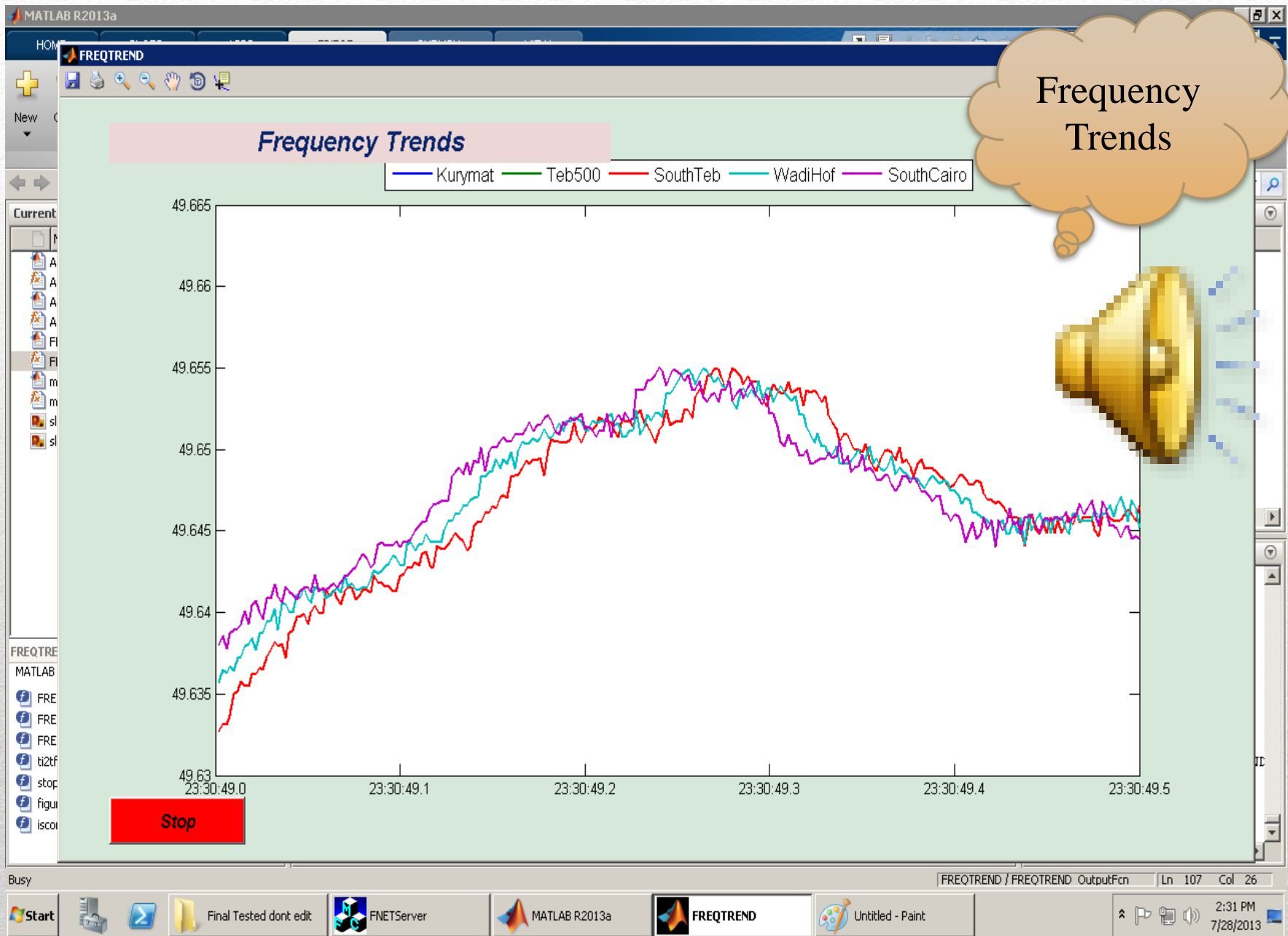


# Online Visualization of Synchronized Measurements

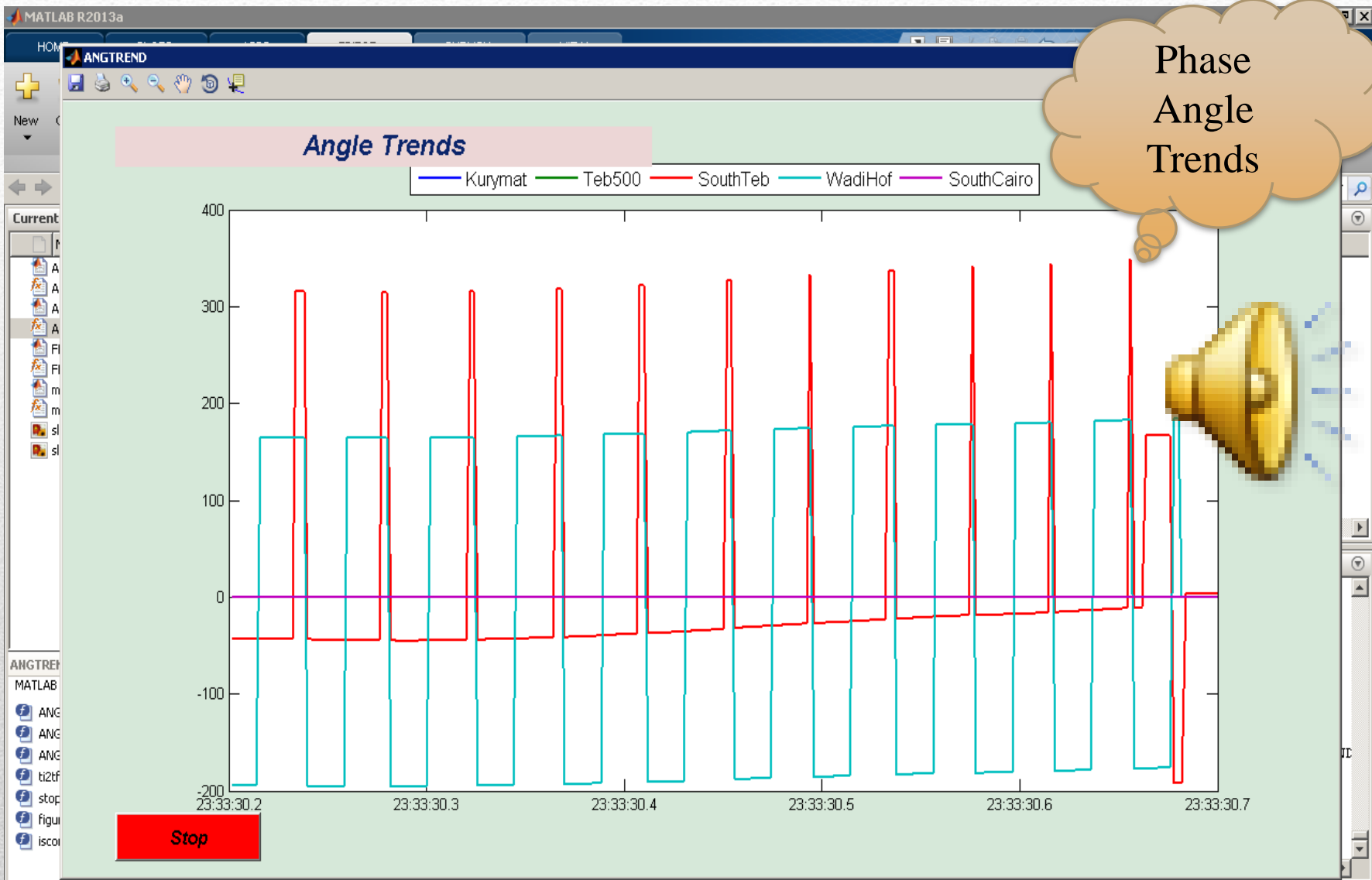




# Online Visualization of Synchronized Measurements



# Online Visualization of Synchronized Measurements





## Application-2

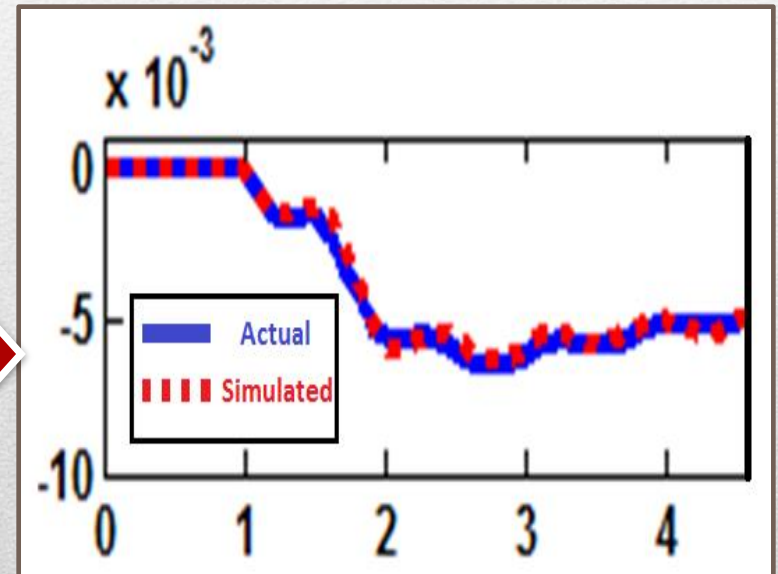
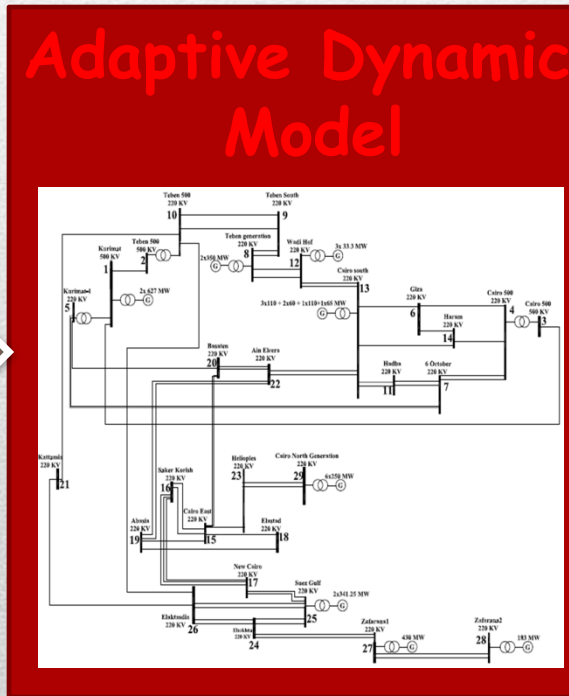


# **Adaptive Dynamic Model Based on WAMS Using Harmony Search Technique**

# Problem Formulation

52

Event →

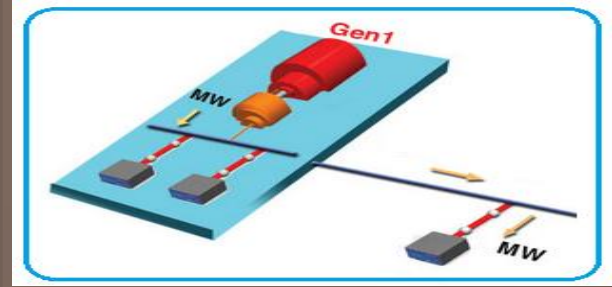
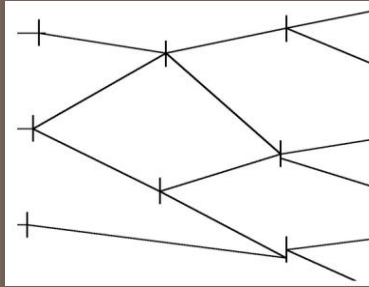


Actual System Response 52

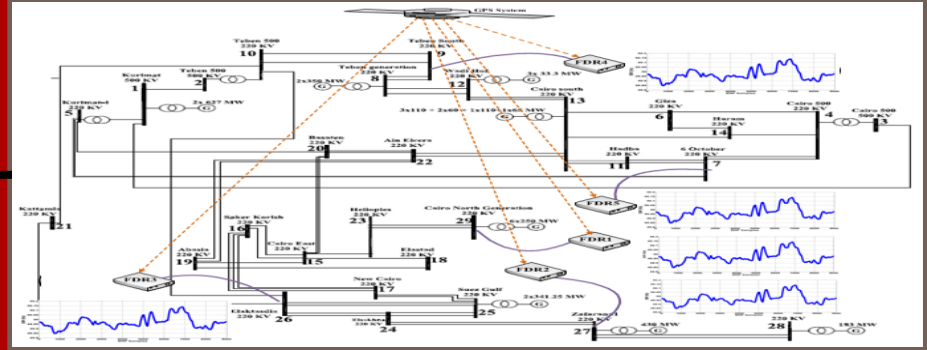


# Power System Topology

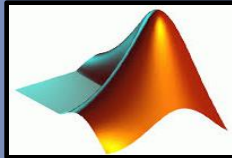
**Connectivity Matrix**

$$\begin{bmatrix} 1 & 0 & \dots & 1 \\ 0 & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 1 & 1 & \dots & 1 \end{bmatrix}$$


# Real Time Measurements

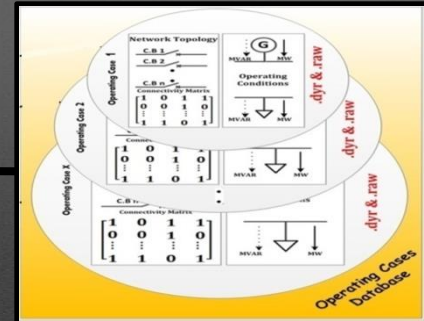


# Tools



# ADM

**Model Parameters for unforeseen Topology**



Building DB

# Outline

Introduction



Conventional Power System Simulation



Adaptive Power System Simulation



Power System Simulators



PSS®E Interface Programs



*Power System Model Parameters Effectiveness on Simulation Behavior*



ADM Scheme



Unforeseen Operating Cases



Testing Case



# Application-3



## **Generator Trip Identification Using Minimum Distance Classifier Technique**

# Outline

**When Generator trips**

**Generators Trip Identification Using Minimum Distance Classification**

**Training and Testing Cases**

**The main problem encountered with the proposed technique is the faulty Data**

**Testing case under Faulty Data**

**Sensitivity Analysis of PCA**

**FDR Setup at Helwan University and Online Application**



# Testing Cases

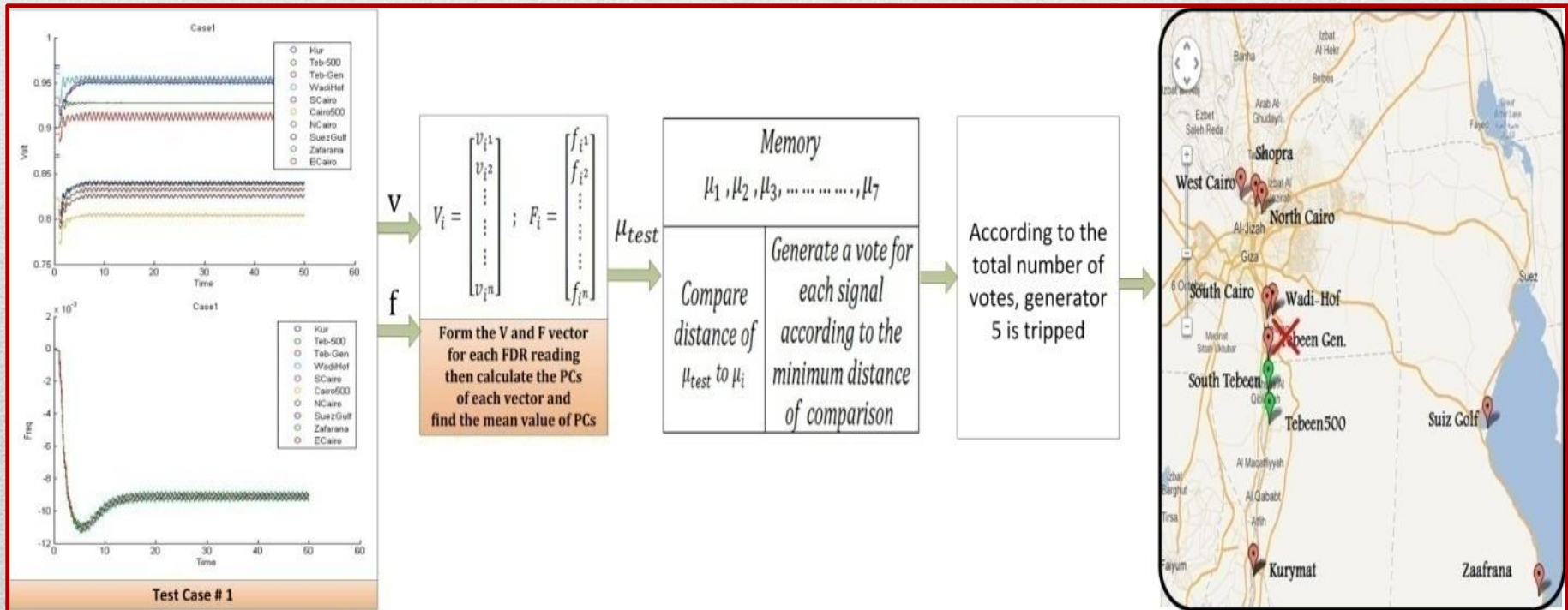
57

## Testing Case I:

### Tebeen Station Trip

#### Topology :

disconnecting two lines between Cairo-South bus and Ain-Sera and removing a load of 349 MW at North Cairo bus



## Application-4



- Event location estimation



# Event Location Estimation



EventLocationRes.txt - Notepad		
File	Edit	Format View Help
2013-07-22 15:18:12	failed	Triangulation 1400 Mw GeneTrip
2013-07-22 15:24:32	failed	Triangulation 650 Mw LoadShedding
2013-07-22 15:26:54	failed	Triangulation 900 Mw GeneTrip
2013-07-22 15:32:55	failed	Triangulation 850 Mw LoadShedding
2013-07-22 15:34:14	failed	Triangulation 1600 Mw LoadShedding
2013-07-22 15:36:10	failed	Triangulation 740 Mw GeneTrip
2013-07-22 15:37:58	failed	Triangulation 2800 Mw LoadShedding
2013-07-22 15:43:16	failed	Triangulation 1200 Mw GeneTrip
2013-07-22 15:52:45	failed	Triangulation 1300 Mw GeneTrip
2013-07-22 15:55:17	failed	Triangulation 1800 Mw LoadShedding
2013-07-22 15:56:39	failed	Triangulation 660 Mw LoadShedding
2013-07-22 16:00:16	failed	Triangulation 910 Mw LoadShedding
2013-07-22 16:02:19	failed	Triangulation 1100 Mw GeneTrip
2013-07-22 16:04:29	failed	Triangulation 1500 Mw LoadShedding
2013-07-22 16:11:41	failed	Triangulation 1000 Mw GeneTrip
2013-07-22 16:13:37	failed	Triangulation 580 Mw LoadShedding
2013-07-22 16:16:49	failed	Triangulation 1600 Mw LoadShedding
2013-07-22 16:18:58	failed	Triangulation 930 Mw GeneTrip
2013-07-22 16:23:27	failed	Triangulation 1500 Mw LoadShedding
2013-07-22 16:25:13	failed	Triangulation 1100 Mw LoadShedding
2013-07-22 16:27:44	failed	Triangulation 1100 Mw LoadShedding
2013-07-22 16:29:00	failed	Triangulation 1600 Mw LoadShedding
2013-07-22 16:38:15	failed	Triangulation 1200 Mw LoadShedding
2013-07-22 16:39:57	failed	Triangulation 3200 Mw LoadShedding
2013-07-22 16:41:53	failed	Triangulation 1100 Mw GeneTrip
2013-07-22 16:48:13	failed	Triangulation 1500 Mw LoadShedding
2013-07-22 16:55:27	failed	Triangulation 1000 Mw LoadShedding
2013-07-22 16:58:24	failed	Triangulation 1000 Mw GeneTrip

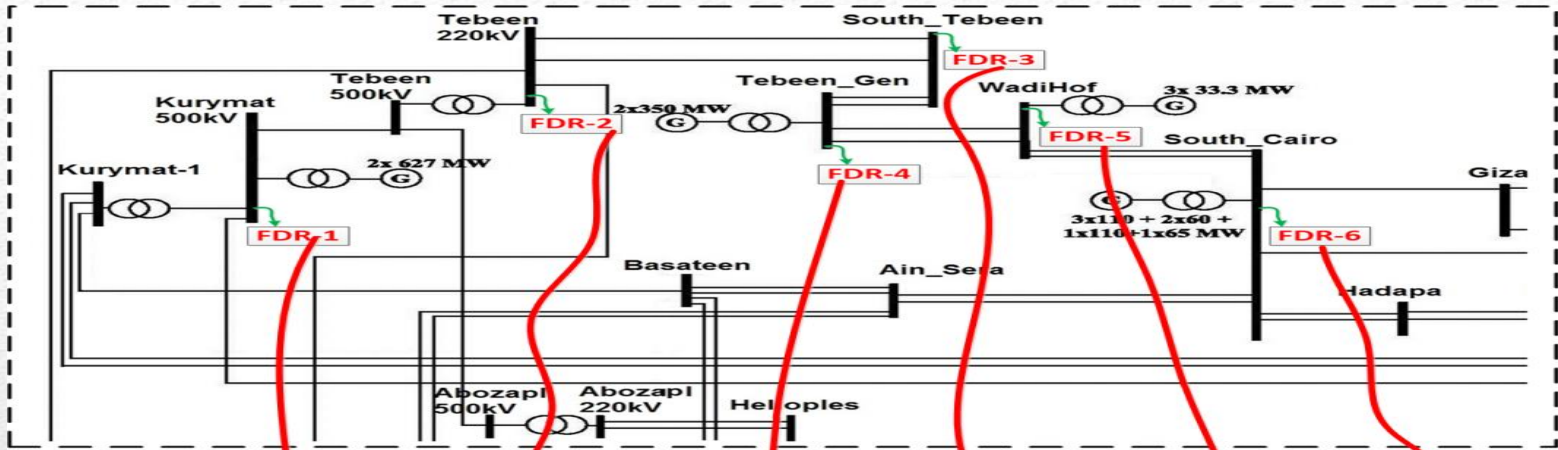
# Application-5



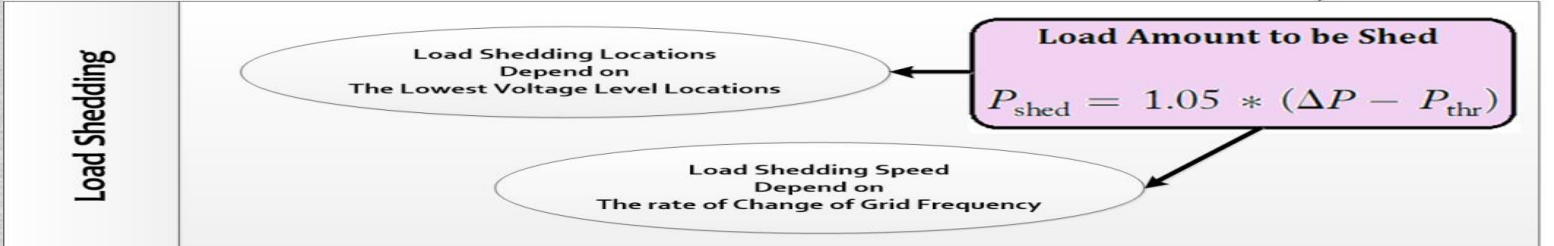
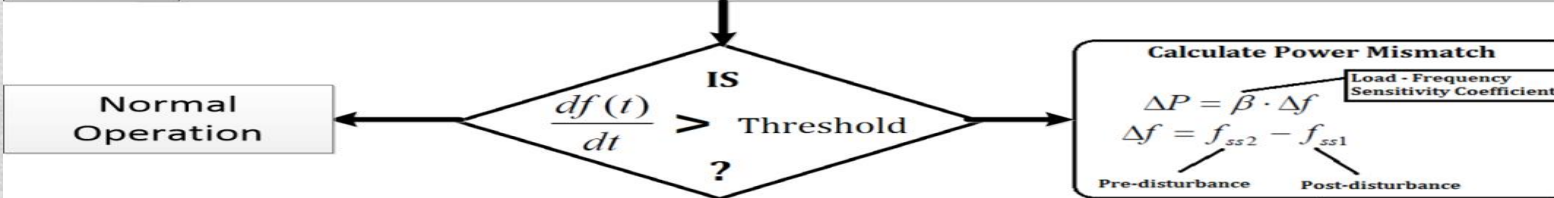
- Smart Load shedding



# Smart Load Shedding



Calculate Disturbance Size	$\frac{df(t)}{dt} = \left( \sum_{i=1}^{m(t)} \frac{df_{n_i}(t)}{dt} \right) / m(t)$ <p><math>n</math> is the total number of the FDRs <math>m(t)</math> is the number of available FDRs</p>
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# Acknowledgment

The team gratefully acknowledge funding and support from **National Telecom Regulatory Authority (NTRA)**, Egypt (<http://www.ntra.gov.eg>) to implement the EWAMS architecture presented in this work. More details about project activities are given in [www.helwan-ntra.com](http://www.helwan-ntra.com).







**Thank you for  
your attention**

# Q&A

