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State Estimation via Phasor Measurement Units for Iraqi National Super Grid Power System Network

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Abstract- *In this paper describes the operation of power system networks to be nearest to stability rated values limits. State estimation for monitoring and protection power system is very important because it provides a real-time (RT) Phase angle of different nodes of accuracy and then analysis and decided to choose control way (methods). In order to detect the exact situation (instant state) for power system networks parameters. In this paper proposes a new monitoring and analysis system state estimation method integrating with MATLAB environment ability, by using phasor measurement units (PMU's) technology, by this system the estimation problem, iterations numbers, and processing time will reduce. The measurements of phasors value of voltage signal and current estimated and analyzed. Mat lab/PSAT package use as a tool to design and simulate four electrical power systems networks such as INSG 24 buses, IEEE14 bus, Diyala city 10buses (IRAQ), and IEEE6 bus and then installed and applied PMU's devices to each system. Simulation results show that the PMU's performances effectiveness appear clearly. All results show the validation of PMU's devices as an estimator to power system networks states and a significant improvement in the accuracy of the calculation of network status. All results achieved and discussed through this paper setting up mathematical models with Graph Theoretic Procedure algorithm.*

Index Terms **- PMU; State Estimation; Iraqi Super Grid; Power System Monitoring; and Transmission Lines Systems.**

I. INTRODUCTION

Nowadays the state estimation can provide a platform to monitor the power system networks. State estimators give ideal appraisals of transport voltage phasors taking into account the access estimations, furthermore, information about the system topology. Up to this point, accessible estimation sets did not contain stage edge estimations because of the specialized troubles connected with the synchronization of estimations in remote areas.

Adaptive weight assignment function to dynamically adjust the measurement weight based on the distance of big unwanted disturbances from the PMU measurements is therefore proposed to increase algorithm robustness [1].

In PS networks, the control focus gets the framework wide gadget data and estimation for the most part through a SCADA framework. [13]. Notwithstanding, the data and estimation information given by SCADA may not generally be exact and dependable. Then again, the gathered estimations may not permit direct extraction of the relating constant AC operation condition of the framework. These worries drive the advancement of force framework innovation. [14]

A numerical definition of the ideal PMU position issue will be exhibited. Preparatory results, which didn't represent the loss of PMUs are introduced before. This plan prompts an arrangement in light of whole number programming furthermore encourages examination of system recognizes ability. Besides, it is sufficiently general to represent the loss of a single PMUs, presence of zero and non-zero force infusions and power stream estimations.

Utilizing the estimation plan found by this strategy, the paper researches the execution of straight estimators that only utilize PMUs and depicts location and distinguishing proof of fizzled

PMUs by utilizing the lingering based awful information handling strategies[2]. Power framework state estimation constitutes the center of the on-line framework checking, examination and control capacities [3].

State estimation acts like a channel between the crude estimations got from the framework and all the application capacities that require the most solid information base for the present framework operation state, and it commonly incorporates terrible information handling, state estimation arrangements, parameter and topology mistake preparing, and different investigations [4]. In spite of the aforementioned points of interest related to the organization of PMUs in the force matrix, it may not be plausible to introduce a PMU at each transport of the framework.

The prohibitive cost of PMU, and additionally specialized and financial necessities of the related correspondence hardware, constrains their establishment. Be that as it may it be still conceivable to determine the advantages of PMU establishment if a percentage of the transports are checked specifically by the establishment of PMU and some are observed by implication, by the PMUs introduced on associated transports. Deciding a base number of PMUs to make the framework discernible is regularly alluded to as Optimal PMU Placement issue [5].

Finally, in this paper phasor measurement units investigated to state estimation of monitoring and analysis for each of Iraq national super grid INSG 24 bus, IEEE14 bus, Diyala city 10buses (IRAQ), and IEEE6 bus as a real time (RT) Phase angle of different nodes and buses voltage has been well done. PSAT is a MATLAB package is a free tool box was utilized to achieve the paper objective. Simulation results obtained using Phasor estimation technique has been done.

II. A STATE ESTIMATION METHOD INTEGRATING PHASOR MEASUREMENT UNITS (SEPMU)

A. Power Systems Networks

By using MATLAB/ PSAT package, 4 networks was designed such as Iraq super grid INSG 24 bus, IEEE14 bus, Diyala city 10buses (IRAQ), and IEEE6 bus. Table (I) shown the summary of the power system networks data.

TABLE I
SUMMARY OF THE POWER SYSTEM NETWORKS DATA.

Network name	Bus NO.	LINE NO.	Generator NO.	Load NO.
INSG	24	36	11	17
IEEE14	14	15	5	11
Diyala city (IRAQ)	10	15	3	7
IEEE6	6	11	3	3

B. Phasor Measurement unit

PMU’s used to break down the well being of the framework in which electric waves on power matrix are measured. Synchrophasor estimations are the estimations that happen in the meantime. PMUs are utilized to give synchronization. The PMU units can provide waveforms with a frequency of 50Hz at during faults in the network, using separate channels. This feature gives the operator a real-time graphical representation of system during a fault, and also allows transient assays real time.

The PMU measurements can also be used for precise determining the location, time and the consequences of any error that is difficult simulated, proving that the applications that use data synchronized measurements are very important for system analysis in during disorders.

Fig.1 shows that the PMU is utilized for different applications as a part of power system, for example, insurance, state estimation, shortcoming area of transmission line. PMU have both online (Real-Time) and disconnected from the net (not constant) applications. PMU gives answers for wide zone checking, wide zone interconnected framework security and control [6].

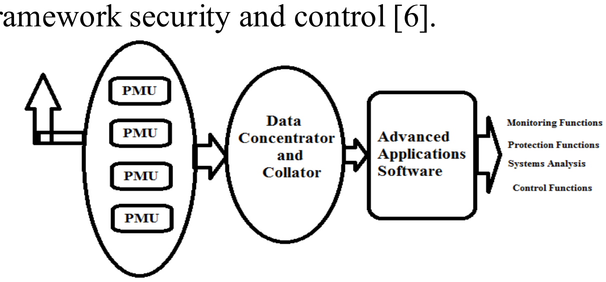

Fig.1 Application of PMU’s in power systems. [12].

C. State Estimation (SE) By PMU

The state estimation relates to the process of finding the measure and the angle the voltage of all network scales at a given time. This can achieve directly by using means that include very precise and synchronized measurements adoptive phase measurements of all scales. However, such an approach would be highly vulnerable erroneous measurements or telemetry errors. To address this, the state estimation using these measurements than those needed to filter and delete the incorrect, and then compute the optimal assessment. Measurements include not only conventional power and voltage measurements, but as well as other power meter measurements and synchronized measurements adoptive phase voltage [8].

Simultaneous measurements at different points in the network are almost impossible to be therefore small time differences between measurements are normal and tolerated. This is explained by the fact that under normal operating conditions network status changes very slowly. Since state estimation estimates the voltage adoptive phase the scales of the network are to be done properly should topology and all network parameters to they're known. However, errors in these figures may occur for various reasons such as small lesions of systemic problems in transmission lines heavy load days [10].

Phase Measurement unit provides two types of measurements, bus voltage phasors and branch current phasors. Being dependent on the type of PMUs used the number of channels used for measuring voltage and current phasors will vary. There is a relationship between the system state before and after PMU installation as gave in equation (1).

$$z = H.x + e \qquad (1)$$

Where:
z : is R+jX (for measured voltage and current phasors).
H : is Jacobian constant
x: is the state vector R+jX (for measured voltage and current phasors).
e: is error vector.

The linear state estimator can give in equation (2).

$$\hat{x} = G^{-1}.H^{T}.R^{-1}.z \qquad (2)$$

$\hat{x}$: is state estimated.
G = $H^{T}.R^{-1}.H$: is matrix constant gain.
$R = E\{ e \,.\, e^{T}\}$: is an act the diagonal error.

D. SYNCHROPHASOR

A phasor is commonly used for AC power system analysis. A sinusoidal signal and phasors form is represented as in equation (3).and (4)(4a) and(4b).[7].

$$x(t) = Xm \cos(wt + \vartheta) \qquad (3)$$

$$X = \frac{Xm}{\sqrt{2}} e^{j\vartheta} \qquad (4)$$

$$e^{j\vartheta} = (cos\vartheta + jsin\vartheta) \qquad (4a)$$

$$X = Xr + jXi \qquad (4b)$$

$\frac{Xm}{\sqrt{2}}$ is the R.M.S. signal . (5)
ϑ is phase angle.

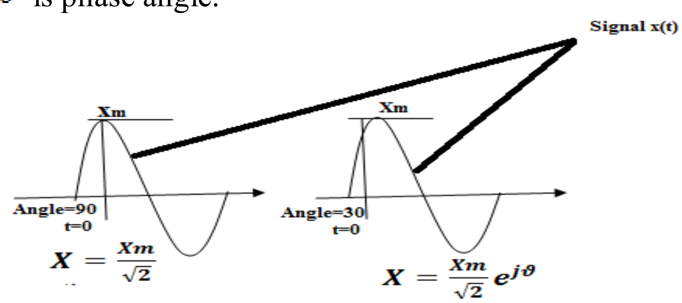

Fig.2 Synchrophasor representation

Fig.2 and Fig.3 shows that the synchrophasor representation and basic applications (power systems networks). Exposes system (local and inter area mode) oscillations and can be used to validate system performance, model parameters, control equipment settings Set up more reliable protection systems and System restoration [7].

If the phase difference between the reference peak and the measured signal peak is 30 degrees, the phasor representation is given in equation (4).If the phase difference is zero hence the phasors representation becomes as in equation (5). [8].

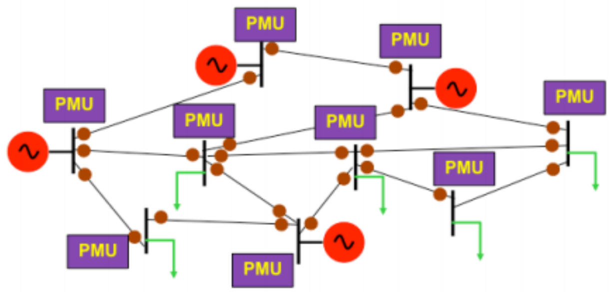

Fig.3 Synchrophasor Basic Applications (power systems networks)[7].

III.PMU MATHEMATICAL MODEL

Mat lab /PSAT package used to simulate power system networks with phase measurement unit (PMU's). To modeling PMU mathematically the magnitude and phase angle of currents and voltages must calculated as shown equations (6-13) [6].

$$V(t) = \cos\ (wt + \vartheta), \quad w = 2\pi * f$$

$$g(t) = y(t) - y\left(t - \frac{1}{f}\right) \qquad (6)$$

For real part , Frequency (f) in (Hz) = 50Hz.

$$y(t) = 100 \int v(t) \sin(t)\ dt = \left(\frac{1}{1-w^2}\right)(-100) * (v(t)\cos(t) - wsin(wt + \vartheta)\sin\ (t)) \qquad (7)$$

$$y\left(t - \frac{1}{f}\right) = 100 \int v\left(t - \frac{1}{f}\right) sin\left(t - \frac{1}{f}\right) dt$$

$$= \left(\frac{1}{1-w^2}\right)(-100^* \cos\ (w\left(t - \frac{1}{f}\right))^* \cos\left(t - \frac{1}{f}\right) - 100(w) \sin\left(w\left(t - \frac{1}{f}\right) + \emptyset\right) * sin\left(t - \frac{1}{f}\right)) \qquad (8)$$

For imaginary part

$$y(t) = \int u(t)dt \text{ ,and } u(t) = 100\ v(t)\cos\ (t)$$

$$k(t) = y(t) - y\left(t - \frac{1}{f}\right) \qquad (9)$$

$$= \left(\frac{1}{1-w^2}\right)(-100) * (v(t)\cos(t) - wsin(wt + \vartheta)\cos\ (t)) \qquad (10)$$

$$y\left(t - \frac{1}{f}\right) = 100 \int v\left(t - \frac{1}{f}\right) sin\left(t - \frac{1}{f}\right) dt = \left(\frac{1}{1-w^2}\right)\ (100^*(v\left(t - \frac{1}{f}\right)) *-100(w)^* \sin\left(w\left(t - \frac{1}{f}\right) + \emptyset\right) * cos\left(t - \frac{1}{f}\right)) \qquad (11)$$

$$|Re| = \sqrt{(g(t))^2 + (y(t))^2} \qquad (12)$$

$$\emptyset = \tan^{-1}\left(\frac{y(t)}{g(t)}\right) \qquad (13)$$

Where

|Re| and$\emptyset$: is the magnitude value and phase angle respectively.

IV. GRAPH THEORETIC PROCEDURE ALGORITHM

Fig.4 shows in the flow chart of Graph Theoretic Procedure algorithm. The first PMU is placed on the bus with the largest number of connected branches, and taking into account pure transit nodes. Assign one current pseudo-measurement to each branch where current can be indirectly calculated by the Kirchhoff current law. This rule is applied when the current balance at one node is known, i.e. if the node has no power injections [10].

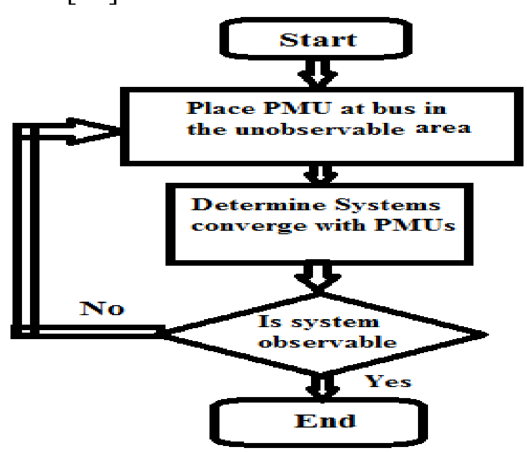

Fig.4 Flowchart of the Graph Theoretic procedure algorithm [10].

V. NUMERICAL OBSERVABILITY

The network is observable. If the number of independent columns of Jacobean matrix H (x) is equal to the size of the state vector minus one. Otherwise, they are observable islands. Another way is arithmetic control diagonal gain matrix G (x). Specifically, the network is observable if the matrix profit can be calculated without zeros occur in the diagonal elements. Otherwise, introduced pseudo voltage angle or power injector to self observable scales to eliminate the corresponding zeros on the diagonal of G (x) or considered unobservable and other scales assessed. This algorithm is very simple and easy and is used to estimate the state.

The only problem is the case that very small values usually rounded to zero in the calculations, and that makes selection difficult Right unobservable by the diagonal elements of the gain matrix. The necessary and sufficient condition to be observable network is the actual measurements to create at least one tree to it contains all the scales (not necessarily all sectors). If not, then the algorithm looks for observable islands by the same method small trees or adds pseudo measurements to create a tree and make observable the network.

VI. SIMULATION RESULTS

In this paper phasors measurement units applied on four systems once in time two networks are locally such as (Iraqi National Super Grid, & Diyala city 10buses (IRAQ) and the second two internationals networks (IEEE14 bus, and IEEE6 bus). All these systems were designed for PSAT package [11] it is a powerful tool box used with MATLAB software. To test the performance and measurements of PMU's [9].

The content of Table II is Computation Time required to synchronization and PMUs locations and its illustration Phasors measurements unite numbers for each system network.

TABLE II
COMPUTATION TIME REQUIRED TO SYNCHRONIZATION & PMUS LOCATIONS.

Network name	Bus NO.	PMU's NO.	PMU's Location	Time in (Sec.) Requirement
INSG	24	8	BGN, Baiji, Bus10 Bus13, Bus18, Bus20, Kirkuk, MMDH	0.36341
IEEE14	14	5	Bus 1,4,6,10,14	0.06635
Diyala city (IRAQ)	10	3	DAL3, HMRN,KNK N	0.22188
IEEE6	6	1	Bus5	0.26837

A. Iraq National Super Grid INSG 24buses

INSG has 24 buses , 36 lines,11 generator and 17 of loads. Table III shows the Bus voltage and Angles of buses voltage actual and estimated (after &before PMU's installation) for IRAQ National Super Grid.

TABLE III
BUS VOLTAGE AND ANGLE OF BUS VOLTAGE ACTUAL AND ESTIMATED (AFTER &BEFOREPMU'S INSTALLATION) for IRAQ SUPER GRID.

NO.	Bus Code	Bus Voltage (p.u) before PMU's installation	Bus Voltage (p.u) estimated After PMU's installation	Angle of bus voltage before PMU's installation	Angle estimated of bus voltage after PMU's installation	PMU Ranking

1	BAJG	1	0.9578	-0.88489	-1.2613	--
2	**BGN**	**0.62126**	**0.65372**	**-1.7337**	**-1.0785**	**PMU5**
3	Baghdad East	0.7656	0.81934	-1.5546	-1.2035	--
4	**Baiji**	**1**	**0.83958**	**-0.73969**	**-1.1953**	**PMU2**
5	**10**	**0.92317**	**0.74813**	**-0.82113**	**-1.1218**	**PMU8**
6	**13**	**0.94539**	**0.76294**	**-1.6631**	**-1.1709**	**PMU4**
7	14	0.9272	0.78031	-1.6557	-1.1823	--
8	15	0.95094	0.83438	-1.7268	-1.21184	--
9	16	1	0.83002	-1.6056	-1.2116	--
10	17	1	0.81815	-1.6308	-1.2056	--
11	**18**	**0.87315**	**0.70302**	**-1.5622**	**-1.1187**	**PMU1**
12	19	0.7769	0.78612	-1.6135	-1.1823	--
13	**20**	**1**	**0.88471**	**-1.7526**	**-1.2491**	**PMU3**
14	21	0.96362	0.92823	-1.7626	-1.2679	--
15	22	1	0.86863	-1.6957	-1.2361	--
16	23	1	0.88635	-1.7459	-1.2483	--
17	8	0.86396	1.1126	-1.0136	-1.323	--
18	9	1	0.84178	-0.74088	-1.1926	--
19	Dyala	0.81866	0.98708	-1.3541	-1.2825	--
20	IRAN SIDE	Not connected	Not connected	Not connected	Not connected	--
21	**Kirkuk**	**1**	**0.74545**	**-1.1087**	**-1.1387**	**PMU7**
22	**MMDH**	**1**	**0.83491**	**0**	**-1.1842**	**PMU6**
23	MOSUL	0.93243	1.1697	-0.36985	-1.3332	--
24	QDSG	0.58906	0.69258	-1.7886	-1.1158	--

Fig.5 shows the single line diagram of the Iraqi national super grid network (INRSG 24 buses) with connected PMU's. Fig.6 shows Graph representation of "INSG 24 bus" Network. Fig.7 shows the Elimination tree of "INSG 24 bus" network, i.e. If there is more than one bus with this characteristic, one is randomly chosen. Following PMUs are placed with the same criterion. Until the complete network observes ability is obtained.

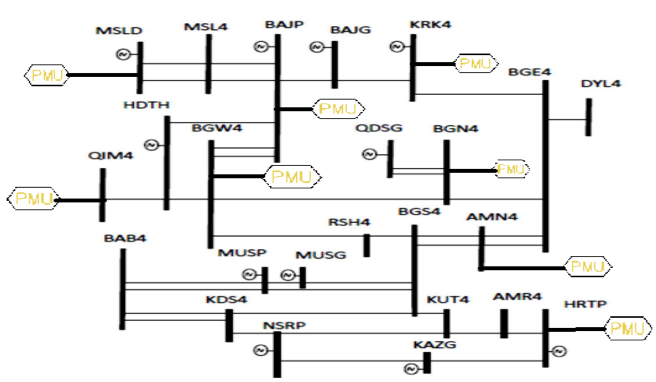

Fig.5 Single Line diagram of Iraq national super grid network (INRSG 24 bus) with PMU's installation

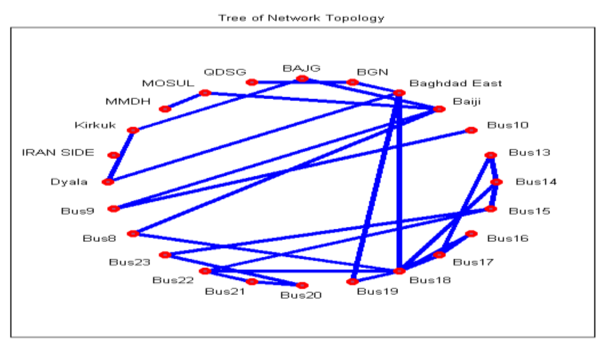

Fig.6 Graph Representation of " INSG 24 bus" Network

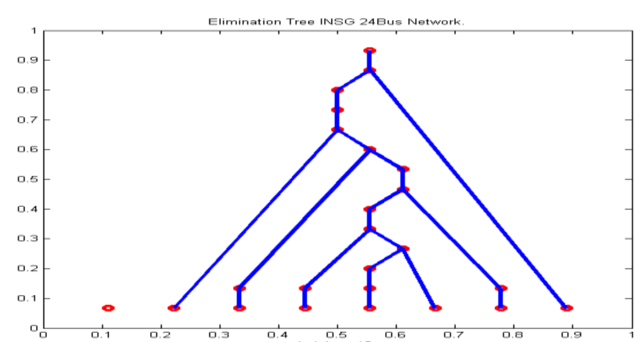

Fig.7 Elimination Tree of "INSG 24 bus" Network.

B. IEEE14 buses Network

IEEE14buses has 15 lines,5 generators and 11 loads. Table IV shows that the Bus voltage and Angle of bus voltage, actual and estimated (after &before PMU's installation) for IEEE14bus. Fig.8 shows the Single Line diagram of IEEE14 bus Network with PMU's installation. Fig.9 shows the Graph Representation of "IEEE 14 bus" Network. And Fig.10 shows the Elimination Tree of "IEEE14 bus" Network.

TABLE IV
BUS VOLTAGE AND ANGLE OF BUS VOLTAGE, ACTUAL AND ESTIMATED (AFTER &BEFORE PMU'S INSTALLATION) for IEEE14BUS.

Bus NO.	Bus Voltage (p.u) before PMU's installation	Bus Voltage (p.u) estimated After PMU's installation	Angle of bus voltage before PMU's installation	Angle estimated of bus voltage after PMU's installation	PMU Ranking
1	**1.06**	**1.0428**	**0**	**-0.11044**	**PMU5**
2	1.045	1.0281	-0.0871	-0.20188	---
3	1.045	1.0281	-0.22267	-0.29067	---
4	**1.01**	**1.0318**	**-0.1785**	**-0.20745**	**PMU1**
5	1.012	1.0298	-0.23091	-0.23794	---
6	**1.0493**	**1.024**	**-0.15273**	**-0.18416**	**PMU2**
7	1.016	1.0442	-0.25161	-0.27163	---
8	1.07	1.039	-0.23091	-0.25706	---
9	1.09	1.0378	-0.25853	-0.2485	---
10	**1.0328**	**1.0268**	**-0.26223**	**-0.23705**	**PMU4**
11	1.0318	1.0197	-0.25897	-0.20774	----
12	1.0471	1.0176	-0.26645	-0.21501	---
13	1.0534	1.0357	-0.2671	-0.21958	----
14	**1.047**	**1.0341**	**-0.28018**	**-0.23374**	**PMU3**

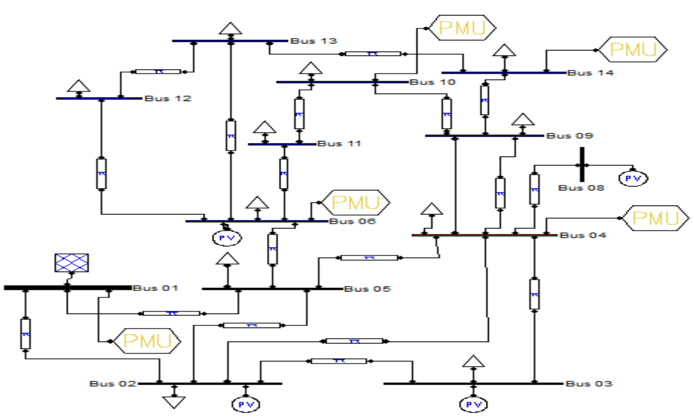

Fig.8 Single Line diagram of IEEE14 bus Network with PMU's installation.

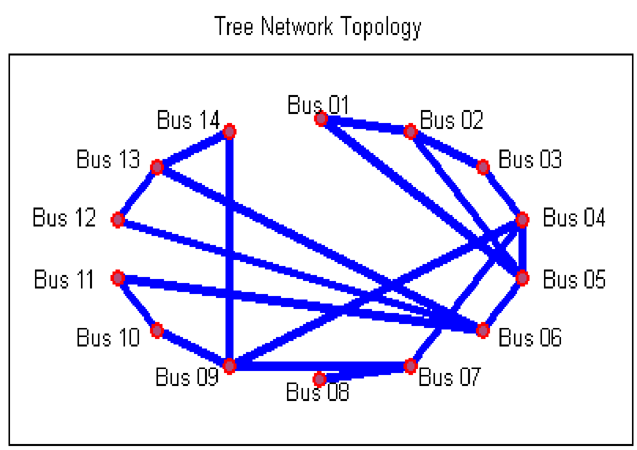

Fig.9 Graph Representation of " IEEE 14 bus" Network

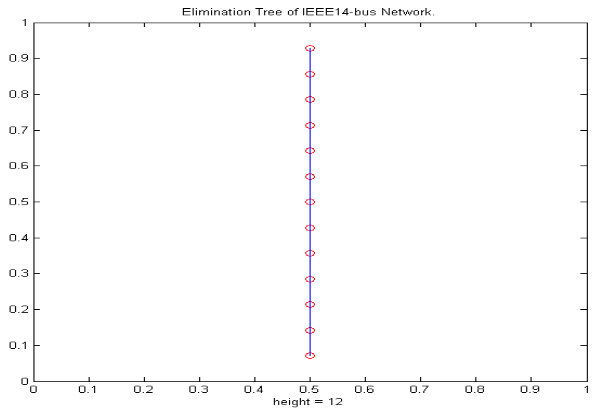

Fig.10 Elimination Tree of " IEEE14 bus " Network.

C. Diyala City 10buses (IRAQ) Network

Diyala power system network has 10bus,15 lines,3 generators and 7 loads. Table V shows that the Bus voltage and Angle of bus voltage actual and estimated (after &before PMU's installation) for Diyala city 10buses (IRAQ) network. Fig.11 shows the Single Line diagram of Diyala city (IRAQ) 10bus Network with PMU's installation . Fig.12 shows the Graph Representation of "Diyala city 10 bus" Network. Fig.13 shows the Elimination Tree of "Diyala City 10 bus" Network.

TABLE V
BUS VOLTAGE AND ANGLE OF BUS VOLTAGE ACTUAL AND ESTIMATED (AFTER &BEFORE PMU'S INSTALLATION) for DIYALA CITY 10BUSES (IRAQ) NETWORK.

Bus NO.	Bus Code	Bus Voltage (p.u) before PMU's installation	Bus Voltage (p.u) estimated After PMU's installation	Angle of bus voltage before PMU's installation	Angle estimated of bus voltage after PMU's installation	PMU Ranking
1	BLDZ	0.95151	0.9692	-0.04734	-0.04778	--
2	BQBE	0.95337	0.96705	-0.02092	-0.3129	--
3	BQBW	0.98455	0.97898	-0.00864	-0.00038	--
4	**DAL3**	**1**	**0.98312**	**0**	**-0.01782**	**PMU1**
5	HMRH	1	0.97868	0.01922	-0.00235	--
6	**HMRN**	**0.98105**	**0.98339**	**0.01026**	**-0.01486**	**PMU3**
7	KALS	0.994	0.98165	-0.00529	-0.098	--
8	**KNKN**	**0.96273**	**0.97739**	**0.0156**	**-0.00721**	**PMU2**
9	MQDA	0.9602	0.97079	-0.00607	-0.04033	--
10	ZERBIL	1	0.96251	0.09655	-0.0926	--

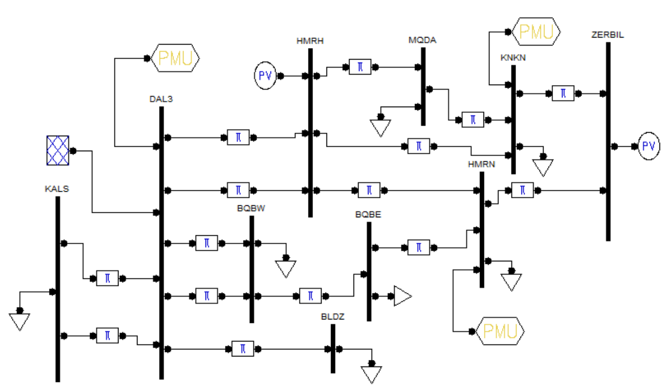

Fig.11 Single Line diagram of Diyala city (IRAQ) 10bus Network with PMU's installation.

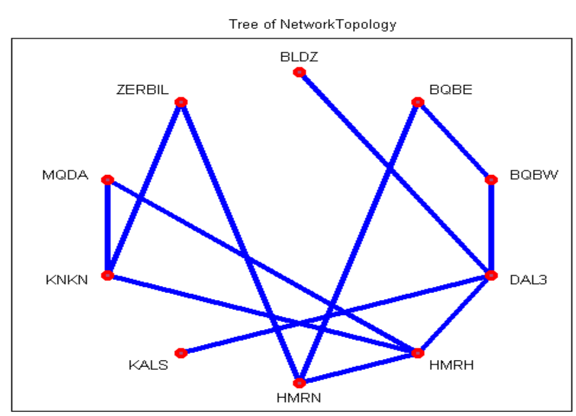

Fig.12 Graph Representation of " Diyala city 10 bus" Network.

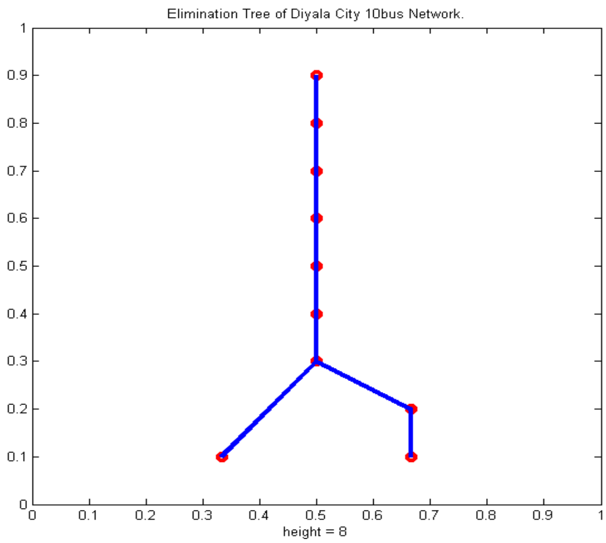

Fig.13 Elimination Tree of " Diyala City 10 bus " Network.

D. IEEE6bus network

IEEE6 bus network has 11 lines,3 generators and 3 loads. Table VI shows the Bus voltage and Angle of bus voltage actual and estimated (after &before PMU's installation) for IEEE6bus network. Fig.14 shows the Single Line diagram of IEEE 6bus Network with PMU's installation. Fig.15 shows the Graph Representation of "IEEE 6 bus" Network. Fig.16 shows the Elimination Tree of "IEEE 6 bus" Network.

TABLE VI
BUS VOLTAGE AND ANGLE OF BUS VOLTAGE ACTUAL AND ESTIMATED (AFTER &BEFORE PMU'S INSTALLATION) for IEEE6BUS NETWORK

Bus NO.	Bus Voltage (p.u) Before PMU's installation	Bus Voltage (p.u) estimated After PMU's installation	Angle of bus voltage before PMU's installation	Angle estimated Of bus voltage After PMU's installation	PMU Ranking
1	1.05	0.95509	0.02534	-0.12354	-
2	1.05	0.95757	0	-0.12967	-
3	1.05	0.94959	-0.03529	-0.14147	-
4	0.98592	0.93895	-0.04064	-0.20437	-
5	**0.96854**	**0.966854**	**-0.07261**	**-0.07261**	**PMU1**
6	0.99121	0.94788	-0.0735	-0.20633	-

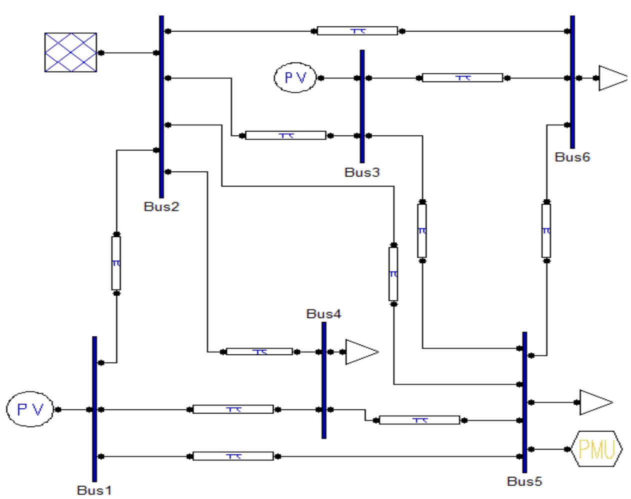

Fig.14 Single Line diagram of IEEE 6bus Network with PMU's installation.

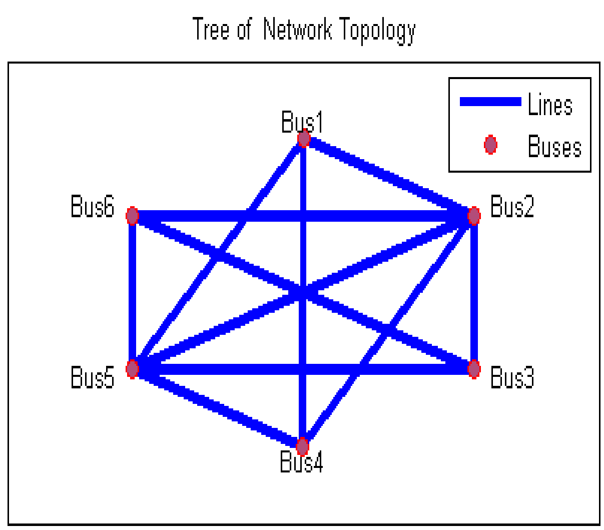

Fig.15 Graph Representation of " IEEE 6 bus" Network.

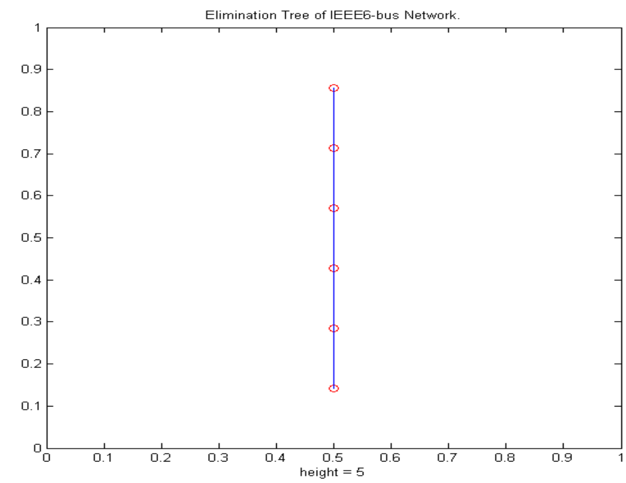

Fig.16 Elimination Tree of "IEEE 6 bus" Network.

E. Linear Static State Estimation

Phase measurement unites was chosen randomly to cover all the networks areas , Table VII shows the Summary of linear static state estimation .as shown there are no buses out of PMU's control , all the measured voltage and measured currents was discovered and recorded the bad data acts as a pseudo measured currents discovered and recorded.

TABLE VII
SUMMARY OF LINEAR STATIC STATE ESTIMATION

Network name	Measured voltage	Measured Currents	Pseudo Measured Currents	Actual PMU Number	Non observable buses
INSG	8	29	8	8	0
IEEE14	5	15	5	5	0
Diyala city (IRAQ)	3	13	2	3	0
IEEE6	1	5	6	1	0

VII. CONCLUSIONS

In this paper, the monitoring system analyzed and presents, the Graph Theoretic procedure method used to prove that the accuracy state estimation is a priority by using PMU's devices in a power system. The PMU is able to measure the voltage magnitude, current and phasors and it is investigated with the linear formulation for power system state estimation. The algorithm is applied on four power system networks such as (INSG 24 bus, IEEE14 bus, Diyala city 10buses (IRAQ), and IEEE6 bus) and the execution time is enough small for each of networks is (less than one sec.). By adding PMU device in random form in a power system grid to improve the result of the network state estimation. Simulation results show that the accuracy indicators improved clearly in the phasors voltage angles and more accurate voltage meters for all four PSN's. Simulation results are done by using matlab /PSAT as a tool.

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