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Phase Measurement Units based FACT's Devices for the Improvement of Power Systems Networks Controllability

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ABSTRACT

This paper describes the importance of FACTS devices; it presents the outcome of the study of its reflectance on the performance of power system networks. It seeks to increase and guarantee the fact and accuracy of response systems under disturbance conditions when the phase measurement units are introduced as Real-Time Measurement (RTM) stations. This paper also describes the importance of FACTS devices. The combination of FACTS devices and PMUs is presented to increase the controllability performance of power systems. This paper demonstrates how PMUs measure voltage, current and their angles. It provides, through a communication link, a Phase Angle Data Concentrator (PDC) to make an appropriate decision to correct the power system state using the FACTS device (TCSC). We utilized the Graph-Theoretic Algorithm to optimize the number and location of PMUs. The technique proposed was tested on the Iraqi National Super Grid's 24bus network, Diyala City's regional 10bus network and the 14bus IEEE standard test system. The MATLAB/PSAT package was utilized for the simulation of results. It is evident that our proposed algorithm and technique achieved the purpose of this paper as confirmed by the level of accuracy of the results obtained from most of the cases tested.

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NOMENCLATURES

WAMC	:	Wide area Estimation Control.
PMU	:	Phasor Measurement Units.
X_{TCSC}	:	Capacitive reactance of FACTs devices.
|Re|	:	Magnitude value.
XL, XC	:	Inductance reactance and capacitance reactance.
TCSC	:	FACT's Devices Thyristor Controlled Series Capacitor.
TL	:	Transmission lines.
PDC	:	Phase Angle Data Concentrator.
UPFC	:	Unified Power Flow Controller.
PS	:	Power system.
RTO	:	Real Time Operations.

Greek Symbols

α	:	Controlled thyristors angle (α) ranging between 90° and 180°.
θ	:	Phase angle value.

1. INTRODUCTION

This paper highlights Iraq's transmission system which comprises of a 400KV and a132KV systems. The whole framework consists of about 24 substations of 400KV capacity and 233 substations of 132KV capacity. The failure of the 132KV systems to handle the expansion in burden request in the 1970s necessitated the acquisition of the 400KV lattice transmission system; a reliable system that transmits power from the south and north of Iraq to the focal districts. The country's ever-changing power needs have, in recent years, necessitated the development of new generation plants, substations and transmission lines [1]. However, all the effort put into developing the power sector was geared towards energy generation to cope with the ordinate dictation of loads, but not to improve the performance of the system. The very complex Iraqi transmission network has an immense capacity.

The National Control Centre is responsible for monitoring and managing the whole system. It is made up of three regional control systems located in the north, center and south of the country. These regional control centers receive information from substations in their operational areas [2].

A close check of the working conditions of the framework is required to ensure that force power systems are secure and that there are no disruptions in their operations. This task is undertaken by a State Estimator in the control focus PC accessing data from reliable estimations sourced from various substations. It is from remote terminal units of substations that these estimations are sourced. The estimations include: force infusions, dynamic/receptive force streams, transport voltages and branch ebbs and flow extent; electrical switch state (turn on/off) and tap changer positions of transformers. It is difficult to ascertain the unwavering quality of the framework using ordinary (SCADA) estimations because of low estimating rates and the usually low precision of estimations [3].

For the determination of the points where qualification contrivances should be installed to maximize the monitoring area, the optimum monitor allocation is utilized [4]. Observability analysis, which determines the tenacity of bus numbers and the location of monitors, can be carried out with documented procedures based on topological or numerical methods. This method has the advantage of solving the observability quandary with low data input requirement. The survival matrix is the only input data it needs. The matrix provides all the data it requires to solve the quandary. The observability constraint, obtained from Kirchhoff's laws, ensures that all the state variables are quantified by at least one monitor. A PMU placed at a given bus can provide the phasor currents of several, or all, lines incident to that bus and the voltage phasor [5-8].

Another component of smart grids, the Wide Territory Estimation Control (WAMC), focuses on giving time synchronized by Phasor Measurement Units (PMU) close continuous estimation of the force network. The WAMC framework must be tested so as to ensure sufficient execution and dependability after it has been set up. The WAMC framework requires estimation, control activities, information handling and correspondence. The framework might produce undesirable results if any of the components malfunction or suffers an interruption. To improve the WACM framework requires an examination of the force framework execution, steadiness and execution of controllers and corresponding systems and the physical security of the framework [9].

To stabilize voltage and enhance power systems transient, the TCSC, a type of FACTS device used with a TL, damps power system oscillation and resonance and reduces asymmetrical components. Figure 1(a) shows a compensator TCSC, a type of series FACTS compensator. The compensator is comprised of a capacitance connected in parallel with an inductance which is controlled by a device placed in anti-parallel with conventional thyristors, controlled by an angle of extinction (α) ranging from 90° to 180°. The compensator TCSC injected a variable capacitive reactance (X_{TCSC}) in the transmission line as depicted in Figure 1(b). As shown in Figure 1, X_{TCSC} is directly related to the controlled thyristors' angle (α), varied between 90° - 180° [10], [11].

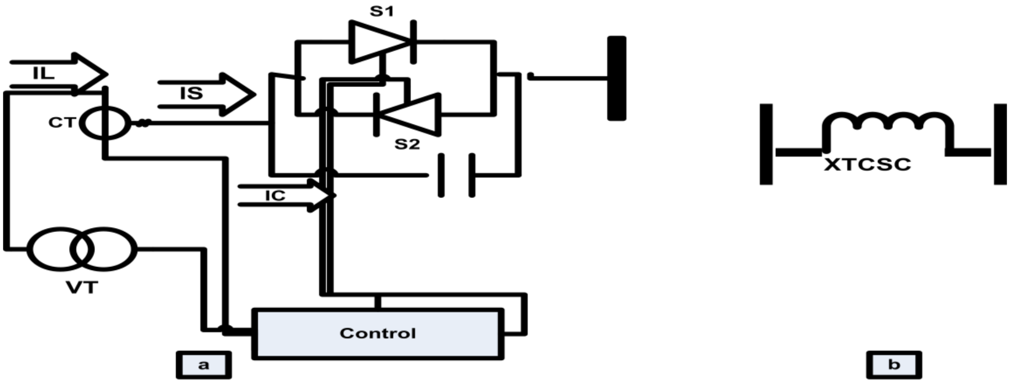


Figure 1. TCSC model connected to Transmission line (a) mounting and (b) apparent reactance [10]

Phasor Measurement Units (PMUs) technology is used to detect system estimation problems, iteration of numbers and to reduce processing time. The measurement of phasor values of voltage signals and current estimates is done with a PMU analyzer's MATLAB/PSAT package [12]. The power system state estimation has become a critical tool for the power system operator in the actual context of power markets and the increased concerns for the power grid system. The purpose of state estimation in power system operation is shown in Figure 2 [13].

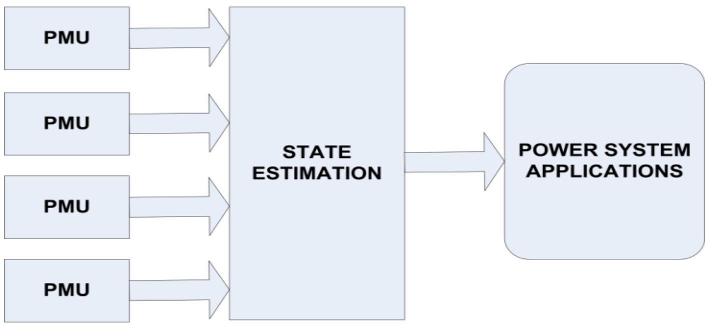


Figure 2. General diagram for state estimation in powersystem operation [13]

A given numerical model of power lines, transformers and other transmission gadgets combine to determine the handling state estimation. The application of FACTS innovation to improve framework controllability and increase power exchange limits by presenting power electronic gadgets at the correct spots of the AC current framework is, however, not substantial with conventional SE strategy. There is a method of calculating the state estimation of systems that are implanted with FACTS gadgets. Keeping in mind the end goal, the state estimation plan is adjusted to consolidate the point-by-point model of the Unified Power Flow Controller (UPFC). This needs the use of fairness and disparity imperatives that records the points of confinement linked to the gadget's operations appraisals. The proposed calculation is used for state estimation. It can also be used to decide the controller settings of FACTS gadgets for a desirable working condition as introduced by [14].

The Thyristor Switched Series Capacitors (TCSC) are chosen, in this paper, as the FACT's devices to, with PMUs, build new techniques or schemes. PMUs measure voltage, current and their angles. They provide, through a communication link, the phase angle differences in a phase data Concentrator PDC to make decisions and correct the power system state using FACTS devices (TCSC). All the results are obtained from using MATA/PSAT packages [15]. This suggests a validation of the proposed technique and algorithm.

2. PHASE MEASUREMENT UNITS MODEL

Power system networks with Phase Measurement Units (PMUs) are stimulated by Mat lab/PSAT packages. The magnitude and phase angle of currents and voltages must be calculated, as shown in (1)-(12), to mathematically model PMU [16].

$$v(t)=cos\ (wt+\theta)$$

$$w = 2\pi f,$$

$$A=\left(t-\frac{1}{f}\right), B=\left[\frac{1}{\left(1-w^{2}\right)}\right],$$

$$g(t)= y(t)-y(A) \tag{1}$$

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

$$y(t)=100\int v(t)sin(t)\ dt = -100B\left[v(t)cos(t)-wsin(wt+\theta)sin(t)\right], \tag{2}$$

$$y(t)=100\int v(A)\ sin(A)\ dt$$
$$= -100B\left[\left(cosw(A)\right)cos(A)\right]-100(w)\left[sin\left(w(A)+\theta\right)sin(A)\right] \tag{3}$$

For imaginary part

$$y(t)=\int u(t)dt$$

and

$$u(t)=100\ v(t)cos(t) \tag{4}$$

$$k(t)=y(t)-y(A) \quad = -100B\left[v(t)cos(t)-wsin(wt+\theta)cos(t)\right] \tag{5}$$

$$y(A)=100\int v(A)sin(A)dt = B\left[100\left(v(A)\right)-100(w)sin\left(w(A)+\theta\right)cos(A)\right] \tag{6}$$

$$|\mathrm{Re}|=\sqrt{\left[(g(t))^{2}+(y(t)\ )^{2}\right]} \tag{7}$$

$$\phi = tan^{-1}\left[\frac{y(t)}{g(t)}\right] \tag{8}$$

Where

|Re| and Ø: is the magnitude value and phase angle respectively.

3. FACT'S DEVICES THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC)

FACT's devices can be utilized to control power systems and, taking care of its ability to access transmission foundations closer to its warm evaluation, improve power by controlling interrelated parameters overseeing its operations. The interconnected parameters consist of current, stage point, voltage, damping of under-recurrence motions and, shunt and arrangement of impedances. Fast thyristors are used as FACTS gadgets to switch out and switch in transmission line compensators, like capacitors and reactors, and to stage movement of transformers for operations [17]. Figure 2 depicts how this is communicated by taking after condition.

$$x_{\mathrm{TCSC}(\alpha)}=\frac{x_{\mathrm{c}}}{x_{\mathrm{L}(\alpha)}}=\frac{\left(x_{\mathrm{c}}\, x_{\mathrm{L}(\alpha)}\right)}{\left(x_{\mathrm{c}}+x_{\mathrm{L}(\alpha)}\right)} \tag{9}$$

$$X_{L(\alpha)} = X_{(L\max)} \cdot \frac{\pi}{\pi - 2\alpha - \sin(2\alpha)} \quad (10)$$

Where

$$X_{(L\max)} = L.w \quad (11)$$

$$X_C = \frac{-1}{jwc} \quad (12)$$

X_L, X_C : Is inductance reactance and capacitance reactance.
X_{TCSC} : FACTs reactance and *L is* Inductance.
α : Controlled thyristors angle (α) ranging between 90° and 180°.

4. GRAPH THEORETIC PROCEDURE ALGORITHM

A flowchart of the Graph Theoretic Procedure Algorithm is depicted in Figure 3. Taking into account pure transit nodes, the first PMU is placed on the bus with the highest number of connected branches. One current pseudo measurement is assigned to each branch where it can be indirectly calculated by application of the Kirchhoff current law. This rule is applicable when the current balance at one node is known and if the node has no power injections [18].

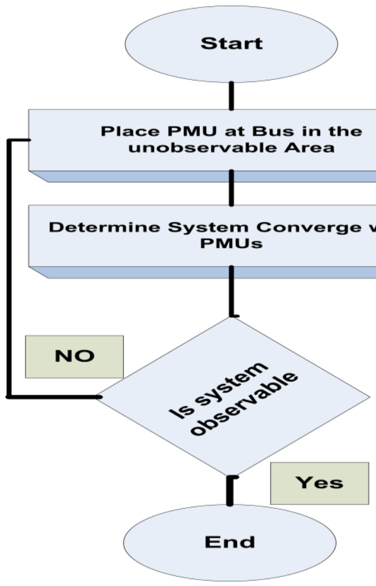


Figure 3. Flowchart of the Graph Theoretic procedure algorithm [18]

5. PROPOSED METHOD OR CONTROL SCHEME

The values of V, I, and phase angles taken from the sending and receiving ends of the TL of PMUs are sent to a PDC via a communication link. Thereafter, the values are compared with their respective communication satellite time. The aim is to try to control the power flow. There are some pre-defined algorithms in the control room, values obtained from PMUs that are thereafter compared with those algorithms. The power that flows is changed if there is a difference in the values of voltage, current and phase angle. To overcome that, therefore, a signal is generated and sent to the local area control room. To find the optimal locations of PMUs, a Graph Theoretic Procedure algorithm is used [18]. A variable capacitive reactance is then injected into the TC by a compensator TCSC. As mentioned in Equation (9) to Equation (12), the expression X_{TCSC} is injected to the controlled thyristors angle (α) ranging between 90° and

180°. Data is then passed from the PMUs to the PDC through a communication link. Using a FACTs device controller (TCSC), the PDC makes the right decision and corrects the power system status [19].

The technique proposed was tested (as a first time) (on the Iraqi National Super Grid's 24bus network, and the Diyala City regional 10bus network in central Iraq) and then tested on the 14bus IEEE standard test systems. The networks mentioned in this paper all utilized TCSC FACTs devices whose locations on the bus gave them voltages that were under the rated value. The form of a TCSC control with a PMU application on PS network is shown in Figure 4. The basic scheme for a PMU with a FACTS control (the proposed method), is shown in Figure 5.

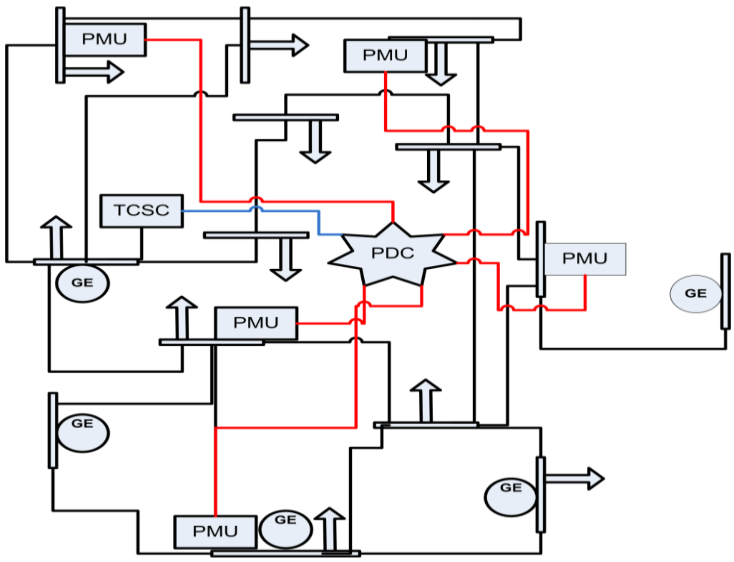


Figure 4. TCSC control with PMU Application on PS. Network

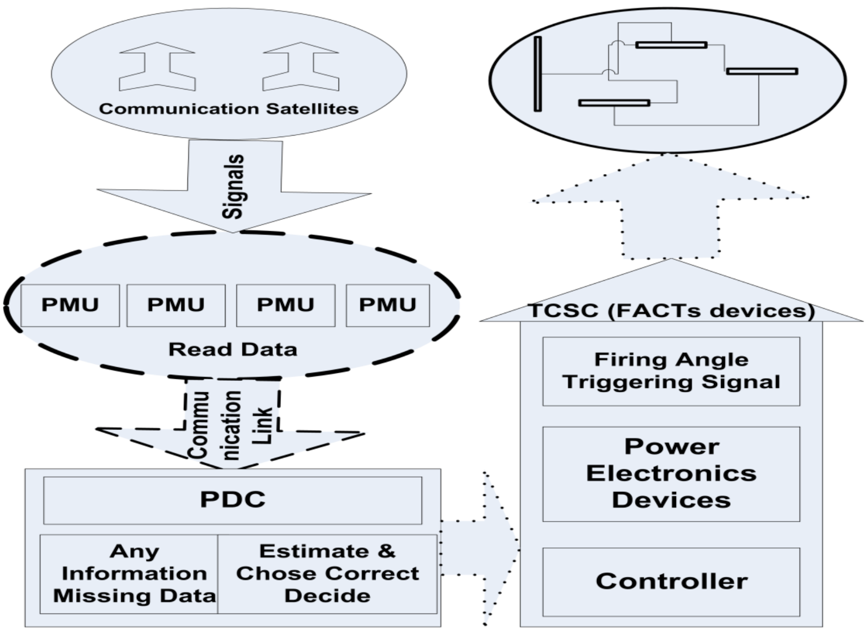


Figure 5. Basic scheme for PMU with FACT's control (Proposed method)

6. SIMULATION RESULTS AND DISCUSSION

The phasor measurement units under consideration in this paper were applied in three cases, once in two local networks like (Case 1) the Diyala City 10buses network and (Case 2) the Iraqi National Super Grid. The third is the IEEE 14bus international network (Case 3). These were designed by a PSAT package, a powerful tool box used with MATLAB software. All results are done as comparison with the true values for bus voltage (VB) and angle bus voltage (δ) befor adding devices for power system network ,and after installation TCSC only,and the third part after installation both (TCSC&PMU) all of that discussed with details. The placement of the FACTs devices (TCSC) was chosen randomly to study the effects on power system control with PMUs.

In case 1, two TCSC devices were connected on Line (BQBW-BQBE) between (B2 B3) and on Line (KALS-DAL3) between (B4 B7).
In case 2, four TCSC devices were connected on the Line between (B5 B6) and the Line between (B10 B3) and Line between (B23 B19) and the Line between (B13 B14).
In case 3, there are three TCSC devices connected on Line between (B9 B10), on Line between (B4 B2) and on Line between (B9 B10).

Table 2, Table 4, and Table 6 show the PMU's locations for each of the cases enumerated above. The true voltage magnitude, bus voltages after TCSC installation, and bus voltage after both installation TCSC &PMU (combination (TCSC & PMUS)) for each case is depicted on Table 1, Table 3, and Table 5. The PMU location and angle values for true bus voltages, with only TCSC, and then after both installation TCSC &PMU (combination (TCSC & PMUS)) for each case are shown on Table 2, Table 4, and Table 6.

As showed on Table 7, the proposed technique is a valid method of improving the performance of power systems control. It promptly detects failure problems and reduces total loss (in comparison to the total loss for each network).

Table 1. True Voltages Magnitudes, bus voltages after only TCSC installation, and bus voltage after both installation (TCSC &PMU)For Diyala city 10buses (Iraq)

Bus NO.	True Voltage (p.u)	Bus Voltage (p.u) with TCSC	Estimated Bus Voltage (p.u) for both (TCSC &PMU) after installation
1	0.95151	1.0431	0.99023
2	0.95337	1.0141	0.98498
3	0.98455	0.98321	0.98539
4	1	1	1
5	1	1	1
6	0.98105	0.9962	0.98583
7	0.994	1.0011	0.99025
8	0.96273	0.9626	0.98255
9	0.9602	0.96013	0.97535
10	1	1	1.0023

Table 2. PMU location and angles values for bus voltages for true, with only TCSC and after both installation (TCSC &PMU) (combination with (TCSC & PMUS)) for Diyala city 10buses (Iraq)

Bus NO.	True Angle in (rad)	Angle (rad) with TCSC	Estimated Angle (rad) For both (TCSC &PMU) after installation	PMU Location
1	-0.04734	0.06822	-0.03835	--
2	-0.02092	0.02047	-0.01816	--
3	-0.00864	-0.00998	0.02543	
4	-0.02692	0.02347	0.04439	PMU1
5	0.01922	0.03148	0.01155	
6	0.01026	0.03348	0.01167	PMU3
7	-0.00529	0.00141	0.04262	
8	0.0156	0.03032	0.072	PMU2
9	-0.00607	0.00728	-0.02615	
10	0.09655	0.11471	-0.08183	

Table 3. True Voltages Magnitudes, bus voltages after only TCSC installation, and bus voltage after both installation (TCSC &PMU) for 24bus Iraqi National Super Grid

BUS NO.	True Voltage (p.u)	Voltage (p.u) with TCSC	Estimated Bus Voltage (p.u) for both (TCSC &PMU) after installation
1	0.91082	0.96148	0.959
2	0.90552	0.90691	0.92036
3	1	1	1.0038
4	0.8696	0.96778	0.966
5	0.90097	1.0548	1
6	0.92049	0.99462	1.001
7	0.89891	0.95348	0.98223
8	1	1	1
9	0.92687	0.94242	1.01
10	0.93711	1.05409	1.035
11	1	1	1
12	1	1	1
13	1	1	1
14	0.93553	0.97101	0.9912
15	1	1	1
16	1	1	1
17	0.91822	0.9017	0.9145
18	1	1	1.0254
19	1	1.0301	1.025
20	1	1	1
21	0.90401	0.93912	0.9453
22	1	1	1.003
23	0.92317	0.92317	0.9445
24	1	1	1

Table 4. PMU location and angles values for bus voltages for true, with only TCSC, and after both installation (TCSC &PMU) (combination with (TCSC & PMUS)) for 24bus Iraqi National Super Grid

Bus NO.	True Angle in (rad)	Angle (rad) with TCSC	Estimated Angle (rad) For both (TCSC &PMU) after installation	PMU Location
1	-1.9343	-1.8577	-1.3579	---
2	-2.132	-2.0524	-1.4431	---
3	-1.0804	-1.0468	-1.4514	---
4	-2.0217	-1.9429	-1.3853	PMU4
5	-1.8611	-1.785	-1.3803	---
6	-1.9769	-1.8961	-1.3354	PMU5
7	-1.8979	-1.8238	-1.3536	PMU1
8	-0.8941	-0.86584	-1.4011	PMU2
9	-1.21	-1.1722	-1.4813	---
10	-1.629	-1.5628	-1.4347	---
11	-0.8953	-0.8669	-1.397	---
12	-2.1085	-2.0271	-1.4214	PMU3
13	-1.7779	-1.7682	-1.3536	---
14	-2.0048	-1.9255	-1.3936	---
15	-1.3442	-1.3054	-1.3797	PMU7
16	-2.093	-2.011	-1.4248	---
17	-2.0658	-1.9895	-1.4238	---
18	-2.093	-2.017	-1.3894	PMU6
19	-0.4470	-0.43293	-1.4862	---
20	-1.9984	-1.9201	-1.4014	---
21	-1.9986	-1.9213	-1.4149	---
22	-2.0619	-1.9787	-1.4136	---
23	-0.9755	-0.94715	-1.3526	PMU8
24	-1.9854	-1.9039	-1.3687	

Table 5. True Voltages Magnitudes, bus voltages after only TCSC installation, and bus voltage after both installations (TCSC &PMU) for IEEE14bus

Bus NO.	True Voltage (p.u)	Voltage(p.u) with TCSC	Estimated Bus Voltage (p.u) for both (TCSC &PMU)after installation
1	1.06	1.06	1.0545
2	1.045	1.045	1.043
3	1.01	1.01	1.0376
4	1.013	1.022	1.0377
5	1.0167	1.0225	1.0362
6	1.055	1.07	1.0307
7	1.0525	1.0561	1.0567
8	1.09	1.09	1.0482
9	1.039	1.0419	1.045
10	1.0369	1.0409	1.0428
11	1.0497	1.0517	1.0332
12	1.0558	1.0628	1.0329
13	1.0514	1.0533	1.0257
14	1.04	1.04	1.0431

Table 6 PMU location and angles values for bus voltages for true, with only TCSC, and after both installation (TCSC &PMU) (combination with (TCSC & PMUS)) for IEEE14bus

Bus NO.	True Angle in (rad)	Angle (rad) with TCSC	Estimated Angle (rad) For both (TCSC &PMU) after installation	PMU Location
1	-0.12873	-0.1233	-0.13745	PMU5
2	-0.08705	-0.0873	-0.23078	--
3	-0.22255	-0.21682	-0.1757	--
4	-0.17873	-0.1713	-0.19351	PMU1
5	-0.15273	-0.14727	-0.22522	--
6	-0.25047	-0.24321	-0.17211	PMU2
7	-0.2314	-0.22384	-0.22094	--
8	-0.2314	-0.22384	-0.25252	--
9	-0.25902	-0.25156	-0.24381	--
10	-0.26244	-0.25475	-0.23641	PMU4
11	-0.25857	-0.25114	-0.22089	--
12	-0.26581	-0.25911	-0.19041	--
13	-0.26787	-0.25994	-0.19892	--
14	-0.28664	-0.27778	-0.20717	PMU3

Table 7. Comparison between Total Losses for each Network

Test	Total Losses		Total losses With TCSC		Total losses After installation both (Combination (TCSC & PMUS))	
	MW [p.u.]	MVAR [p.u.]	MW [p.u.]	MVAR [p.u.]	MW [p.u.]	MVAR [p.u.]
10bus	0.05503	-0.13529	0.03716	-0.22734	0.03113	-0.239
24bus	0.18506	1.8497	0.112	1.1192	0.01173	0.1163
14bus	0.13475	0.26993	0.11111	0.29009	0.04552	0.0519

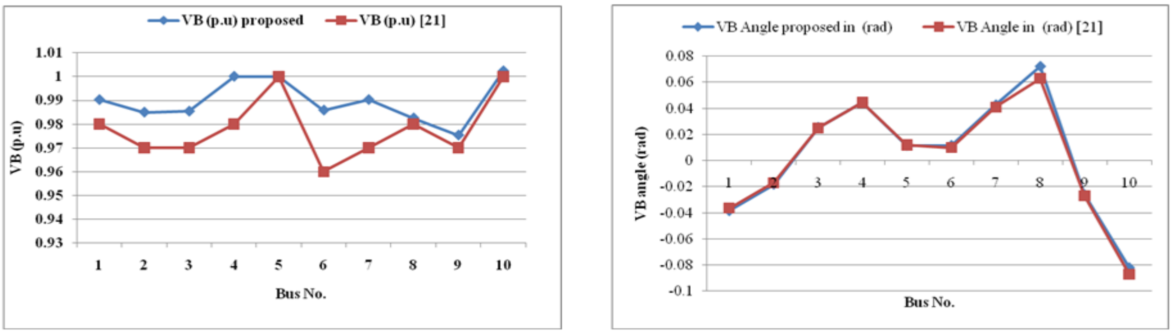
7. COMPARISON AND ANALYSIS APPROACH

As comparison and to make the network are observable at all buses provide the power system network with less number of PMUs [20], in this paper another method used To reduce number of PMUs based optimization approach is introduced by using Integer Linear Programming in [21], its work to PMUs placement and give the number of PMUs when the operation condition is normal. As shown in Table 8. The location and number of PMUs are shown for each method and each network.

As shown in Figure 6, Figure 7 and Figure 8 the buses voltages and angles are comparison by two methods after PMUs placements and change the number of PMUs by mean by used Graph Theoretic Procedure algorithm and Integer Linear Programming. From the results of the differences between the two methods are very small to behalf the proposed technique. FACTs devices (TCSC) locations are chosen randomly as mention above.

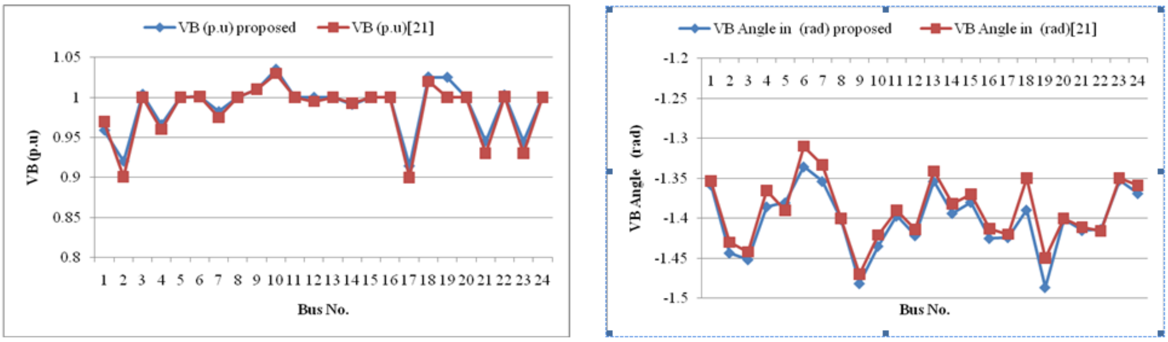
Table 8. PMUs locations comparison

Networks	Location of PMUs proposed work	Location of PMUs [21]
10 bus Diyala	4,6,8	1, 4, 8
24 bus Iraq	4,6,7,8,12, 15, 18, 23	4,6,7,12, 17, 18, 23
IEEE 14 bus	1,4,6,10,14	1,3,6,8,10,14



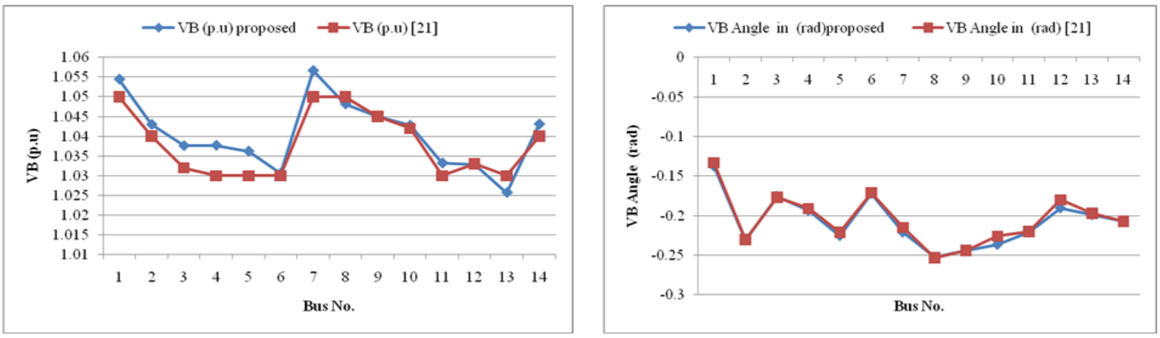
(a) (b)

Figure 6. 10 buses Diyala city network, (a) Voltage bus (p.u) comparisons (b) Voltage bus angles (rad) comparison



(a) (b)

Figure 7. 24 bus Iraq network, (a) Voltage bus (p.u) comparisons for 24 bus Iraq network, (b) Voltage bus Angles (rad) comparisons.



(a) (b)

Figure 8. IEEE14 bus network, (a) Voltage bus (p.u) comparisons, (b) Voltage bus Angles (rad) comparisons

8. CONCLUSIONS

It has been demonstrated in this paper that FACT's control devices respond fast to critical problems in power systems. The PMU were mathematically modeled and their utility's performance demonstrated. It has also been shown that the proposed method is fast and efficient for Real Time Operations (RTO). Also, the Graph-Theoretic Procedure Algorithm was utilized for the optimal placement of PMUs. The results obtained from the simulation of the Iraqi National Super Grid's 24bus network, the Diyala City's 10bus network and the 14bus IEEE standard test system validates the technique proposed in this paper. A comparison is then made with and without the TCSC and PMU and a blend of PMUs and TCSC FACTs devices in a system. The technique we propose can, as confirmed by simulation results, be used to improve the grid controllability performance of power systems which were achieved by use of a MATLAB/PSAT package. From the results of the PMU gives a more precision measurement of voltages and angles of bus voltages in the power systems. Many of researchers are interested and worked with this proposal work but with the local networks such as (Iraqi National Super Grid's 24bus network, and Diyala City's 10bus network) that are the first time that applied this technique on it. As a future work and recommendation it can use the intelligent methods and computational techniques to placement of FACTs devicesand PMUs devices.

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