Advances in Environmental Biology, 8(11) Special 2014, Pages: 1343-1349

AENSI Journals

Advances in Environmental Biology

ISSN-1995-0756 EISSN-1998-1066

Journal home page: http://www.aensiweb.com/AEB/

Optimal Placement of PMUs, in the Presence SCADA Meters, Considering the Sensitivity Constraints

[1]Mohammad ZohourAttar, [2]Farhad namdari, [3]Maryam Zohour Attar

[1]Departmanet of Electrical Engineering, Shoushtsar Branch, Islamic Azad University, Shoushtar, Iran
[2]Departmanet of Electrical Engineering, Lorestan University, Khoramabad, Iran
[3]Sama Technical and Vocational Departmanet,Islamic Azad University,DezfulBranch, Dezful, Iran

ARTICLE INFO

Article history:
Received 15 April 2014
Received in revised form 22 May 2014
Accepted 25 May 2014
Available online 15 June 2014

Keywords:
Power flowmete , power injectionmeter, double redundancy,optimal placement,sensitive bus,observability, phasor measurement unit.

ABSTRACT

Real-time state estimation of power system and resulting in the full observability of buses in smart grid, be done to help the optimal placement of phasor measurement unit.In this paper, in order to provide a suitable use of phasor measurement units, buses of high sensitivity, is be taken into consideration.Therefor optimal placement of the units considering the direct observability sensitive bus, observability with double redundancy for sensitive buses and direct observability sensitive buses with the double redundancy sensitive buses has been done. Also to minimize these meters to reduce costs, is considered effect meters presence power flow and power injection in the network. In this paper, the integer linear programming in MATLAB software environment for the implementation of 230 and 400 KV network in Khouzestan province of Iran has been used. Results, suggest theincreases to observability reliability of the network.

To Cite This Article: Mohammad Zohour¬Attar, Farhad namdari, Maryam Zohour Attar, Optimal Placement of PMUs, in the Presence SCADA Meters, Considering the Sensitivity Constraints. ***Adv. Environ. Biol., 8(11),*** *1343-1349, 2014*

INTRODUCTION

Nowadays with the introduction of smart grid technology, power grid has changed from a static infrastructure to a flexible and dynamic infrastructure. Therefore it is important to accurately estimate the state of the network and thus ensure sustainable performance of the network. Phasor Measurement Units (PMU) as one of the main components of the smart grid transformation, are the fundamental solutions for the real time monitoring power grids [1,12].

PMUis able to measure phasor voltage and current with high accuracy and speed[5,11,13] and by conversion of non-linear state estimation equations to linear equations there is no and need for sophisticated computational methods for solve them[7,13], which improves the speed control systems, safety and management systems, that use the results of state estimation[11].

Optimal placement of PMU to the electric grid observability is the research objective of this system.Since PMUs ability to quickly react to changes in the voltage phasor on sensitive buses when an error or overloading the power system have occurred, it is recommended that the equipment be installed in the buses of a power system with high sensitivity or the so-called critical buses[15].

Reference [11] has studied the problem of placement of Khouzestan province network by considering redundancy doubles for sensitive buses with GA method, But in the case of other sensitivity constraints there is no.

In this paper, due to the more rapid and efficient to answer the ILP method, it is used for optimal placement of PMU. Also in order to convenient user of PMU, according to selection criteria sensitive bus, have been considered for 230 and 400 KV network in Khouzestan province of Iran. Therefore because the is high the cost of PMU installation, is investigated to minimum the number of PMUs, the effect of the existing scada meters in these conditions.

Observability analysis based on PMU:

The power network when are observed that could be calculated all the state variables it namely phasor voltage of all buses, and current all its branches [14].

Corresponding Author: Mohammad ZohourAttar, Departmanet of Electrical Engineering, Shoushtsar Branch, Islamic Azad University, Shoushtar, Iran
E-mail: Zohuratar@yahoo.com

Installed of phasormausurement units on each bus, is able to measure the phasorvoltage this bus and phasorcurrent of branches connected its bus. As a result voltage size and phase angle connected buses to bus equipped the PMU also can are calculated with Kirchhoff relations. So the buses that in their have been installed PMU, are directly observed, and buses that are connected to the bus with PMU, they are indirectly observed [2].

The number of PMU that have the potential observability of a bus say the bus observability index (BOI), and the sum of bus observability for all the busses of a system, is say the (SORI)[8].

Placement the Phasor Measurement units:

Since the PMU installed at a bus can be possible the indirect visibility bus of adjacent to himself, it can be reduce the number of PMU installed on the network.

Optimum placement of PMUs for n bus system is formulated with relations (1)[3,4,9]:

$$\text{Min} \sum_{i=1}^{n} x_i \tag{1}$$

$$s.t \quad y = Ax \geq b$$

That in this connection A shows how to connect to other busses and transmission lines such as equation (2), also the PMU installed at bus i in the $x_i$variable is expressed in equation (3) is a binary variable associated with i bus[3,4,9]:

$$A_{n\times n}(i,j) = \begin{cases} 1 & i = j \\ 1 & \text{if buses i and j are connected} \\ 1 & \text{otherwise} \end{cases} \tag{2}$$

$$x_i = \begin{cases} 1 \text{ if PMU is installeat bus i} \\ 0 \text{ otherwise} \end{cases} \tag{3}$$

Since the minimum number of PMU should be enough for at least one time every bus is observable, the matrix b is shown in equation (4) [3,4,9]:

$$b_{n\times 1} = [1\ 1\ 1 \ldots 11]^T \tag{4}$$

Effect the Zero Injection Buses in Optimal Placement of PMU:

The bus which not associated with any active and passive load is called zero injection bus [8].

Formulation for optimal placement of PMU a considering zero injection buses in system with ILP algorithm as equation (5) [8]:

$$\begin{aligned} &Objective: \min \sum_{i=1}^{n} x_i \\ &Subject\ to: Ax \geq u \\ &and\ \mu_j = 1\ \ \forall j \notin B_1 \cup B_2 \ldots \cup B_z \\ &and \sum_{k\in B_i} \mu_k \geq |A_i| \quad \forall i \in Z \\ &or \quad a_i u \geq |A_i| \end{aligned} \tag{5}$$

Here, $B_i = A_i \cup \{i\}$ and $|A_i|$ is size of theA_i set and Z is set of the zero injection buses. In this equation $a_i$shows the corresponding row with zero injection buses in the binary connection matrix (A). the second constraint in this equation is ensures that the buses that are not related to the zero-injection busses, make sure observability[8].

Placement of PMU considering the sensitive constraints:

The bus which may have many changes of voltage phasor, due to the system changes is called sensitive bus [1]. System changes could be due to one error in system or changing load.

Since the PMU have be the rapid response capability against voltage phasor changes, whenever happens on the sensitive busses an error or overloading, the power system operator predict status the power system, through the study of PMUs data installed on sensitive buses. And the proper functioning the prevent of entire system outages [15].

Criterions for selection of sensitive busses are as follows:

- Being power plant busses
- Having long transmission lines
- Higher capacity of generators and transformers
- Short circuit level
- Restriction on operation maneuver
- Having old equipment
- Disagreement of dispatching with blackout for service and repair
- And ... [11].

Formulation of the optimal placement of PMU problem, considering the sensitivity constraints, the purpose of the observability system takes place in three phases:

1. *Direct Observability Sensitive Bus in Placement of PMU:*

In this case, should be installed of PMU on every sensitive bus, then is formulated to form equation (6)[10]:

$$\min \sum_{i=1}^{n} x_i$$
$$\text{subject to: } A_{n\times n} \times X_{n\times 1} \geq b_{n\times 1} \quad (6)$$
$$A'_{n\times n} \times X_{n\times 1} = b'_{n\times 1}$$
$$X_{n\times 1} = [x_1 x_2 \dots x_n]^T$$
$$x_i \in \{0,1\}$$

That in above equations, equality $A'_{n\times n} \times X_{n\times 1} = b'_{n\times 1}$is the related constraint to sensitive buses. Matrix $A'_{n\times n}$ and $b'_{n\times 1}$vector is defined as equation (7):

$$A'_{n\times n}(i,j) = \begin{cases} 1 \; if \; i = j \; and \; bus \; i \; is \; sensitive \; buse \\ 0 \; otherwise \end{cases} \quad (7)$$
$$b'_{n\times 1} = \begin{cases} 1 \; if \; bus \; i \; is \; sensitive \; bus \\ 0 \; otherwise \end{cases}$$

2. *System Observability considering Double Redundancy for Sensitive Busses:*

In this case, each one of sensitive busses must be observed at least the two PMU[11]. Hence, after determining the sensitive buses can be defined equations as the equation (8).

$$\min \sum_{i=1}^{n} x_i$$
$$\text{subject to: } A_{n\times n} \times X_{n\times 1} \geq b_{n\times 1} \quad (8)$$
$$X_{n\times 1} = [x_1 x_2 \dots x_n]^T$$
$$x_i \in \{0,1\}$$

In the above equations, is defined the $A_{n\times n}$ matrix and $X_{n\times 1}$ vector same of the basic model. And $b_{n\times 1}$vector is defined as equation (9):

$$b_{n\times 1} = \begin{cases} 2 \quad if \; \; bus \; i \; is \; sensitive \; bus \\ 1 \quad otherwise \end{cases} \quad (9)$$

3. *Direct Observability Sensitive Busses considering the Double Redundancy to the Sensitive Buses:*

In this case, should be provided the constraints in case 1 and 2 be considered simultaneously Form of equation (10):

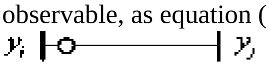
$$\min \sum_{i=1}^{n} x_i$$
$$\text{subject to: } A_{n\times n} \times X_{n\times 1} \geq b_{n\times 1} \quad (10)$$
$$A'_{n\times n} \times X_{n\times 1} = b'_{n\times 1}$$
$$X_{n\times 1} = [x_1 x_2 \dots x_n]^T$$
$$x_i \in \{0,1\}$$

$A_{n\times n}$Matrix and $X_{n\times 1}$vector is similar to the basic model. $b_{n\times 1}$vector is calculated of the equation above in mode 2, and $A'_{n\times n}$matrix and $b'_{n\times 1}$vector of the equation in mode 1.

Optimal Placement of Phasor Measurement Units with considering available measurement (SCADA):

a) *Power flow measurement:*

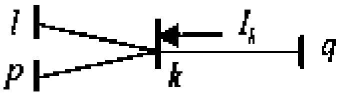
If one flow measurement be on line ij, then by being a observability the one bus, also other bus is observable, as equation (11) [3,15].



$$y_i y_j \geq 1 \quad (11)$$

b) *Power injection measurement:*

By placing one injection measurement on k bus, is reduced one of the observability constraints. With the model in problem such as modeling zero injection bus, similar to equation (12) [3,15].

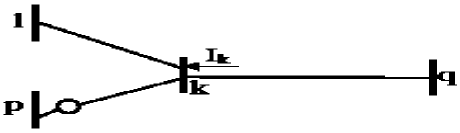


$$y_l + y_p + y_k + y_q \geq 3 \quad (12)$$

Advances in Environmental Biology, 8(11) Special 2014, Pages: 1343-1349

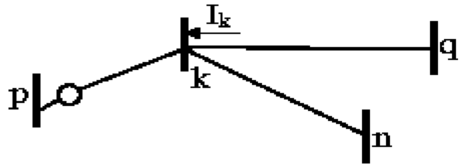
c) Combined the flow power and power injection measurement:

If exist the combination of measurement according to the following is becomes in equation (13) [3,15]



$y_l + y_q \geq 1$ (13)

And similarly to following figure we have in equation (14):



$y_q + y_n + y_l \geq 2$ (14)

So the problem of optimal placement of PMU can be modeled as ILP problem in equation (15) [14].

$$\begin{bmatrix} I_{M\times M} & 0 \\ 0 & A_{meas} \end{bmatrix}(PY) = A_{con}PY = A_{con}PYX \geq b_{con} \quad (15)$$

Thatb_{con} vector dramatic the b matrix with proposed conditions in the measurement equations, and P matrix, is the matrix arrange the buses, that is shown how the arrangement buses in A_{con} matrix. A_{con} matrix, is related to the presence of measuring devices, and where m is the number of unrelated buses to the common measurement installed on the network.

A_{meas} matrix that is expressed these entries use the relations meters, is expression of arrangement measuring devices installed in the buses.

So the problem of optimal placement PMU, can be modeled the linear problem as equation (16) [14].

$$\begin{aligned} &\min \sum_{i=1}^{n} x_i \\ &subject \quad to: \ A_{con}.P.A.X \geq b_{con} \\ &\qquad X_{n\times 1} = [x_1 \quad x_2 \quad \cdots \quad x_n]^T \\ &\qquad x_i \in \{0,1\} \end{aligned} \quad (16)$$

Simulation results placement PMU:

In this section, in order to evaluation of formulation, in the 5 steps to has been studied the optimal placement of PMU, considering sensitivity constraints and the presence of SCADA meters for observability 230 and 400 KV Khouzestan province (in Iran) network with integer linear programming (ILP) algorithm in MATLAB software. It should be noted that in these cases has been considered the effect of zero injection buses.

Figures (1) and (2) shows network diagram 230 and 400 KV Khuzestan province in Iran. In table (1) is presented post names for better clarity network and easier analysis it.

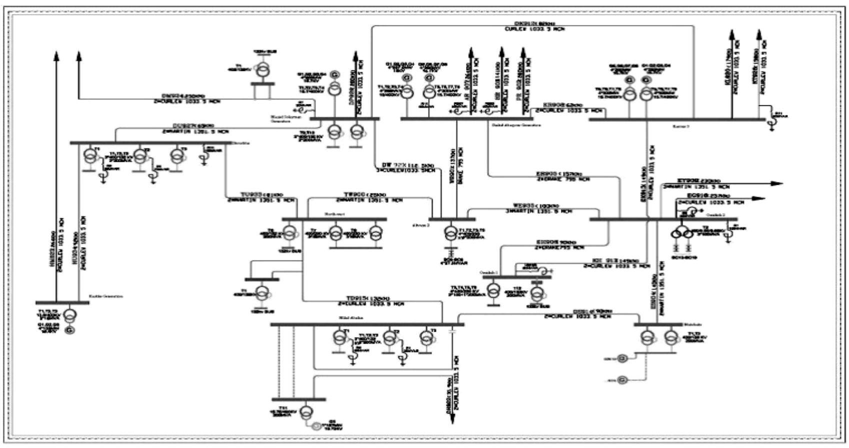


Fig. 1: 230 KV network in khouzestan province.

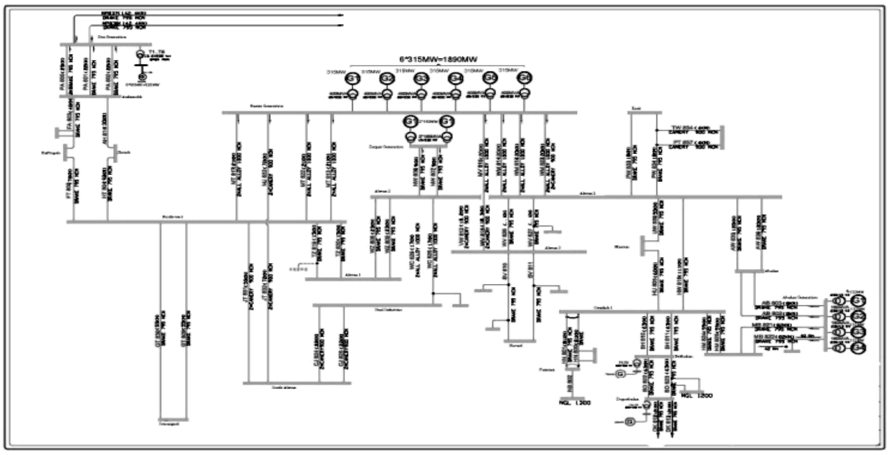


Fig. 2: 400KV network in Khouzestan province.

Table 1: The post names of Khouzestan province.

400kv khouzestan province		230 KV Khouzestan province	
Post name	*Post number*	*Post name*	*Post number*
ShahidAbaspour Generation	1	Ramin Generation	1
Karoun 3	2	Abadan Generation	2
MasjedSoleyman Generation	3	Dez Generation	3
Karkhe Generation	4	Zergan Generation	4
Ahwaze2	5	Ahwaz 2	5
Milad Abadan	6	North-west	6
Omidieh 1	7	South Ahwaz	7
Omidieh 2	8	Steel Industries	8
Mahshahr	9	Abadan	9
Shoushtar	10	Omidieh 1	10
North west	11	Behbahan	11
-	-	Dogonbaadan	12
-	-	Ahwaz 1	13
-	-	Andimeshk	14
-	-	Hafttapeh	15
-	-	Shoush	16
-	-	Ahwaz 3	17
-	-	Navard	18
-	-	Pezenan	19
-	-	Maroun	20
-	-	Kerit	21
-	-	Sousangerd	22

In 230 KV Khuozestan network, there is no zero injection buses. But in 400 KV network bus number 8(Omidiye2) has a zero injection.

Sensitive buses in 230 KV Khouzestan network include [11]:1-Ramin Generation, 2-Dez Generation, 9-Abadan, 10- Omidiye 1, 17-Ahwaz3.

Sensitive buses in 400 KV Khouzestan network include [11]:1-Shahid Abbaspour Generation, 3-Masjed Soleyman Generation, 4-Karkhe Generation, 11-North West.

First case) optimal placement with the direct observability of sensitive bus.:

At this stage using (6) and (7) given the sensitive buses in Khouzestan network respectively are listed, in table (2) to obtain the number and location of optimal PMU, considering direct observability sensitive bus, has been in comparison with the normal state. And in table (3) has been investigated BOI and SORI in this conditions.As can be seen the installation PMU of on the sensitive bus, is causing increase the number of PMU in 230 KV network from 6 to 9 and in 400 KVKhouzestan network from 3 to 5, and has increased SORI them from 34 to 45 and from 11 to 19.

Table 2: Positioning the PMU with and without considering the direct observability the sensitive buses.

Test system	Without considering the sensitive bus		With considering the sensitive bus	
	No. of PMUs	Location PMUs	No. of PMUs	Location PMUs
230KV khouzestan province	6	5,8,10,11,14,17	9	1,2,5,8,9,10,11,14,17
400KV khouzestan province	3	1,6,10	5	1,3,4,8,11

Table 3: BOI and SORI the PMU with and without considering the direct observability the sensitive buses.

Test system	Without considering the sensitive bus		With considering the sensitive bus	
	BOI	SORI	BOI	SORI
230KV khouzestan province	3,1,1,1,3,1,1,1,1,3,2, 1,2,1,2,2,2,1,1,2,1,1	34	4,3,1,1,5,1,2,2,3,4,2, 1,2,1,2,2,3,1,1,2,1,1	45
400KV khouzestan province	1,1,1,1,1,1,0,1,1,1,2	11	1,2,1,1,4,1,1,2,1,3,1	19

Second case) Optimal placement with the double redundancy for sensitive buses:

In this case, using (8) and (9), and specified the sensitive busesfor 230 and 400 KV Khouzestan provincenetworks, are calculated number and place in table (4), and BOI and SORI in table (5) for placement of PMUs with the double redundancy for sensitive buses, and has been the comparing their with normal condition.Is observed the installation of PMU on sensitive buses, Increase the number of PMU from 6 to 7And from 3 to 5 for 230 and 400 KV networks of Khouzestan. In this case, each sensitive buses, has been observed at least two PMU, and thus SORI of networks has increased considerably.

Table 3: Number and Positioning the PMU with considering double redundancy for sensitive buses.

Test system	Without considering double redundancy for sensitive bus		With considering double redundancy for sensitive bus	
	No. of PMUs	Location PMUs	No. of PMUs	Location PMUs
230KV khouzestan province	6	5,8,10,11,14,17	7	5,8,9,10,11,14,17
400KV khouzestan province	3	1,6,10	5	2,4,8,10,11

Table 4: Comparison BOI and SORI in placement of PMU with and without considering double redundancy for sensitive buses

Test system	Without considering double redundancy for sensitive bus		With considering double redundancy for sensitive bus	
	BOI	SORI	BOI	SORI
230KV khouzestan province	3,2,1,1,4,1,1,1,2,3,2,1,2,1,2,2,2,1,1,2,1,1	34	3,1,1,1,3,1,1, 1,1,3,2,1,2,1,2, 2,2,1,1,2,1,1,	37
400KV khouzestan province	2,1,2,2,2,1,2,1,1,3,2	11	1,1,1,1,1,1, 0,1,1,1,2	19

Third stage) optimal placement of PMU, considering direct observability and double redundancy as sensitive buses for observability network:

In this stage both conditions are level at the same time. Thus using (16) and given the sensitive buses, is achieved number of place in table (7). The results shows that needs more the PMU for full observability system in this stage.

Table 6: Positioning the PMU with considering direct observability and double redundancy for sensitive buses.

Test system	Without considering the sensitive bus		With considering the sensitive bus	
	No. of PMUs	Location PMUs	No. of PMUs	Location PMUs
230KV khouzestan province	6	5,8,10,11,14,17	9	1,2,5,8,9,10,11,14,17
400KV khouzestan province	3	1,6,10	6	1,3,4,8,10, 11

Table 7: BOI and SORI with considering direct observability and double redundancy for sensitive buses.

Test system	Without considering the sensitive bus		With considering the sensitive bus	
	BOI	SORI	BOI	SORI
230KV khouzestan province	3,1,1,1,3,1,1,1,1,3, 2,1,2,1,2,2,2,1,1,2,1,1	34	4,3,1,1,5,1,2,2,3,4,2,1, 2,1,2,2,3,1,1,2,1,1	45
400KV khouzestan province	1,1,1,1,1,1,0,1,1,1,2	11	2,2,2,2,4,1,1,2,1,4,2	19

Fourth stage) placement of PMU considering direct visibility and double redundancy for sensitive buses, in the presence SCADA meter:

At this stage, is considered sensitive constraints known the first and second stage with the presence SCADA meters for placement PMUs in table (8). The results has indicating of reduction the number PMUs.

Table 7: Positioning the PMU with considering direct observability and double redundancy for sensitive buses with in presence SCADA meter

Test system	Sensitive buses	Power injection meter	Flow Power meter	Location PMUs	SORI
230Kv khouzestan province	1,2,9,10, 17	7,12	1-5 2-5 3-4	5,7,10,11,14,17,2 2	33
400Kv khouzestan province	1,3,4,11	7,12	1-5 2-5 3-4	5,7,10,11	19

Fifth stage) optimal placement of PMUs considering the installation of constraints and the presence SCADA meters:

At this stage is done optimal placement of PMU, constraints the installation of PMU on some buses, at the same time Consideration Sensitivity Constraints and SCADA meters. So in table (5), is done location and number of units considering the bus number 10 in 400 KV network and bus number 21 in 230 KV network Khouzestan province in Iran are restrictions the installation of PMU. As can be seen remain the observables network considering the installation of constraints of PMU.

Table 8: Positioning the PMU with considering installation Restrictions on some buses and in presence SCADA meter.

Test system	Sensitive buses	Power injection meter	Flow Power meter	Location PMUs	SORI
230Kv khouzestan province	1,2,9,10,17	7,12	1-5 2-5 3-4	1,2,3,5,8,9,10,17	40
400Kv khouzestan province	1,3,4,11	7,12	1-5 2-5 3-4	1,3,4,8,11	19

Result:

In this paper for optimal placement phasor measurement units, considered direct observability sensitive bus, and double redundancy sensitive bus in 230 and 400 KV electricity transmission network in the Khouzestanprovince of Iran. The results shows, increase the observability despite the increasing number of PMU, butthis constraints be causing the increase observability confidence of system.Well as to reduce costs according to the high cost of installing these units, is suggested include power distribution and power injection meters found in some buses network. And results shows reduce the number of PMU, despite preservation observability network. Of course obviously the reduced SORI of system in this case towards the observability of system only by the PMUs.

REFERENCES

[1] Hesami Naghshbandi, A., F. Khavari, V. Naseri, 2010. “Optimal Placement of Phasor Mesurement Units for Observability Power System Using of Exploding a Grende”, International Power System Conference, PSC, 25’th, pp: 1-10, tehran 2010(perian).

[2] Mortezavi, S.S., M. Heidari, D. Mirabbasi, 2011. “GA and BIP basedOptimal Allocation of Phasor Measurement Units (PMUs) for Khouzestan Transmission Network compete observability ,Considering Ddouble Redundancy for Sensitive Substation”s,.International Conference on Sustainable Energy Technologies,10: 1-5, Istanbul,Turkiy,4-7.

[3] Wang, B., D. Liu, L. Xiong, 2009. ”An improved ant colony system in optimizing power system PMU placement problem”, Asia-Pacific Power and Engineering Conference, pp: 1-3.

[4] Xu, B., Y.J. Yoon and A. Abur, 2005. “Optimal placement and utilization of phasor measurements for state estimation”, Power Systems Computation Conference, Liege, Belgium.

[5] Makram, E., Z. Zhao, A. Girgis, 2011. An Improved Model in Optimal PMU Placement Considering Sensitivity Analysis, Power Systems Conference and Exposition (PSEC), pp: 1-6.

[6] Aminifar, F., C. Lucas, A. Khodaei, M. Fotuhi-Firuzabad, 2009. “Optimal placement of phasor measurement units usingimmunity genetic algorithm”, IEEE Transactions on PowerDelivery, 24(3).

[7] Dua, D., S. Dambhare, R. Gajbhiye, S.A. Soman, 2008. Optimal Multistage Scheduling of PMU Placement: AnILP Approach, IEEE Transactions on Power Delivery, 23(4): 1812-1820.

[8] Mao, A., J. Yu and Z. Guo, 2005. ” PMU placement and dataprocessing in WAMS that complements SCADA, IEEE InPower Engineering Society General Meeting, 1(12-16): 780-783.

[9] Amiri, S., H. Zahedi, 2012. “ ICA Algorithms for Optimal Placement of Phasor Measurement Units for Network Observability”, Conference on Electricity Distribution Network., EPDC, 17’th, Tehran,2012(persian).

[10] Enshaei, A., R. Hoshmand, F. Haghighatdar Fesharaki, 2010. ”Optimal Placement of Phasor measurement units to maintain full observable power networks if single out the line”, Smart Grids in electrical engineering, 2(2).

[11] Su, C., Z. Chen, 2010. “Optimal Placement of PhasorMeasurement Units with New Considerations”, Powerand Energy Engineering Conference (APPEEC), pp: 1-4.

[12] Aminifar, F., M. Fotuhi-Firuzabad, M. Shahidehpour, 2011. ,” Probabilistic Multistage PMU Placement inElectric Power Systems, IEEE Transactions on Power Delivery, 26(2): 841-849.