International Conference on Information Engineering, Management and Security 2015 [ICIEMS 2015]

ISBN	978-81-929742-7-9		**VOL**	01
Website	www.iciems.in		**eMail**	iciems@asdf.res.in
Received	10 - July - 2015		**Accepted**	31- July - 2015
Article ID	ICIEMS026		**eAID**	ICIEMS.2015.026

Optimal Pmu Placement For Tamilnadu Grid Under Controlled Islanding Environment

Dhanalakshmi G[1], Rajeswari R[1], Vignesh G[2]

[1]G.C.T., Coimbatore

[2]BHEL, Tiruchirapalli

ABSTRACT: *This paper proposes an optimal phasor measurement unit (PMU) placement model considering power system controlled islanding so that the power network remains observable under controlled islanding condition as well as normal operation condition. The optimization objectives of proposed model are to minimize the number of installed PMUs and to maximize the measurement redundancy. These two objectives are combined together with a weighting variable so that the optimal solution with minimum PMU number and maximum measurement redundancy would be obtained from the model.At last, IEEE-14 bus standard systems and the Tamil Nadu state power grid (83 bus system) are employed to test the presented model. Results are presented to demonstrate the effectiveness of the proposed method.*

Keywords: Controlled islanding, integer linear programming, measurement redundancy, optimal phasor measurement unit (PMU) placement.

I INTRODUCTION

Synchronized phasor measurement unit (PMU) is essentially a digital recorder with synchronized capability. It can be a stand-alone physical unit or a functional unit within another protective device. By measuring the magnitude and phase angles of currents and voltages a single PMU can provide real-time information about power system events in its area, and multiple PMU can enable coordinated system-wide measurements. PMU also can time-stamp, record, and store the phasor measurements of power system events. This capability has made PMU become the foundation of various kinds of wide area protection and control schemes.

A lot of PMU potential applications in power system monitoring, protection, and control have been studied since it was introduced in mid-1980s. Specially, in recent years, PMUs have been and extensively used or proposed to be used in many applications in the area of power system protection and control with the cost reduction of PMUs and improvement of communication technologies in power system [11]. Synchrophasors are precise measurements of the power systems and are obtained from PMUs. PMUs measure voltage, current, and frequency in terms of magnitude and phasor angle at a very high speed (usually 30 measurements per second). Each phasor measurement recorded by PMU devices is time-stamped based on universal standard time, such that phasors measured by different PMUs installed in different locations can be synchronized by aligning time stamps. However, PMU and its associated communication facilities are costly. Furthermore, the voltage phasor of the bus incident to the bus with PMU installed can be computed with branch parameter and branch current phasor measurement [5]. So it is neither economical nor necessary to install PMUs at all system buses. Thus, one of the important issues is to find the optimal number and placement of PMUs. Optimal PMU

Cite this article as: Dhanalakshmi G, Rajeswari R, Vignesh G. "Optimal Pmu Placement For Tamilnadu Grid Under Controlled Islanding Environment." *International Conference on Information Engineering, Management and Security (2015)*: 159-167. Print.

placement (OPP) is firstly attempted in [6], formulating as a combinatorial optimization problem of minimizing the PMU number for system observability. In [7], an integer programming formulation of OPP problem is proposed with the presence of conventional measurements. A generalized integer linear programming (ILP) formulation for OPP is presented in [8]. Generally, the existing OPP models concerns about the determination of minimum number and optimal location set of PMUs, ensuring thattheentirepowersystemremainsasingleobservableisland [1]. In another word, these models can only handle the cases in which the power system is operated as a single and integrated network. However, some severe faults may lead parts of the network to angle, frequency or voltage instability. In that case, trying to maintain system integrity and operate the system entirely interconnected is very difficult and may cause propagation of local weaknesses to other parts of the system [11]. As a solution, controlled islanding (CI) is employed by system operators, in which the interconnected power system is separated into several planned islands prior to catastrophic events [12], [13]. After system splitting, wide area blackout can be avoided because the local instability is isolated and prevented from further spreading [14]. In order to operate each island with power balancing and stability after controlled islanding, it is essential to provide an OPP scheme which can keep the network observable for the post-islanding condition as well as normal condition.

In this paper, an ILP model of OPP considering controlled islanding (OPP-CI) is proposed. This model is able to determine the minimal number and optimal location set of PMUs in order to provide the full network observability in normal operation as well as in controlled islanding scenario. To distinguish multiple optimal solutions, measurement redundancy is incorporated into the optimization objective. The performance of the proposed new model is assessed using several IEEE-14 bubs standard systems and a Tamil Nadu state power grid system.

II INTEGER LINEAR PROGRAMMING

Integer Linear Programming(ILP) is a mathematical optimization method for getting an optimal outcome from a given mathematical objective function, subject to some linear inequality constraints. In this thesis ILP is used for finding the minimum set of PMUs for a given power grid to achieve its complete observability. The objective of the PMU placement problem is that a bus will be reached by at least one

PMU. The detailed description of ILP was reported in Refs. Two assumptions are made before applying ILP for PMU placement. First, there is no constraint on the number measuring channels for the PMU, i.e., a PMU can measure the current phasors from any number of branches that are connected to it. Second, there are no

problems with the availability of the communication system. i.e., all buses are well equipped with communication facilities for the transfer of data from PMUs .

The Program for objective function and constraints of IEEE-14 Bus test systems are mentioned below

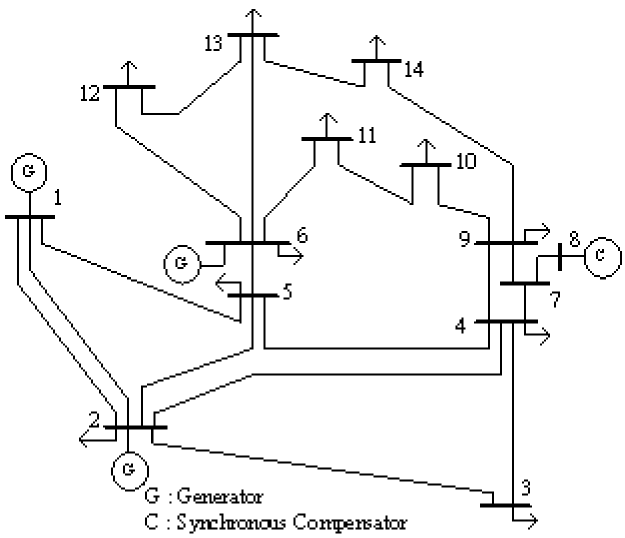

Figure 1 IEEE14 bus system

. The first stage of ILP for complete observability is to create a matrix U_{PMU}, in such a way that, its entries are defined as

$U_{i,j} = 1$, (if i and j are connected) (1)

In a power system network, the PMU placement at a bus can be seen as a binary decision variable defined as

$$u_i = \begin{cases} 1 & \text{if PMU is placed at bus } i \\ 0 & \text{otherwise.} \end{cases} \quad (2)$$

For a system with buses, therefore, the optimal PMU placement problem can be formulated as an integer linear programming problem as follows:

Cite this article as: Dhanalakshmi G, Rajeswari R, Vignesh G. “Optimal Pmu Placement For Tamilnadu Grid Under Controlled Islanding Environment.” *International Conference on Information Engineering, Management and Security (2015)*: 159-167. Print.

$$\min F_1 = \sum_{i=1}^{n} c_i u_i \tag{3}$$

subject to constraints

$$f_i = \sum_{j=1}^{n} a_{i,j} u_j \geq 1 \qquad i = 1, 2, \ldots, n \tag{4}$$

where

- C_i is the cost of installing a PMU at bus . Without loss of generality, cost of PMU installation at each bus is assumed to be equal to 1 per unit in the present study.
- f_i refers to the number of times that the th bus is observed through PMU measurements.
- $a_{i,j}$ is the *i-j* th entry of network connectivity matrix defined as

$$a_{i,j} = \begin{cases} 1 & \text{if } i = j \text{ or if } i \text{ and } j \text{ are connected} \\ 0 & \text{otherwise.} \end{cases} \tag{5}$$

For example, with (3), minimizing the number of PMUs for the IEEE 14-bus system (Fig. 1) can be formulated as follows:
Constraints function:

```
function [c ceq ]=fourteencons (x)
c(1)=-(u(1)+u(2)+u(5))+1;
c(2)=-(u(1)+u(2)+u(3)+u(4)+u(5))+1;
c(3)=-(u(2)+u(3)+u(4))+1;
c(4)=-(u(2)+u(3)+u(4)+u(5)+u(7)+u(9))+1;
c(5)=-(u(1)+u(2)+u(4)+u(5)+u(6))+1;
c(6)=-(u(5)+u(6)+u(11)+u(12)+u(13))+1;
c(7)=-(u(4)+u(7)+u(8)+u(9))+1;
c(8)=-(u(7)+u(8))+1;
c(9)=-(u(4)+u(7)+u(9)+u(10)+u(14))+1;
c(10)=-(u(9)+u(10)+u(11))+1;
c(11)=-(u(6)+u(10)+u(11))+1;
c(12)=-(u(6)+u(12)+u(13))+1;
c(13)=-(u(6)+u(12)+u(13)+u(14))+1;
c(14)=-(u(9)+u(13)+u(14))+1;
        ceq=[ ];
```

In this thesis, an ILP model of OPP considering controlled islanding (OPP-CI) is proposed. This model is able to determine the minimal number and optimal location set of PMUs inorder to provide the full network observability in normal operation as well as in controlled islanding scenario.
Compared to (4), the observability constraints of OPP-CI model are modified as follows:

$$f_i = \sum_{j=1}^{n} a_{i,j}^{CI} u_j \geq 1 i = 1, 2, \ldots, n \tag{6}$$

where $a_{i,j}^{CI}$ is the binary entry in the connectivity matrix for post-islanding network, which is defined as

$$a_{i,j}^{CI} = \begin{cases} 0 & \text{if line } i - j \text{ is opened in } CI \text{ process} \\ a_{i,j} & \text{otherwise.} \end{cases} \tag{7}$$

III CONCEPTS OF ISLANDING AND REDUNDANCY MEASUREMENT

Cascading failures are the most significant threats for power system security. Cascading failures together with additional line tripping can lead the system to uncontrolled splitting [11]. Formation of uncontrolled islands with significant power imbalance is the main reason for system blackouts. In order to avoid catastrophic
wide area blackouts due to cascading failures, controlled islanding has been considered as an effective defense strategy. The main advantages of controlled islanding of power systems can be listed as follows [11]:

- It can separate weak and vulnerable areas from other stable parts of the system.
- Compared to the whole system, small subsystems are easier to be handled and controlled under dynamic and emergency conditions.

Cite this article as: Dhanalakshmi G, Rajeswari R, Vignesh G. “Optimal Pmu Placement For Tamilnadu Grid Under Controlled Islanding Environment.” *International Conference on Information Engineering, Management and Security (2015)*: 159-167. Print.

After establishment of planned islands, there exist some factors which may threat the stability and integrity of each island, such as power imbalance, line overloading, voltage, angle and frequency instabilities, etc. [11]. Therefore, to maintain static and dynamic stability, necessary load shedding and other control actions may be needed in each island, which always require real-time information throughout the island. In addition, real-time measurements in different islands should be collected and analyzed together to determine whether and how the power system can be restored to normal operation. To ensure the effectiveness of all the above actions, it is essential to keep each island totally observable through properly placed PMUs. In other words, the optimal placement of PMUs should be carried out in such a manner that the network remains observable under controlled islanding condition as well as normal operation condition.

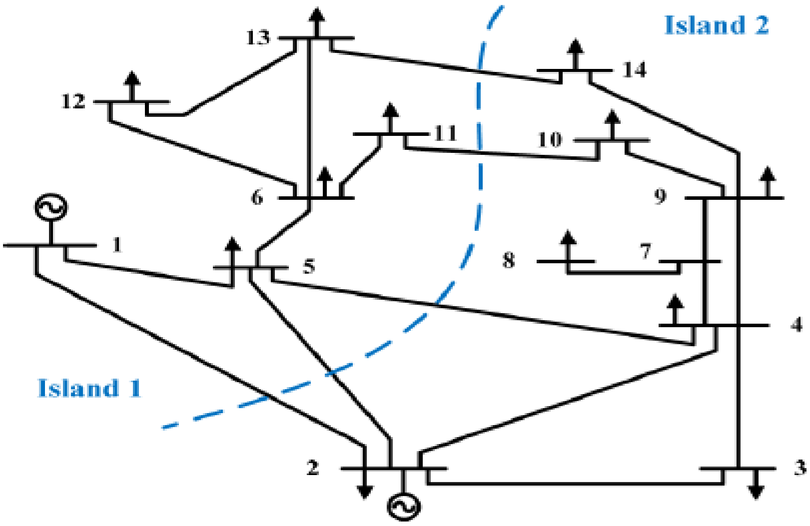

Figure 2 IEEE-14 Bus system under CI condition

For example, with (6), minimizing the number of PMUs for the IEEE 14-bus system (Fig. 2) can be formulated as follows:

$$\begin{aligned}
f_1 &= u_1 + u_5 \geq 1 \\
f_2 &= u_2 + u_3 + u_4 \geq 1 \\
f_3 &= u_2 + u_3 + u_4 \geq 1 \\
f_4 &= u_2 + u_3 + u_4 + u_7 + u_9 \geq 1 \\
f_5 &= u_1 + u_5 + u_6 \geq 1 \\
f_6 &= u_5 + u_6 + u_{11} + u_{12} + u_{13} \geq 1 \\
f_7 &= u_4 + u_7 + u_8 + u_9 \geq 1 \\
f_8 &= u_7 + u_8 \geq 1 \\
f_9 &= u_4 + u_7 + u_9 + u_{10} + u_{14} \geq 1 \\
f_{10} &= u_9 + u_{10} \geq 1 \\
f_{11} &= u_6 + u_{11} \geq 1 \\
f_{12} &= u_6 + u_{12} + u_{13} \geq 1 \\
f_{13} &= u_6 + u_{12} + u_{13} \geq 1 \\
f_{14} &= u_9 + u_{14} \geq 1.
\end{aligned} \tag{8}$$

In this thesis, thus, maximizing the measurement redundancy is considered as an additional objective to pick out the most suitable OPP scheme for power systems. Conventionally, measurement redundancy is defined as the ratio of the number of measurements (including direct measurements and indirect measurements) to the number of states [7]. Considering that the most important state variables in state estimation are bus voltage phasors, the measurement redundancy can be redefined as the ratio of the number of voltage measurements to the number of system buses. Moreover, the measurement redundancy under islanding operation scenario as well as normal operation should be considered.

To keep consistency with (3) which is a minimization problem, the objective function of maximizing measurement redundancy is formulated as a minimization problem as well:

$$\min F_2 = \frac{1}{n}\sum_{i=1}^{n}\left[\omega_1(m_i^N - t_i^N) + (1-\omega_1)(m_i^I - t_i^I)\right] \tag{9}$$

where n is the total number of system buses; constant m_i^N is the maximum number of times that the i^{th} bus can be observed in normal operation, which equals to the number of its incident lines plus one; variable t_i^N represents the number of times that the i^{th} bus is observed by the solved OPP scheme in normal operation; m_i^N and t_i^N refer to the corresponding constant and variable in islanding operation condition, respectively ω_1 and (1- ω_1); and are weighting factors assigned to the two components of the objective function. Since there is greater probability for a power system to be operated in normal condition than in islanding condition, in this study ω_1 and (1- ω_1) are set at 0.7 and 0.3, respectively.

IV RESULTS AND DISCUSSION

TAMIL NADU STATE POWER GRID

The Tamil Nadu state Indian power grid consists of 83 buses of UHV, EHV and HV which are interconnected by 126 branches. The single line diagram of the power grid is depicted in figure 3 and their bus details are given in Table I. The ILP described in above has been applied to the grid for finding the optimal locations of the PMUs for the complete observability

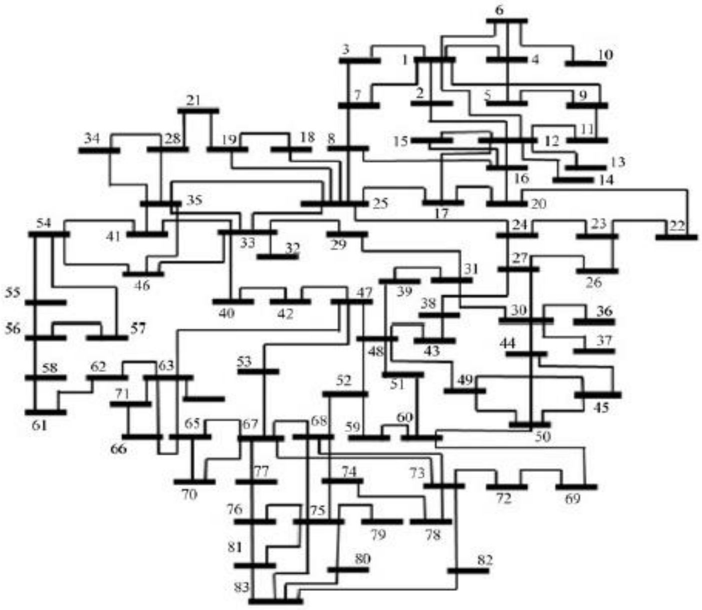

Figure 3 Single line diagram of TN State Indian Power Grid

Table.I Bus details for TN State Indian Power Grid

Bus No.	Bus Name	Bus No.	Bus Name	Bus No.	Bus Name	Bus No.	Bus Name	Bus No.	Bus Name
1	Chennai	18	V. Mangalam	35	Mettur TPS	52	Alagarkoil	69	Paramkudi
2	Gummidipoondi	19	Hosur	36	Bahoor	53	RGPuram	70	Theni
3	Almathy	20	Kalpakkam	37	Villianur	54	Arasur	71	Kadamparai
4	Ennore	21	Karimangalam	38	Eachengadu	55	Pykara	72	Sipcot
5	Monali	22	Acharapakkam	39	Peranbalur	56	Kundah3	73	Tuticorin
6	Tondiarpet	23	Villupuram	40	Unjanai	57	Kundah2	74	Sathur
7	Mosur	24	TV malai	41	Gobi	58	Kundah1	75	Kayathur
8	Thiruvalam	25	Singarapettai	42	P. Chandai	59	Valthur	76	Viranam
9	Korattur	26	Cuddalore	43	Samaypuram	60	Karaikudi	77	Kodikurchi

Cite this article as: Dhanalakshmi G, Rajeswari R, Vignesh G. "Optimal Pmu Placement For Tamilnadu Grid Under Controlled Islanding Environment." *International Conference on Information Engineering, Management and Security (2015)*: 159-167. Print.

10	Mylapore	27	Neyveli TS1	44	Kdalangudu	61	Thudiyalur	78	Sterlite
11	Koyambedu	28	Mettur	45	Nallur	62	O.K.Mandabam	79	Auto
12	Budur	29	D. Kurchi	46	Ingur	63	Udumalpet	80	Udayathur
13	Kadperi	30	Neyveli TS2	47	Pugalur	64	Ponnapuram	81	Thirunelveli
14	Hyundai	31	STCMS	48	Trichy	65	Sembatti	82	S.R.Pudur
15	Tharamani	32	SAIL	49	Thanjavur	66	Myvadi	83	Sankaneri
16	SP Koil	33	Salem	50	Thiruvarur	67	Madurai		
17	Arni	34	M. Tunnel	51	Pudukottai	68	Pasumalai		

To establish a planned islands, there exist some factors which may threat the stability and integrity of each island, such as power imbalance, line overloading, voltage, angle and frequency instabilities, etc. Therefore, to maintain static and dynamic stability, necessary load shedding and other control actions may be needed in each island, which always require real-time information throughout the island. In addition, real-time measurements in different islands should be collected and analyzed together to determine whether and how the power system can be restored to normal operation. Hence the generation capacity of all the 83 buses in Tamil Nadu state grid is found as listed in table II

The one line diagram of TN State Power Grid having 83 buses is shown in figure.3. Here the OPP schemes are solved for normal and CI conditions.

TN STATE POWER GRID - NORMAL OPERATION

Figure 3 shows the single line diagram of TN State Power Grid. To determine the OPP for normal operation, entire bus is considered as a single island and their observability constraints are determined.

This observability constraints are solved by using ILP in MATLAB and OPP is determined. The results of solved ILP for TN State Power Grid shows that, the system is made completely observable by placing 20 PMUs in buses **5, 7, 10, 12, 19, 22, 27, 30, 32, 34, 40, 45, 48, 54, 58, 60, 63, 67, 73, 75.**

Table II Bus details for TN State Grid with Generation Capasity

Bus No.	Bus Name	MW	Bus No.	Bus Name	MW	Bus No.	Bus Name	MW	Bus No.	Bus Name	MW	Bus No.	Bus Name	MW
1	Chennai	2026	18	V. Mangalam	18.6	35	Mettur TPS	1440	52	Alagarkoil	10	69	Paramkudi	9
2	Gummidipoondi	130	19	Hosur	8	36	Bahoor	36	53	RGPuram	7.5	70	Theni	19
3	Almathy	22	20	Kalpakkam	470	37	Villianur	24.5	54	Arasur	5	71	Kadamparai	400
4	Ennore	450	21	Karimangalam	10	38	Eachengadu	10	55	Pykara	253.2	72	Sipcot	10
5	Monali	43	22	Acharapakkam	10	39	Peranbalur	22	56	Kundah3	180	73	Tuticorin	1050.5
6	Tondiarpet	1500	23	Villupuram	77.5	40	Unjanai	10	57	Kundah2	175	74	Sathur	10

Cite this article as: Dhanalakshmi G, Rajeswari R, Vignesh G. "Optimal Pmu Placement For Tamilnadu Grid Under Controlled Islanding Environment." *International Conference on Information Engineering, Management and Security (2015)*: 159-167. Print.

7	Mosur	10	24	TV malai	84.3	41	Gobi	4	58	Kundah1	60	75	Kayathur	130
8	Thiruvalam	5	25	Singarapettai	10	42	P. Chandai	15	59	Valthur	187.2	76	Viranam	1320
9	Korattur	12	26	Cuddalore	71.5	43	Samaypuram	48	60	Karaikudi	19	77	Kodikurchi	10
10	Mylapore	9	27	Neyveli TS1	1020	44	Kdalangudu	101	61	Thudiyalur	7.5	78	Sterlite	160
11	Koyambedu	0.25	28	Mettur	370	45	Nallur	340.5	62	O.K.Mandabam	10	79	Auto	3.18
12	Budur	70	29	D. Kurchi	7.5	46	Ingur	6.4	63	Udumalpet	25.7	80	Udayathur	7.5
13	Kadperi	400	30	Neyveli TS2	1750	47	Pugalur	47.12	64	Ponnapuram	182.5	81	Thirunelveli	96.7
14	Hyundai	200	31	STCMS	270	48	Trichy	19.5	65	Sembatti	7.5	82	S.R.Pudur	10
15	Tharamani	12	32	SAIL	60	49	Thanjavur	152.66	66	Myvadi	5.625	83	Sankaneri	1.25
16	SP Koil	50	33	Salem	14	50	Thiruvarur	109.38	67	Madurai	117.5			
17	Arni	31	34	M. Tunnel	12.5	51	Pudukottai	35.5	68	Pasumalai	10			

6.2.2 TN STATE GRID - CONTROLLED ISLANDING (CI) CONDITIONS

In islanding conditions, the whole system is separated into two subsystems based on measurement of generation and distribution capacity of all the buses. The islanding are done by proper load shedding so as to make the generation capacity and distribution around the island remains equal. Thus 4 different cases of islanding are chosen for TN State Power Grid.

These different cases leads to multiple solution for OPP scheme. Therefore, maximizing the measurement redundancy is considered to pick out the most suitable OPP scheme for power systems. ILP is solved for all the cases to determine the OPP and measurement redundancy is found to chose the most feasible solution. The different cases of islanding are shown in fig 4, 5, and 6 The results obtained for OPP scheme are shown in table III and the comparison on measurement redundancy of different OPP solutions for TN State Power Grid is listed in table IV.

CASE 1

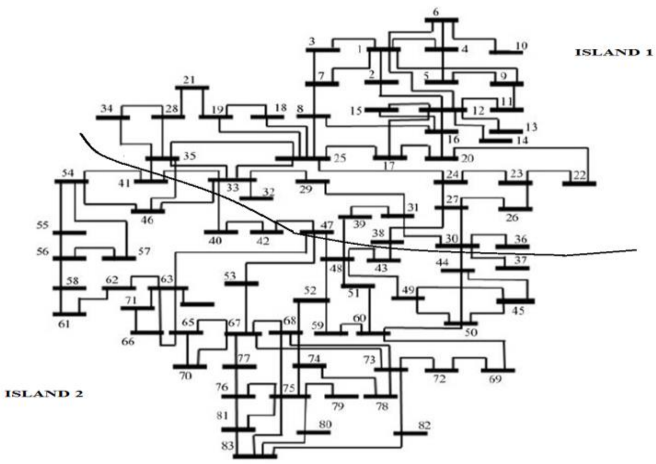

Figure 4 TN State Power Grid under CI - Case 1

CASE 2

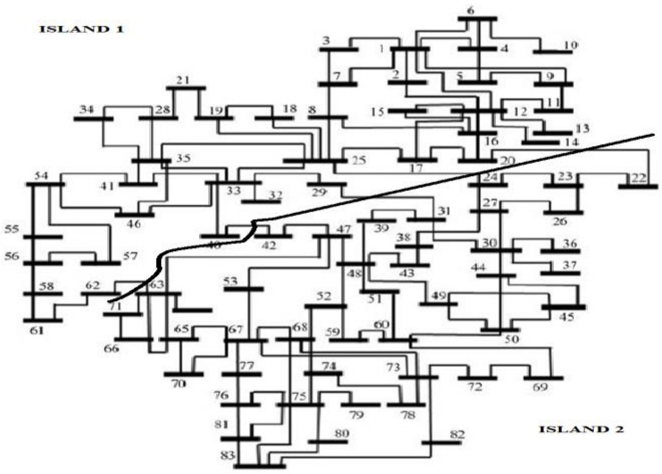

Figure 5 TN State Power Grid under CI - Case 2

CASE 3

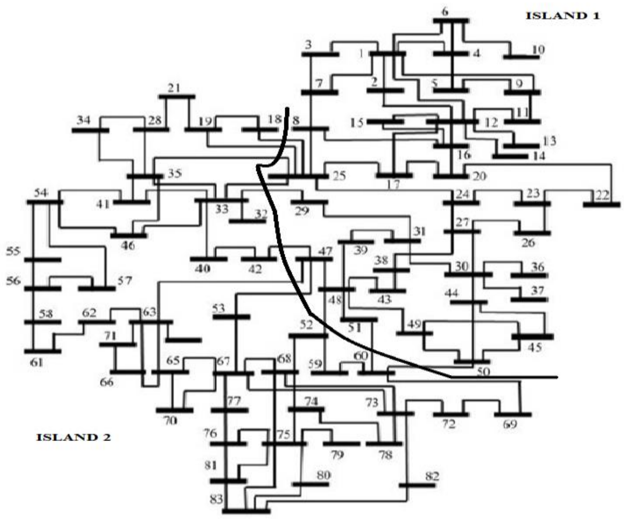

Figure 6 TN State Power Grid under CI - Case 3

Table III Results for Solved OPP in Controlled Islanding conditions

S.No	Cases	Results For OPP
1	Case 1	5, 7, 10, 12, 19, 22, 27, 30, 32, 34, 40, 45, 48, 54, 58, 60, 63, 67, 73, 75.
2	Case 2	1, 6, 12, 16, 19, 23, 30, 33, 34, 42, 43, 45, 48, 55, 56, 60, 62, 63, 67, 73, 75.
3	Case 3	1, 6, 8, 12, 19, 22, 27, 29, 30, 33, 35, 42, 48, 50, 54, 58, 60, 63, 67, 68, 73, 75.

Cite this article as: Dhanalakshmi G, Rajeswari R, Vignesh G. "Optimal Pmu Placement For Tamilnadu Grid Under Controlled Islanding Environment." *International Conference on Information Engineering, Management and Security (2015)*: 159-167. Print.

Table IV Comparison on measurement redundancy of different OPP solutions for IEEE-14 bus system

OPP Solutions	Measurement Redundancy Difference		
	Normal Operation	*Islanding Operation*	*Value of F_2*
Case 1	2.8313	2.5904	2.7590
Case 2	2.6506	2.5663	2.6253
Case 3	2.5060	2.4578	2.4916

Therefore, for the TN State Power Grid system, Case 3 is the most suitable solution because it has smaller value of redundancy factor than other ones, as shown in table IV

V CONCLUSION

Smart Grid(SG) can deliver reliable electric power to consumers with efficient utilization of power network than that provided by the traditional power system. SG is essential for a developing and highly populated country like India. One of the key requirements for the implementation of SG is the complete observability of the power grid, which can be achieved by using PMUs.

An effective OPP scheme should ensure complete observability of a power network under various operation conditions. To avoid wide-area blackout following cascading failures, power system might be operated in controlled islanding mode. In this thesis, an OPP model considering controlled islanding of power system is proposed. The proposed model guarantees complete observability of power network for normal condition as well as controlled islanding condition. By introducing the measurement redundancy into the optimization objective, our OPP-CI model can find the globally optimal solution with the minimum number of PMUs and maximum measurement redundancy. At last, case studies on IEEE-14 Bus standard test systems and Tamil Nadu State Power Grid (83 Bus System) practical system provide verification of the effectiveness of the presented OPP models.

This investigation can be applied to remaining all the National Power Grid of India so that the OPP schemes under Normal and Controlled Islanding conditions can be determined. Thus wide-area blackout following cascading failures can be avoided.

REFERENCES

[1] Lei Huang, Yuanzhang Sun and JianXu., "Optimal PMU Placement Considering Controlled Islanding of Power System", IEEE Transactions on Power Systems, 2013 IEEE, 0885-8950 .

[2] A. Enshaee, R. A. Hooshmand, and F. H. Fesharaki, "A new method for optimal placement of phasor measurement units to maintain full network observability under various contingencies," Elect. Power Syst. Res., vol. 89, no.1,pp. 1–10, Aug.2012.

[3] Gou,B., "Generalized Integer Linear Programming Formulation for Optimal PMU Placement". Power Systems , IEEE Transactions on, 2008. 23(3): 1099- 1101.

[4] B. Gou, "Optimal placement of PMUs by integer linear programming," IEEE Trans. Power Syst., vol. 23, no. 3, pp. 1525–1526, Aug. 2008.

[5] Pathirikkat GOPAKUMAR,G .Surya CHANDRA,M .jayabharata REDDY, "Optimal placement of PMUs for the smart grid implementation in Indian power Grid - A case study". Front. Energy 2013, 7(3): 358-372

[6] F. Aminifar, A. Khodaei, M. Fotuhi-Firuzabad, and M. Shahidehpour, "Contingency-constrained PMU placement in power networks," IEEE Trans.Power Syst., vol. 25, no. 1, pp. 516–523, Feb. 2010.

[7] M. R. Aghamohammadi and A. Shahmohammadi, "Intentional islanding using a new algorithm based on ant search mechanism," Int. J. Elect. Power Energy Syst., vol. 35, no. 1, pp. 138–147, Feb. 2012.

[8] G. Xu, V. Vittal, A. Meklin, and J. E. Thalman, "Controlled islanding demonstrations on the WECC system," IEEE Trans. Power Syst., vol. 26, no. 1, pp. 334–343, Feb. 2011.

[9] S. S. Ahmed, N. C. Sarker, A. B. Khairuddin, M. R. B. A. Ghani, and H. Ahmad, "A scheme for controlled islanding to prevent subsequent blackout,"IEEE Trans. Power Syst., vol. 18, no. 1, pp. 136–143, Feb. 2003.

[10] R. F. Nuqui and A. G. Phadke, "Phasor measurement unit placement techniques for complete and incomplete observability," IEEE Trans. Power Del., vol. 20, no. 4, pp. 2381–2388, Oct. 2005.

[11] Bindeshwar Singh, N.K. Sharma, A.N. Tiwari, K.S. Verma, and S.N. Singh "Applications of phasor measurement units(PMUs) in electric power system networks incorporated with FACTS controllers ", International Journal of Engineering,Science and Technology Vol. 3, No. 3, 2011, pp. 64-82.

[12] A.G. Phadke and J. S. Thorp " History And Applications Of Phasor Measurements",IEEE,142440178X/06/2006.

[13] A.G. Phadke , "Synchronized Phasor Measurements - A Historical Overview", 0-7803-7525-4/02/ 2002 IEEE

Cite this article as: Dhanalakshmi G, Rajeswari R, Vignesh G. "Optimal Pmu Placement For Tamilnadu Grid Under Controlled Islanding Environment." *International Conference on Information Engineering, Management and Security (2015)*: 159-167. Print.