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INTEGER LINEAR PROGRAMMING BASED OPTIMAL PMU PLACEMENT IN LARGE POWER NETWORK BASED ON TOPOLOGICAL AND OPERATIONAL CONSIDERATIONS

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ABSTRACT

This paper focuses on the problem of optimal placement of the PMU (Phasor Measurement Unit) in a large power network.

Optimal PMU placement has multiple solutions depending upon the consideration of constraints and therefore consideration of field based topological and operational criteria can give better and actual result. This has been carried out using integer linear programming with the consideration of different types of criteria such as, zero injection measurement, cost constraint, voltage level, future expansion, bus location in the network, owner of the substation, centre of load point, availability of communication link, connection with generating station and evaluation based on system operating condition. Different indices like BOI (Bus Observability Index), SORI (System observability Redundancy Index) and System Operating conditions are also being considered for determination of location at which PMU can be installed to achieve full network observability. It has been clearly visualized change in location of PMU in cases of with and without consideration of said criteria.

KEYWORDS: Phasor Measurement Unit(PMU), Integer Linear Programming(ILP), Optimal PMU Placement(OPP), System Observability Redudancy Index (SORI), Bus Observability Redudancy Index(BORI)

I. INTRODUCTION

Currently, drastic changes in generation and transmission system, i.e., power system restructuring, dynamic loading conditions etc. Result in stressed operation of power system. In such circumstances, to make stable & reliable operation of power system. An accurate measurement and monitoring is a mandatory requirement. Mainly monitoring is performed by the Supervisory Control and Data Acquisition (SCADA) system and Remote Terminal Unit (RTU). The limitation of the said system is that the measurements acquired are not time synchronised. Latency in time can lead to mal-operation or delayed operation of load dispatch and load shedding. Hence result into catasphoric situation in power system. To overcome this limitation, recently developed synchrophasor based techniques are quite useful and superior. This improves the system operation, monitoring and system protection. The synchrophasor technology implements PMU (Phasor Measurement Unit), a device for fast and synchronised measurement based on Global Positioning System (GPS).PMU reports phasor data of voltage and current, Frequency, Rate of change of Frequency. Further, PMU data is applicable for calculation of other data such as positive, negative and zero sequence of voltage and current, active power, reactive power etc. All measured and calculated data can be managed by PDC. It will be useful for analytical study to improve the overall reliability and security of power system network. But, one of the major challenges associated with implementation of this technology is identification of optimal location of the PMU in a network to make network fully observable and at the same time it should be cost efficient as well. Further, one also has to look into several other topological and operational considerations such as network configuration, system voltage level, power transfer through transmission line, availability of communication infrastructure & further expansion. These informations will be helpful to locate the PMU in the system at proper place considering holistic approach to power system. The problem of deciding an optimal location of PMU can be decided into two sub problems i.e. objective function and system constraints. The objective function is to minimize the number of PMUs subject to ensuring factor of full network observability overall above the same it is also constrained by several other parameter such as cost, types of PMU, availability of the channel, availability of communication network, network topology, power transfer during particular time period, etc. As the nature of objective function and constraint is linear. This can be found out from integer linear programming method. It is generally observed in different literature that the decision of locating PMU at particular bus is mostly based on the topology of the power network only. Further, some authors have discussed the PMU placement based on constraints such as cost & availability of channels in a PMU as well. Therefore no of other consideration of practical/field situation along with conventional considerations result into better placement scheme [2] [3] [4].

Section I contains introductory discussions related to Wide area measurement system based technology and usage of PMU for the same. It has highlighted the problem of necessity optimal location of PMU in large network not only of deciding the base of ensuring network observability and cost involved but several other practice coniferous as well. Section II gives conventional system observability rules and relative procedure. Section III explains formulation of ILP method to evaluate the problem of deciding optimal location of PMU in large network. Section IV provides information regarding the power network considered for said analysis. It included description of system parameter, different voltage level, type of substation, etc. Section V contains the algorithm which has been tested for the said system in MATLAB environment. Section VI contains conclusion and references.

II. SYSTEM OBSERVABILITY

System observability referred to as the system measurement set and these is mandatory for solving the current state of system. The power system connectivity consists of N nodes which represents number of busbar in power system, connected with corresponding network branches between the busbars. To assess a topological observability of system with placement of PMUs, the following rules and assumptions. [4][5][9]

- **Rule 1:** If the current phasor and voltage phasor of the one terminal end are known then other end voltage and current phasor can be calculate based on branch bound equation.
- **Rule 2**: If the voltage phasor of the two terminal known then current phasor at other branch can be calculated.
- **Rule 3**: If there is a zero-injection node without PMU, associated branch current is calculated using KCL equation.
- **Rule 4**: If there is a zero-injection node without PMU, associated node voltage is calculated using KVL equation.

III. INTERGER LINEAR PROGRAMMING METHOD

Integer Programming is mathematical programming method of solving an optimization problem having integer design variable, while the constraints and the objective function are linear, nonlinear, or quadratic, thus leading to integer linear programming (ILP). ILP formulation based on the measurement configuration and the system topology. The description of simple ILP based optimal placement method ensuring complete topological observability of the system under some constraint case, which has been considered in the optimal PMU placement. Additionally sometimes communication link constraints of power network are considered as measurement limitation. Based on the practical aspect only this constraint are not sufficient feasible to make the system fully observable and economical. Integer linear programming mainly depends on the objective function and constraints. The objective function includes summation of the number of connected bus or buses which will be select to place PMU. Constraint will govern the final result of the optimization [5][10].

A. Formulation Step of ILP

Step 1: Objective Function

$$Min \sum_{i=1}^{n} C_i X_i \qquad \text{.... (1)}$$

Here, C_i= Constraint factor

X_i= i^{th} bus

The objective function of the Optimal PMU Placement is to minimize, number of PMU to make fully observable network.

Step 2: Subject to,

$$F_{(x)} = \sum_{j=1}^{n} a_{ij} X_j, \forall i \in I$$

$$F_{(x)} \geq 0$$

...... (2)

Here, a_{ij}= Bus connectivity matrix

Here, a_{ij} are depend on the transmission line connection between i-bus and j-bus which is as follows,

$$a_{ij} = \begin{cases} 1, if\ j = i \\ 1, if\ j\ and\ i\ connected\ to\ each\ other \\ 0, otherwise \end{cases}$$

Consideration of Different Criteria

Zero Injection Bus (ZIB)

The zero injection buses are of that type of bus where neither the source nor load is connected. It is used to transfer the power from one branch to another only. Consideration of the same will result into reduced no of PMU requirement for same observability. As parameters of the same can be known from KCL & KVL.

Bus Observability Index (BOI)

BOI indicates the probability of observability of a particular bus via direct and/or indirect (Pseudo) measurements under normal as well as under contingency operations. Thus it is basically maximize bus observability of a particular bus by one or more no of PMUs and can be defined as follows,

$$ß_i \leq N + 1 \quad \text{……….. (3)}$$

Where, $ß_i$= Max bus observability, N= No of Bus

System Observability Redundancy Index (SORI)

Summation of the BOI. Maximum SORI have more system observability in term of PMU loss.

$$\text{SORI of the network } (\gamma) = \sum_{i=1}^{n} ß_i \quad \text{…… (4)}$$

Where, n= No of bus

- Cost of PMU, communication network availability, PMU channel, PMU specification
- Bus/Substation- voltage level, loading on the Bus, bus connectivity, Substation's Location in network, Power system analysis, owner.
- Here, C_i is the constraint factor of the PMU which is consideration base on criteria interested at bus i, $F_{(x)}$ is subject set, vector function, whose entries are non-zero if the corresponding bus voltage is solving using the given measurement set and zero otherwise. In the equation (2) greater than zero indicate that the observer at least one or zero time by installed PMU.[6]

Step 3: Results

IV. SYSTEM DESCRIPTION

The system considered for the said analysis is transmission network of Gujarat state. At EHV level, total 50 buses are of the 400kV, 193 buses are of 220kV. These all are EHV substation and more than 15 buses of generating station connected to each other with different type of transmission line. As the type & location of a typical substation where the buses are situated are having their own different characteristics. This can be categorized based on several aspects such as, based on power system analysis, based on the higher voltage level, based on get way point of power, based on connection with interstate station, based on location in the network and connection with generating station. The said locations are few only shown in Table I. There are several similar type of substation in network as well. Based on these, the considered network contains total 243 buses of 400kV &220 kV network, out of which 193 buses are of 220kV, 50 buses are of

400kV[12].

Table 1: Network Criteria Description

Sr No.	Criteria	Description	Location
1	Voltage Level	765kV, 400kV	Vadodara,Vav
2	Power system analysis	Loading condition	Kasor, Vav, Asoj, Chornia, Timbdi
3	Connection	Wind station	Nakhatrana
4	Get way point	Power flow starting point	Chorania
5	Interstate connection	Rajasthan	Kansari
		Madhyapradesh	Asoj

V. SIMULATION AND RESULTS

The base cases are deficient based on voltage level and connectivity with different voltage level buses. These are optimizing with defined constraint factor and algorithm in MATLAB environment.

A. 400&220kV Network Observability

By using ILP formulation formulate 243 bus(400&220 kV) system as follows, in this system all bus connected with the either generator or load so for that with/without considering zero injection bus formulation,

Step 1: Objective Function

$$OF{:}-Min \sum C_1X_1 + C_2X_2 + \cdots + C_{243}X_{243} \quad \text{... (5)}$$

Step 2:- Subject to,

$$F_1{:}\, X_1 + X_{80} \geq 1$$

$$F_2{:}\, X_2 + X_{93} \geq 1$$

$$F_{19}{:}\, X_{19} + X_{20} + X_{21} + X_{22} + X_{23} + X_{24} + X_{38} + X_{39} + X_{45} + X_{65} \geq 1$$

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$$F_{242}{:}\, X_{48} + X_{64} + X_{67} + X_{205} \geq 1$$

$$F_{243}{:}\, X_{30} + X_{31} + X_{243} \geq 1 \quad \text{....... (6)}$$

Step 3: Result

By the help of said algorithm in MATLAB environment gets 73 optimal location of 243 buses system by without considering zero injection measurement. Further by considering zero injection measurement gets 58 optimal locations which is mention in Table III. And also, by considering real field constraint as variable constraint factor gets 54 optimal locations, which is mention in Table III. These 54 locations are as follows, 25 locations are already placed PMU location and remaining are future location to place PMU. Based on said topological and operational criteria factor Changed/choose location mention in Table II. The said Locations are few only. There is several similar type of location as well, which are mentioned in Table III. A few of locations which are changed after the consideration of topological and operational considerations are mentioned in Table II.

Table II: Field Criteria Based Changed Location

Sr. No.	Location	Changed Location	Reason
1	Navsari, karamshad	Vav, Kasor	Voltage level, System importance
2	Pandharo	Nakhatrana	Centre point of generation
3	Chandrapura	Asoj	Load center
3	Gondal	Jetpur	Power flow

B. 400kV Network Observability

In the 400kV network, 50 buses are connected with the either generator or Load. Based on ILP similar producer for the system has been follows,

Step 1: Objective Function

Table III: Results of Optimal PMU Placement for Different Case Studies with Large Network Topological & Operational Criteria

Case No.	No of Bus System	Optimization Result		
		Location of the PMUs	***ZIB***	***Without ZIB***
A	243(400 &220kV) Without ZIB	4,19,26,28,32,36,38,44,45,46,51,54,57,58,62,68,69,76,80,82,83,84,87,88,91,92,93,94,102,103,104,105,106,107,114,122,125,131,134,137,147,148,149,151,152,156,160,162,163,167,171,177,180,183,185,188,192,193,195,196,202,203,204,207,209,210,216,218,227,231,238,239,241	58	73
A	206(400 &220kV) With ZIB	19,26,28,31,32,36,38,39,40,45,46,47,48,49,57,62,65,68,69,72,76,80,81,82,83,84,86,88,91,92,93,94,98,100,102,104,106,114,122,125,131,134,137,142,143,144,145,146,156,160,162,163,167,171,177,180,186,187	58	73
A	206(400&220kV) Variable Constraint factor	19,26,28,31,32,36,38,39,40,45,47,48,49,57,65,68,69,72,80,81,82,83,84,86,88,91,92,93,94,98,100,102,106,114,122,125,131,134,137,142,143,144,145,146,156,160,162,163,167,171,177,180,186,187	54(Field constraint)	73
B	50(400kV)	2,3,9,10,11,14,16,17,23,25,34,38,45,46,48	15	15
B	193(220kV)	19,26,28,31,32,36,38,39,40,45,46,49,51,57,62,68,69,72,76,80,81,82,83,84,86,88,91,92,93,94	58	58

$$OF: -Min \sum C_1X_1 + C_2X_2 + \cdots + C_{50}X_{50} \quad . (7)$$

Step 3: Result

By considering constraint factor as unity, in this system no one has Zero injection bus so that with/without considering ZIB get the 15 optimal locations which are mention in Table III, to make fully observable 400kv network.

C. 200kV Network Observability

In the 220kv network 193 buses are connected with either generator/440kV bus or Load. Based on ILP similar producer for the system has been follows,

Step 1: Objective Function

$$OF{:}-Min\sum C_1X_1+C_2X_2+\cdots+C_{193}X_{193} \quad . \quad (8)$$

Step 3: Result

By considering constraint factor as unity, here in this system no one has zero injection bus so with/without considering ZIB get the 58 optimal location to make fully observable which are given in Table. [III].

CONCLUSIONS

For the control & operation of large & diversified power network it is desirable to have complete observability of the network. And hence to achieve the same the installation of PMUs is now a days very vital and essential. Mainly it is considered that the selection of location for placement is function of network observability and is being affected by the large cost of PMU involved. And therefore can be one of the major concerns for optimal placement of PMU. To have more clarity in depth, there are several other practical field scenario based topological and operational criteria have been followed to finalize the location of PMU. Such parameters are voltage level, location of substation, type of connection, future expansion, availability of communication infrastructure etc. The result can further be improvised using several more advanced methods and numerical observability subject to all concern can also be evaluated. The consideration of contingency may affect the result achieved for steady state operation of power system.

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REFERENCES

1. A.G. Phadke, and J. S. Thorp "Synchronized Phasor Measurements and Their Applications," Springer Science and Business Media, january 2008, pp. 1-246.
2. IEEE Standard, "Synchrophasor Measurements for Power Systems," IEEE Std C 37.118.1 (Revision of IEEE Std C37.118-2005), 2011.
3. IEEE Standard, "Synchrophasor Data Transfer for Power Systems," IEEE Std C 37.118.2-2011 (Revision of IEEE Std C37.118-2005), 2011.
4. S. A. Soman, Devesh Dua, Sanjay Dambhare and Rajeev Kumar Gajbhiye, "Optimal Multistage Scheduling of PMU Placement: An ILP Approach," Power Delivery, IEEE Transactions on (Volume: 23, Issue: 4), page(s): 1812 -1820, Oct. 2008.

5. Bei Xu and Ali Abur, “Observability Analysis and Measurement Placement for Systems with PMUs", Power Systems Conference and Exposition, IEEE PES, page(s) :943 - 946 vol. 2, 2004.

6. Bei Gou, “Optimal Placement of PMUs by Integer Linear Programming,” Power Systems, IEEE Journals & Magazines (Volume: 23, Issue: 3, Page(s):1525 - 1526), Aug. 2008.

7. B.K. Saha Roy, A.K. Sinha, A.K. Pradhan, “An optimal PMU placement technique for power system observability,” Power system, Science direct paper (Volume: 42, Issue:1), Page(s):71-77, May 2012.

8. Ichino. M, Sklansky .J, “Optimum feature selection by zero-one integer programming," IEEE Journals & Magazines, (Volume: SMC-14, Issue: 5), Page(s):737 - 746, Sept.-Oct. 1984.

9. Esmaili. M, Gharani. K and Shayanfar. H.A, “Redundant Observability PMU Placement in the Presence of Flow Measurements Considering Contingencies,” IEEE Journals & Magazines, (Volume: 28, Issue: 4), Page(s):3765 - 3773, Nov. 2013.

10. Manousakis. N. M, Korres. G. N, Georgilakis. P. S, “Taxonomy of PMU Placement Methodologies,” IEEE Journals & Magazines, (Volume: 27 , Issue: 2), Page(s):1070 - 1077, Nov. 2012.

11. Central Electricity Authority, New delhi, “Manual on Transmission Planning Criteria,” Page(s):1 - 50, Jan. 2012.

12. http://getco.co.in/getco_new/pages/power%20map.php - Power Map of Gujarat Network

13. www.mathswork.com – MATLAB Environment