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Optimal Location of Phasor Measurement Unit for Complete Network Observability of Power Systemt

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ABSTRACT

This paper presents analytical method to find optimal location of PMU to make power system observable. This Optimal PMU Placement (OPP) is optimization problem which has been solved using BILP (Binary Integer Linear Programming). The analytical method has been coded in the MATLAB and applied to different IEEE test systems up to 118 buses. Moreover OPP is offline optimization problem. The method has also been implemented for certain contingent conditions like line outage and PMU failures. The number of PMUs required is almost one third of system buses however their numbers actually depends on the topology of the network.

KEYWORDS: PMU, OPP, BILP, IEEE-test system

I-INTRODUCTION

The various Electrical Power supply system operating all across the world are larger and most complex control systems which are constantly monitored and controlled centrally through EMCs (Energy Management Centers. The Voltage Magnitude along with Phasor angle of all the connected nodes (buses) of the power system network are state variables of any power system. To monitor any control system it is essential that system is observable i.e. the measurement of set should be able judge the current state of the power system. However the conventional measurement techniques can only measure voltage magnitude of buses directly but phasor angle cannot be measured directly. Thus conventionally state estimator program is used to calculate state variables of power system from available set of traditional measurements i.e. voltage magnitude and line flows of the power system [1].

II- PHASOR MEASUREMENT UNIT[i]

The PMU has evolved from Symmetrical Component Digital distance relay thus as shown in fig 1. Its architecture is almost similar to that of Numerical relay except a GPS receiver. The analog signal of currents and voltages of various buses and feeders are obtained from the secondary windings of the current and voltage transformers. All three phase currents and voltages are used so that positive-sequence measurement can be carried out. For the measurement of absolute phases of all the voltages and currents measured by various PMUs located at different location all across the power system a common time stamp is required i.e. sampling is to be carried out simultaneously. This common time stamp is provided by GPS technology. The measurement techniques similar to that of numerical relay, except that sampling process of analogue signals of all PMUs starts at the same time. Thus the output of PMUs is time stamped measurement of bus Voltages, Line currents and respective phasor angles. Thus with PMUs a state measurement rather than state estimation is possible [1].

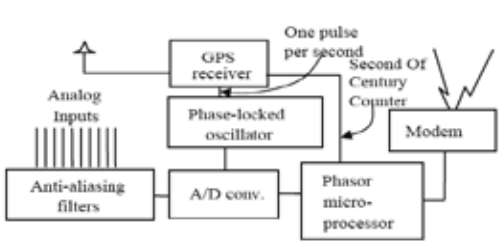

Figure 1 Block Diagram of PMU [1]

However PMU are costlier technology as fiber optics communication along with GPS is required. Thus OPP is optimization problem which could be solved using either analytical or heuristic methods.

III- OPP PROBLEM FORMATION

This paper uses the Binary Integer Linear programming to solve Optimal PMU placement problem for complete network observability [2,3]. The same method is used for OPP under single PMU outage condition i.e. each bus should be observed by two PMU so that even if one PMU fails system remains observable.

Rules for Optimal PMU Placement [4]

1. All buses connected to a directly observable bus are observable themselves.
2. If a bus without injection is observed and all but one of its connecting buses is observed, then the unobserved bus becomes observed.
3. An unobserved bus without injection connected only to observed buses is itself observable.
4. If all the buses neighboring buses with injection are observable, then that bus is also observable provided injection measurement is available at this bus is available i.e. it can also be treated like zero injection bus. Rule 4 is an extension of Rule 3.

1) OPP for complete network observability

The OPP is formulated as follows:

Minimize $\Sigma^{n}_{i=1} U_n$
Subjected to
$AU \geq b$
$U=[u_1, u_2, u_3 \ldots\ldots u_n]$ where $u_i \in \{0,1\}$
Where is PMU placement variable
Where A_c is system connection matrix

$$A_{ij} \begin{cases} 1 & if\ i = j \\ 1 & if\ i\ and\ j\ are\ connected \\ 0 & otherwise \end{cases}$$

and

(nx1) Inequality constraint matrix $b = \begin{bmatrix} 1 \\ 1 \\ \cdot \\ \cdot \\ 1 \end{bmatrix}$

Where n are number nodes or buses in network
2) OPP for complete network observability under single PMU out-

age or single line outage condition

The OPP is formulated as follows:
Minimize $\sum_{i=1}^{n} U_n$
Subjected to
$AU \geq b$
$U=[u_1, u_2, u_3 \ldots\ldots u_n]$ where $u_i \in \{0,1\}$
Where is PMU placement variable
were A_c is system connection matrix

$$A_{ij}\begin{cases} 1 & if\ i=j \\ 1 & if\ i\ and\ j\ are\ connected \\ 0 & ,otherwise \end{cases}$$

and

$$b=\begin{bmatrix} 2 \\ 2 \\ \cdot \\ \cdot \\ \cdot \\ 2 \end{bmatrix}\ (n\times 1)\ Inequality\ constraint\ matrix$$

III -BINARY INTEGER LINAR PROGRAMMING

The optimal solution of BILP problem is obtained by solving a series of LP relaxation problem, in which Binary integer requirement on the variable is replaced by weaker constraint $0 \leq u \leq 1$. The algorithm searches for binary integer feasible solution. Then, it updates the best integer solutions found so far as the search grows. And then, it verifies that no better integer solutions are possible by solving series of LP problem.

Algorithm for OPP:

1. Define objective function for minimization of placement variable of PMU (U).
2. Form system connectivity matrix from system data..
3. Consider zero injection bus, if any.
4. Set the inequality constraint vector b to 1 for OPP and to 2 for single PMU outage constrained OPP.
5. Find optimum solution for objective function using BILP in MATLAB.

IV –RESULTS AND DISCUSSION

TABLE-01

OPP for Complete Network Observability with no PMU at zero injection bus			
Sr. No	Test System	No of PMU	PMU bus
1	6 bus system	2	2,6
2	IEEE 6 bus system	1	2
3	IEEE 7-bus system	2	2,4
4	IEEE 14 bus system	3	2,6,9
5	IEEE 30 bus system	7	1,2,10,12,18,24,29
6	IEEE 57 bus system	11	1,6,13,19,25,29,32,38,51, 54,56
7	IEEE 118 bus system	28	3,8,11,12, 17,21,25,28, 34,35,40,45, 49,53,56,62, 72,75,77,80, 85,86,90,94, 102,105,110,114

TABLE-02

OPP for Complete Network Observability under Single Line Outage considering all the lines going out of service one by one or Single PMU failure at any bus where PMU is located			
Sr. No	Test System	No of PMU	PMU bus
1	IEEE 7-bus system	5	1,2,4,5,6
2	IEEE 14 bus system	7	1,3,6,,8,9,11, 13
3	IEEE 30 bus system	13	1,3,5,10,11,13,14,15,16,19, 2326,30
4	IEEE 57 bus system	19	1,2,6,12,14,19,21,27,29,30,32 33,41,44,49,5153,55,56
5	IEEE 118 bus system	53	1,6,10,11,12,1517,19,21,23,2 6,27,29,34,35,39,41,44,46,49, 51,53,56,57,59,61,67,72,73,7 4,75,76,78,80,83,85,87,89,91 ,92,94,96,100,101,105107,10 9,111, 112,113,114, 116,117

The program was developed in MATLAB to solve OPP. Results of various IEEE test systems are shown in Table-01 and Table-02. In most of the cases numbers of PMU required is one third of the numbers of buses present in the system. The of PMU required under healthy condition are quite lesser than under contingency condition. As seen from Table-01 and Table-02 for IEEE 30 bus test system the number of PMUs in healthy condition are 7 while under contingent condition the number of PMU required becomes 13 which almost doubled than under healthy condition. However this not almost true for all system, as it could seen for case IEEE 57 bus system where numbers of PMUs required are 11 and 19 for non-contingent and contingent case respectively. That is because the numbers of PMU required for complete network observability depends on topology of the network. If system connectivity matrix is very sparse the number of PMU required may be very high for contingent and non-contingent cases. The ratio of number of PMU requirement for contingent and non-contingent can be more than double.

IV –CONCLUSION

The problem of OPP is efficiently solved by binary linear integer programming technique. The method is computationally very efficient and OPP problem can be modeled linearly and solved by BILP. The method has been implemented for certain contingent conditions like line outage and PMU failures along with healthy system conditions.

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