Optimal Placement of PMUs Considering the Single Exit Units, in the presence of SCADA meters for the Network to neighborhood two zero injection buses

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ABSTRACT

One of the modern measuring equipment in the power system are phasor measurement units, that they can make the powerful and accurate state estimation and are cause the observability of network. In this paper placement of phasor measurement units with the minimum number, direction full observability of system in normal conditions and if occurrence of loss one PMUs. Also because the placement this measurement are performed with using a network topology, therefore considering the effect zero injection buses and SCADA meters power flow and power injection present in the network to minimize the number of phasor measurement units. In this problem has been proposed. Methods for solving this article, is simulation with using the Integer Linear Programming in MATLAB software environment to sample 7-bus network. Results suggests of the increase confidence observable the power system and the ability formulation provided direction reviews the effect zero injection buses in the neighborhood two zero injection buses, and reduce the number of units of measurement And is advantage the economic plan.

INTRODUCTION

Careful observed the modes of network performance are done with available state estimators in control center that are access to the various posts measurement. In the traditional approach, these measurements had been nonsynchronous, and were obtained with the presence conventional measurement units in substations. This measurement was consists of active and reactive power in this line and power injection to buses. Nowadays with the advent of phasor measurement units (PMUs), there is possible to synchronous measurement[1]. These units through the receive of time pulse signal that through the satellite global positioning system (GPS), to their measure signals account the time labels until in this way able to be achieved angle relative or through the receive of time pulse signal that through the satellite global positioning system (GPS), to their measure signals account the time labels until in this way able to be achieved angle relative or
to conversion of nonlinear state estimation equations of normality the network to linear equations, and in turn be improvethe speed control systems, conservation and management, that uses the results of state estimation [15].

Power Systems in addition to economic considerations, should be cohesive format to be designed that against the all possible stress to continue his work. One of these stress, is single exit phasor measurement units in power system. So for continuous state estimation in power system, is necessary be done placement this units in such a way that in case of occurrence this event, continue to be provided the complete observability of system[5].

In [5,6,14,17] has been to observability issue in case of loss of PMU, but in this reference not dealt the zero injection buses in the problem of optimal placement of PMUs.

Also the phasor voltage adjacent buses, placement the minimum number of PMU in order to observability electrical network, it is the one the main research objectives [6].

Also in some researches with specifying the buses that has zero the purified power injection, has been survey their effect in reduce the number of PMUs. In reference [11] there are a method for modeling zero injection buses in the problem of placement PMUs, that where is done the modify of network topology, so that
with removing the zero injection buses of network, becomes the main problem to a new problem of placement PMU non-zero injection buses.

In [3,10] although the considered idea as well as modeling the effect of zero injection buses on the constraint of optimization problem, but it has two basic flaws: first, if in a system, bus is connected to two or more bus with power zero injection. Not necessary be mentioned $f_i$ its corresponding bus at the corresponding inequality with individual buses with power zero injection. The second, not specified $f_i$, the Corresponding to the bus should be considered in the corresponding inequality with which of the buses with power zero injection?

In [4,7] to reduce the required number of PMUs, placement PMUs has been propose atcombining with another common measuring devices of available in the network. But then, equations are nonlinear.

In this paper, is done modeling of zero injection buses for the state that two zero injection buses is neighboring in optimal placement of PMUs with using a binary integer linear programming, and also placement of PMUs with considering zero injection buses and single loss units event.

**Placement of Phasor Measurement Units:**

Thus the buses monitored by phasor measurement units are directly observable whereas the neighboring buses connected to the PMU are indirectly observable. The other buses which are not associated with the PMU buses are unobservable [1]. For this purpose, it is sufficient to know the system topology (interconnection method buses and lines) and the type of system buses. Since the PMU installed on a bus can make the indirect visibility of a bus adjacent to it possible, it can reduce the number of PMUs installed on the network.

Optimum placement of PMUs is formulated with relations (1)[2,3,9,10,16]:

$$\text{Min} \sum_{i=0}^{N} x_i$$

$$\text{s.t.} \quad y = A x \geq b$$

In this connection $A$ shows how to connect to other buses and transmission lines such as equation (2). Moreover, the PMU installed at bus $I$ in the $x_i$ variable expressed in equation (3) is a binary variable associated with $I$ bus[2,3,9,10,16]:

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

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

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) [2,3,9,10,16]:

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

**Survey the Effect of the Zero Injection Busses in the Placement of PMU:**

The bus which not associated with any active and passive load is say the zero injection bus. Zero injection buses is the term that is given the bus which not injection any power or current through this to the system [8].

Is formulated placement of PMU any zero injection cause a new constraint that this considering is formulated in ILP environment as the equation (5) [9]:

$$f_i \geq 1 + \sum_{i \in \text{ZIB}} a_{ij} \mu_j s_{ij} - \mu_i, \quad i = 1, 2, \ldots, N$$

$$\sum_{i \in \text{ZIB}} a_{ij} y_{ij} = \mu_i, \quad i = 1, 2, \ldots, N$$

$$\sum_{i \in \text{ZIB}} a_{ij} s_{ij} = \sum_{i \in \text{ZIB}} a_{ij} y_{ij} - 1, \quad k = 1, 2, \ldots, N_{\text{ZIB}}$$

$$s_{ij} \leq y_{ij}, \forall i \in Z, \forall j \in \text{ZIB}$$

In this relationship, are $y_{ij}$ and $s_{ij}$ binary decision variables, ZIB is set buses to power zero injection system, ZIB$_k$ kth member from the collection and $N_{\text{ZIB}}$ indicates is the number of member this set. Buses connected to the ZIB$_k$ use as well their bus. Also set constitute $\zeta_{\text{ZIB}}$, Z set and $\mu_i$ variable are expressed respectively the relations (6) [7]:

$$z = \bigcup_{k=1}^{N_{\text{ZIB}}} \zeta_{\text{ZIB}}$$

$$\{ \mu_i = 0 \text{ if } i \notin Z \}$$

$$\{ \mu_i = 1 \text{ if } i \in Z \}$$
Optimal Placement of PMU Constraints in the case of a Single PMU Loss:

Like other applied to equipment in power system, also there is probability exit the PMU. To ensure the full observability of power system, if a single PMU loss, should be constraints are defined this problem of such that could be calculated the voltage phasor each buses of system at least methods. In other words, each system bus must be at least observable twice.

So $b_{nx1}$ matrix in (5) for maintain observability of system in this case of the placement PMU, changes to (7) $[2,3,7,9,11]$.

$$b_{nx1} = \begin{bmatrix} 2 & 2 & 2 & \ldots & 2 \end{bmatrix}^T$$

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

Already SCADA systems and registers events recorded accidents are responsible for the task, and the PMU is proposed, because of network expansion and will be monitored at once. However, due to the high price for PMU of electricity companies not able to installation PMU in a short period of time. so the system using SCADA, and gradually over the years have attempted to install the pmu in the grid. Including the SCADA meter can be noted the power injection meter.

For modeling power injection measurements in the optimal locating PMU, defined a vector as $Y=AX$. Element $yi=ai.xi$ of vector $Y$, Provision of bus $i$, which is related bus measurement can be observable. In other word, the elements of $Y$ Compliance with buses that are associated with this measure will be zero.

For modeling SCADA measurements in the problem of the optimal placement of PMU, is defined as one $Y=A.X$. Element of $Y$ that accordance with the relevant buses with this measurement will be zero[6,22].

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 (13) [6,22].

$$y_i + y_j \geq 1$$

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 (9) [6,22].

$$y_l + y_p + y_k + y_q \geq 3$$

c) Combined the flow power and power injection measurement:

If exist the combination of measurement according to the following is becomes in equation (10) [6,22]

$$y_l + y_q \geq 1$$

And similarly to following figure we have in equation (11).

$$y_q + y_n + y_i \geq 2$$

To the problem of optimal placement PMU can be modeled to linear problem (12) [18]:

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

That be obtained the $b_{\text{con}}$ vector dramatic the $b$ matrix with proposed conditions in the measurement equations. $P$ matrix, is the matrix arrange the buses, that is shown how the arrangement buses in $A_{\text{con}}$ matrix. $A_{\text{con}}$ 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 (13) [18].

$$
\begin{align*}
\min \sum_{i=1}^{n} x_i \\
\text{subject to: } & A_{con} P A X \geq b_{con} \\
& X_{n \times 1} = [x_1 \ x_2 \ \ldots \ x_n]^T \\
& x_i \in [0,1]
\end{align*}
$$

(13)

Simulation results positioning PMU:

In this section of the paper, the simulation results has been achieved in order to evaluate the ability

formulation provided in optimal placement of PMUs for sample 7-bus network in figure (1), at the four

following step:

First step: optimal placement of PMUs in normal state.

Second step: optimal placement of PMUs with to consider of zero injection buses.

Third step: optimal placement of PMUs with consider the neighborhood two zero injections buses, in case

of loss a PMU.

Fourth step: optimal placement of PMUs with consider the neighborhood two zero injections buses in the

presence of SCADA meters.

Fifth step: optimal placement of PMUs in the presence of SCADA meters with consider the neighborhood

two zero injections buses in the event single loss a PMU.

In order to solve each stage is used integer linear programming (ILP) algorithm in MATLAB.

Fig. 1: Diagram 9 bus sample network.

First step: optimal placement of PMUs in normal state:

At this stage, has been investigated to optimal placement of PMU for samples network by using the equations

(1) - (4). Table (1) is shown the optimal number and location of PMUs for this step. The results show the system

studied with PMU installed at 43% of buses is can be made to fully observability.

Table 1: Number and location of PMU optimal network in normal step.

<table>
<thead>
<tr>
<th>Location of PMUs</th>
<th>No. of PMUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,6,7</td>
<td>3</td>
</tr>
</tbody>
</table>

Second step: optimal placement of PMUs with to consider of zero injection buses:

At this step, has been studied the buses number 6 and 7 in Figure (1) as neighborhood of two zero injection

buses, in placement PMUs problem with help the relations (5) - (7). Table 2 is show at this step, with installation

PMUs on about 29% of the buses, network is fully observability. That it shows the reduce number of PMUs in

this step and more optimal response.

Table 2: Placement PMUs with considering the effect of neighborhood two zero injection buses.

<table>
<thead>
<tr>
<th>Location of PMUs</th>
<th>No. of PMUs</th>
<th>Zero injection buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,7</td>
<td>2</td>
<td>6,7</td>
</tr>
</tbody>
</table>
Third step: optimal placement of PMUs with consider the neighborhood two zero injections buses, in case of loss a PMU:
In this step, the equation (8) is alternatives sequations (4) of PMUs formulation. Table 3 shows the optimal number and location of PMUs with consider the single loss of PMU event. This table shows that for the full observability system with consider the single loss of PMU event, need for more equipment of buses than the normal state.

Table 3: Optimal number and location of PMU with consider the neighborhood two zero injections buses, in case of loss a PMU

<table>
<thead>
<tr>
<th>Location of PMUs</th>
<th>No. of PMUs</th>
<th>Zero injection buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,3,4,5,7</td>
<td>5</td>
<td>6,7</td>
</tr>
</tbody>
</table>

Fourth step: optimal placement of PMUs with consider the neighborhood two zero injections buses in the presence of SCADA meters:
At this step, is shows in the Table (4) the number and location of PMUs in presence one of two samples place SCADA meters, with effect of zero injection buses in sample network.
As can be seen in this network, if the power injection meter on the bus number 4 and power flow meter on the line 2-1, the number of requirement PMUs for the observability network is one, with compared to the normal stat 2 number and also compared placement in the presence injection meter and power flow is reduced one number, and in the general case the optimal placement at this step compared to normal stage need to has the reduce the number of PMU and there probability reduce the number compared to placement with consider the presence of SCADA meters and zero injection buses, depending on location SCADA meter.

Table 4: Optimal number and location of PMU with consider the neighborhood two zero injections buses in the presence of SCADA meters.

<table>
<thead>
<tr>
<th>Zero injection buses</th>
<th>Power injection meter</th>
<th>Power flow meter</th>
<th>no. of PMUs</th>
<th>Location of PMUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>6,7</td>
<td>3</td>
<td>4-5</td>
<td>2</td>
<td>4,7</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1-2</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Fifth step: optimal placement of PMUs in the presence of SCADA meters with consider the neighborhood two zero injections buses in the event single loss a PMU:
In this step, is considered both the third and fourth step simultaneously in the problem of optimal placement PMU. The Placement results are shown in Table 5. Results is shows need to more buses equipped with PMU for observability system with the presence of SCADA meters in the event single loss a PMU, compared to observability system with just PMU.

Table 5: Optimal number and location of PMU in the presence of SCADA meters with consider the neighborhood two zero injections buses in the event single loss a PMU.

<table>
<thead>
<tr>
<th>Zero injection buses</th>
<th>No. of PMUs</th>
<th>Location of PMUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>6,7</td>
<td>4</td>
<td>1,3,5,7</td>
</tr>
</tbody>
</table>

Conclusions:
In this paper was evaluated optimal placement of phasor measurement units in conditions the use of the minimum number, in order to full observability network that have the neighborhood of two zero injection buses. The results is indicate the ability of the solution, at reviews the effect of neighborhood two zero injection buses in optimal placement of PMUs and reduce the number of PMU required to observability network. Also with simultaneously investigating the presence SCADA meters and effect of zero injection buses, in addition to reduce the number of than normal state, Depending on the location of the SCADA meters, there are the possibility of reducing the number of PMUs than separate presence of SCADA meters (Which will reduce the number of PMUs). Also in the end to increase ensure observability, was evaluated single exit PMU event in this case, that then normal state are followed reduce the number and costs.

REFERENCES


