Optimal placement of phasor measurement units using topology transformation method based on Grey Wolf optimization approach

Posicionamento ideal de unidades de medição fasorial usando método de transformação de topologia baseado na abordagem de otimização Gray Wolf

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ABSTRACT
The optimal placement of phasor measurement units (PMUs) requires minimizing both the number of PMUs required and ensure that the whole power system is totally observable. To identify a power system as observable, it is necessary to know the voltages of all the buses in the power system. This paper suggests rules of selection for the topology transformation method, which implies a process of merging a zero injection bus and one of its neighboring buses. The selection of a bus chosen to merge with a zero injection bus will affect the result of the merging process. To determine the most appropriate bus to merge with the zero injection bus, the proposed method will use four rules designed to determine the minimum
number of PMUs required to achieve full observability of the power system. The problem is formulated and solved by a grey wolf optimization (GWO) approach. The suggested GWO has been applied to the IEEE 14-bus, 24-bus, and New England 39-bus.

Keywords: Grey Wolf Optimization (GWO), Phasor Measurement Units (PMUs), topology transformation method, Zero Injection Bus (ZIB).

RESUMO
O posicionamento ideal das unidades de medição fasorial (PMUs) requer a minimização do número de PMUs necessárias e a garantia de que todo o sistema de potência seja totalmente observável. Para identificar um sistema de potência como observável, é necessário conhecer as tensões de todas as barras do sistema de potência. Este artigo sugere regras de seleção para o método de transformação de topologia, que implica um processo de fusão de uma barra de injeção zero e uma de suas barras vizinhas. A seleção de um barramento escolhido para mesclar com um barramento de injeção zero afetará o resultado do processo de fusão. Para determinar a barra mais apropriada para se fundir com a barra de injeção zero, o método proposto utilizará quatro regras destinadas a determinar o número mínimo de PMUs necessárias para alcançar a observabilidade total do sistema de potência. O problema é formulado e resolvido por uma abordagem de otimização do lobo cinzento (GWO). O GWO sugerido foi aplicado aos modelos IEEE de 14 barramentos, 24 barramentos e New England 39 barramentos.

Palavras-chave: Otimização do Lobo Cinzento (GWO), Unidades de Mediación Fasorial (PMUs), método de transformação de topologia, Barramento de Injeção Zero (ZIB).

1 INTRODUCTION
In the modern era, almost everything has been modernized to achieve greater efficiency, reliability and control independence, the traditional power grids are also in transition to become a modernized power grid, or widely known as the smart grid. Smart Grid is designed to monitor and manage the power grid with maximum efficiency while providing better reliability and stability. There is a welcome opportunity to replace an older infrastructure with a smart grid that uses advanced technologies to achieve this vision. Among the advanced technologies used is the phasor measurement unit (PMU) [1].

In the mid-1980s, the Phasor Measurement Unit (PMU) has been introduced as a monitoring device [2]. This device used to estimate both the magnitude and the angular phase of an electrical quantity as a voltage or current phasor in the power system using a common time source for synchronization. Time
synchronization is generally provided by GPS and allows synchronizing real-time measurements of several remote measurement points on the network. The high cost of installing PMUs makes the possibility of changing all traditional measurements in the near future very unlikely. As a result, several techniques have been proposed by the researchers to solve the problem of the optimal placement of PMUs (OPP) [3].

In the past few years, numerous optimization techniques have been implemented to find out the best location of PMUs in a power grid, such as integer linear programming (ILP) [4], [4], [5] and [6], Binary integer linear programming (BILP) [7], biogeography based optimization [8], Cellular Learning Automata [9], Mixed Integer Linear Programming (MILP) [10], Empirical observability Gramian [11], The Gravitational Search Algorithm [12], Revised Analytical Hierarchy Process [13], The exponential binary particle swarm optimization (EBPSO) [14], integer linear programming (ILP) methodology [15], Binary cuckoo search [16], Binary integer linear programming [17].

The presence of a zero-injection bus can also contribute to reducing the number of PMUs required. Several studies have adapted the merging approach to handle with ZIB. However, the merging method has two limitations, one is to identify the exact placement of the PMUs and the other is to choose the right bus to merge. For this reason, this paper proposes three rules to deal with these limitations. Following the three rules developed, the best candidate bus to merge with ZIB will be evaluated. The results obtained by the proposed method will determine the precise location of the PMU.

The main aim of this paper is to find the optimal placement of PMUs in different power systems, by using the topology transformation method, to attain full observability by maximizing the measurement redundancy (SORI).

2 FORMULATION OF THE PMUS PLACEMENT PROBLEM

Generally, the principle goal of the OPP issue is to obtain the minimum number of PMU required and their locations to reach a fully monitored power system. So, the objective function of OPP problem is formulated as following:

$$\text{Min } \sum_{i=1}^{N_{Bus}}(c_i x_i)$$

(1)
Subject to \( f_i = AX \geq \hat{1} \) \hspace{1cm} (2)

Where:

- \( N_{bus} \) is the total number of system buses.
- \( c_i \) is the total installation cost of the PMU at bus \( i \).
- \( f_i \) is the observability function of bus \( i \).
- \( A \) is a binary connectivity matrix; entries are defined as follows:

\[
A_{ij} = \begin{cases} 
1, & \text{if } i = j \text{ or } i \text{ and } j \text{ are connected} \\
0, & \text{Otherwise}
\end{cases}
\] \hspace{1cm} (3)

\( \hat{1} \) is a vector whose all entries are all ones \( \hat{1} = [1, \ldots, 1] \).
\( X \) is a binary variable vector having elements \( x_i \) define possibility of PMUs on a bus \( i \) whose entries are defined as below:

\[
x_i = \begin{cases} 
1, & \text{if PMU is installed at bus } i \\
0, & \text{otherwise}
\end{cases}
\] \hspace{1cm} (4)

2.1 PMU PLACEMENT RULES

**Rule 1:** A PMU-equipped bus, both the voltage of its own phasor and the currents of all the branches attached to it are measured directly by the PMU.

**Rule 2:** When the voltage and current in one end of a branch are determined, it is possible to obtain the voltage in the remaining end of the branch by Ohm's law.

**Rule 3:** The current of a branch can be calculated, by using Ohm's law, if the voltage phasors are known at both ends of this branch.

To detail exactly how these rules work, follow figure 1. When a PMU is installed in bus 1, the value \( V_1, I_{1-2}, I_{1-3} \) and \( I_{1-4} \) can be directly obtained conforming to Rule 1. Once the current branches values determined \( I_{1-2}, I_{1-3} \) and \( I_{1-4} \), the voltages at busses 2, 3, and 4 can be calculated by ohm's law following Rule 2. Lastly, the current phasor of branch 3-4 will be available, according to Rule 3.
2.2 IMPACT OF ZERO INJECTION BUS (ZIB)

Zero-injection buses are charged to transmit power through the transmission lines of the network without injecting or consuming it. Consequently, the sum of the flows on all branches related to the ZIB is equal to zero. The rules of ZIB have been classified as follows:

**Rule 1:** When all buses adjacent to an observable ZIB are observable except one, it is possible to consider the unobservable bus as observable by applying the current Kirchhoff law in the ZIB.

**Rule 2:** When the neighboring buses of an unobservable ZIB are all observable, then the ZIB can be considered observable by applying the node equation.

To explain these rules, consider Figure 2. Here bus 1 is a zero injection bus and its neighboring buses are buses 2, 3, 4 and 5. Assume that buses 1, 2, 3 and 5 are all observable (their voltages are known) excluding bus 4. According to rule 1, when applying the KCL at bus 4 (ZIB), the current value $I_{14}$ can be calculated. Concerning the last rule, assume that buses 2, 3, 4, and 5 are observable and the ZIB is not observable. The voltage of bus 1 can be obtained by applying the node equation at the ZIB.
3 SYSTEM OBSERVABILITY REDUNDANCY INDEX (SORI)

The System Observability Redundancy Index (SORI) is an essential indicator to evaluate the quality of the optimal solution obtained. The set of optimal solutions is chosen on the basis of the greatest SORI value, which denotes the most reliable solution. [18]:

\[
SORI = \sum_{i=1}^{N_{bus}} A_i x_i \quad \forall \ i \in I
\]  

(5)

Where:

\( AX \) is the number of times a bus is observable via PMU.

4 THE PROPOSED TRANSFORMATION METHOD

The method of bus merging involves a merging process between the ZIB and one of its adjacent busses. Therefore, the merging process will merge the constraints of the two buses into a single constraint, which will reduce the number of constraints that need to be satisfied for each bus to be observable by the PMU placement set. According to the observability rules mentioned above, when considering the ZIB, if all buses connected to the ZIB are observable except one, the unobservable bus can be defined as observable. Therefore, the merged bus implies that if it is observable, the bus selected to merge will also be observable. The proposed method consists of four rules for which every candidate bus will be evaluated in sequence. Following are the four rules:

**Rule 1:** Candidate bus must not have been merged previously.

**Rule 2:** Merge the ZIB with its adjacent bus, which is radial bus.
Figure 3, shows that bus 2 is a ZIB and bus 1 is a radial bus. Bus 1 will be chosen to merge with bus 2. After the merging process, bus 3, 4 will be connected to bus 1’ and bus 2 is deleted from the network.

Figure 3 – Modelling the merging of ZIBs for rule 2, bus 1 is merged with bus.

Rule 3: If the rule 2 is not satisfied, merge the ZIB and its adjacent bus that has the most number of branches and one of its neighbors must be connected with the same ZIB. If several buses can respect this rule, choose one of them randomly.

Figure 4 – Modelling the merging of ZIBs for rule 3, bus 3 is merged with bus 2.

This increases the tendency to select buses as PMU placement due to the better coverage of the network among other buses that are adjacent to the ZIB.

Consider Figure 4, where bus 2 is a ZIB and is incident to buses 1, 3 and 4. The lines outgoing from buses 1, 3 and 3 signify that it is connected to other buses that are not illustrated in this figure. As buses 3 and 4 are incidents to each other
and are connected to the same ZIB, they will be considered to merge with bus 2. The selection between bus 3 or 4 to merge with bus 2 will depend on the bus that has the maximum number of neighbors between both buses concerned, and in this case, bus 3 is the best candidate for the merge.

Rule 4: If the above rules are not respected, the ZIB must be merged with the adjacent bus that has the most branches attached to it.

Figure 5 – modelling ZIB merging for rule 4, bus 1 is merged with bus 2.

This scenario achieves a better coverage of the network because it can reach more buses than other adjacent buses when it is chosen to merge with the ZIB.

In the figure 5 above, the bus 2 is a ZIB connected to the buses [19]. When compared the bus 1 versus the bus 3, the bus 1 has the largest number of neighbors, as can be seen It is therefore selected to merge with bus 2. Following the previous rules explained in this section, after the transformation of the topology, bus 2 is removed from the network.

The flowchart in figure 6 shows how to assess each bus on the basis of the above rules.
Figure 6 – flowchart for rules evaluation for candidate bus.

Source: Authors.

5 CASE STUDIES

The proposed topology transformation method is demonstrated using an IEEE 9 bus system as illustrated in Figure 7.

Case I: Base Case (Ignoring ZIBS)

The ZIB is not considered in this case. Furthermore, neither PMU is pre-allocated at the bus that is adjacent to the radial bus. By means equation (3), the binary connectivity matrix $A$ is formed as follows:

$$
[A] = \begin{bmatrix}
1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\
1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 1 & 1 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 \\
\end{bmatrix} \quad (6)
$$

As a result, the final inequality constraints of matrix $A$ can be formulated as follows:
These constraints mean that, for instance, assuming constraint \( f_5 \), when a PMU is placed at bus 5, then buses 4, 5 and 6 become observable. The constraints in the equation are then simulated using MATLAB and the result is as follows:

\[
X = [0 \ 0 \ 0 \ 0 \ 1 \ 0 \ 0 \ 1]
\]  

(8)

Two PMUs need to be placed at buses 5 and 8 respectively to ensure the whole system is fully observable.

**Case II: Existence of ZIBS:**

According to figure 7, there are three ZIBs, which are bus [20] and three radial bus [21]. The topology transformation process can be explained as follows for each ZIB:

In this case, the three ZIBs is located neighboring radial buses, [22], [20] and [20]. Hence, rule 1 should be applied. Figure 7 shows the consequences of the topology transformation process.
It should be noted that the merging process has reduced the number of buses from 9 to 6. As previously mentioned, one bus is "removed" from the power system for each ZIB present in the grid. Form this newly grid, a total of two PMUs need to be placed at bus [20] to ensure full observability of the network.

6 GREY WOLF OPTIMIZATION ALGORITHM (GWO)

The Grey Wolf Optimizer (GWO) is a new optimization method that simulates the behavior of grey wolves. Grey Wolves called "Canis Lupus" is one of the most popular species of Canidae family in the world. The grey wolves live mainly in a group of 5 to 12 individuals and respect a very special social hierarchy as shown in Figure 8 [23].

A couple of wolves called alphas (α) (The alpha male and the alpha female) leads this community. The alpha is the dominant wolf and is the leader of this pack. Alpha must be the only wolf that makes the decisions for the pack: the hunting, the sleeping place, the waking time, etc. In addition, he is also the only wolf in the group allowed to reproduce. In an interesting way, Alpha is not strictly the most powerful member of the pack, but the best to manage this pack. It is clear that the organization and discipline of the pack is much more essential than their strength [24].

The second level in the grey wolf hierarchy is beta (β). Betas are subordinate wolves that assist the alpha wolf in decision-making or other community activities. The beta wolf can be a male or a female, it can be the best candidate to take the place of the alpha wolf in case the latter dies or
becomes very old. The beta wolf must respect the alpha, but can command other lower-ranking wolves [23].

The deltas wolves (δ) are placed in the third position in this group social hierarchy. These wolves are also called subordinates. These wolves receive instructions from the alpha couple via the beta wolves and they dominate the omega wolves (the last in the hierarchy). The delta wolves can be divided into different categories such as sentinels, scouts, elders, Caretakers and hunters [23].

The last wolves in this hierarchy are called omega wolves (ω). They submit to all other wolves and play the role of scapegoats. It appears that the Omega wolves are not significant individuals in the pack and they are the last ones allowed to feed [23].

The process of grey wolf hunting (hunting, encirclement and attacking the prey) can be considered as an optimization procedure that is defined as follows:

1. The process of hunting is called optimization;
2. The prey represents the optimum;
3. The alpha, beta and delta wolves are the optimal solutions and alpha is the best solution. Omega is the rest of the solutions;
4. The hunting is guided by alpha, beta and delta, the omega wolves follow the dominate wolves.

The first stage of the hunting process is the encirclement of the prey. Grey wolves can detect the position of the prey and encircle it. The mathematical model of this phase is the following:

\[
D = |\vec{c} \cdot \vec{x}_p(t) - \vec{x}(t)| \quad (9)
\]

\[
\vec{x}(t + 1) = \vec{x}_p(t) - \vec{A} \cdot \vec{D} \quad (10)
\]

Where:

\( t \) indicates the current iteration, \( \vec{x}_p \) represents the prey's position vector, \( \vec{x} \) denotes a grey wolf's position vector, \( \vec{A} \) and \( \vec{c} \) are coefficient vectors and \( \vec{x}(t + 1) \) indicates the next position of the grey wolf. Therefore, grey wolves update their position by considering the position of their prey using the random equations (9) and (10).
Table 1 – The pseudocode of Grey Wolf Optimization (GWO)

| Initialization of the grey wolf population \( X_i \) \((i = 1, 2, \ldots, n)\) |
| Initialization of \( a, A \) and \( C \) via the equations (10) and (11) |
| Calculating the fitness for each of the research agents (wolf) |
| \( X_a \) = the best search agent |
| \( X_b \) = the second best search agent |
| \( X_\delta \) = the third best search agent |
| While (The maximum number of iterations is not reached) |
| for every search agent |
| Updating the position of the current search agent by equation (18) |
| end for |
| Update \( a, A \) and \( C \) by using the equations (10) and (11) |
| Calculate the fitness values for all search agents |
| Update \( X_a, X_b, X_\delta \) |
| End while |
| Return \( X_a \) |

Source: Authors.

The vectors \( \vec{A} \) and \( \vec{C} \) are determined as follows:

\[
\vec{A} = 2\vec{a} \cdot \vec{r}_1 - \vec{a} \tag{11}
\]

\[
\vec{C} = 2 \cdot \vec{r}_2 \tag{12}
\]

\( \vec{r}_1 \) and \( \vec{r}_2 \) are random vectors of entries varying between \([0, 1]\).

At first, the value of \( a \) is equal to 2 and linearly decreases until reaching 0 during the different iterations of the algorithm. The hunting is generally guided by alpha. Beta and delta participates in this hunt occasionally.

The second stage of the hunting process for grey wolves is carried out by alpha, beta and omega wolves. Assuming that alpha, beta and omega wolves know the potential position of a prey. We will save the position of these wolves and update the position of the other wolves, as indicated in the following equations:

\[
\vec{D}_\alpha = |\vec{C}_1 \cdot \vec{X}_\alpha(t) - \vec{X}(t)| \tag{13}
\]

\[
\vec{D}_\beta = |\vec{C}_2 \cdot \vec{X}_\beta(t) - \vec{X}(t)| \tag{14}
\]

\[
\vec{D}_\delta = |\vec{C}_3 \cdot \vec{X}_\delta(t) - \vec{X}(t)| \tag{15}
\]
\[
X_1 = X_\alpha(t) - \vec{A}_1 \cdot D_\alpha \tag{16}
\]
\[
X_2 = X_\beta(t) - \vec{A}_2 \cdot D_\beta \tag{17}
\]
\[
X_3 = X_\gamma(t) - \vec{A}_3 \cdot D_\beta \tag{18}
\]
\[
\vec{X}(t + 1) = \frac{X_1 + X_2 + X_3}{3} \tag{19}
\]

The final stage consists of attacking the prey when the wolves stop moving. This step is modelled by the decrease in the value of \( a \).

The \( A \) variable has a random value in the range \([-2a, 2a]\), in which \( a \) decreasing linearly from 2 to 0 over the iterations of the algorithm. Thus, the values of \( A \) are also decreasing.

- If \(|A| < 1\), the wolves will attack the prey. This represents the exploitation process.
- If \(|A| > 1\), the wolves are forced to diverge from the prey. This represents the exploration process.

The exploration process in the GWO algorithm is mathematically modelled using the \( A \) variable with random values greater than 1 or less than -1 to force the search agents to diverge from the prey [25].

7 APPLICATION OF THE PROPOSED ALGORITHM

The GWO technique was applied to solve the OPP problem. The decision variables for the OPP problem are PMU installation states. For a system with \( K \) agents, the position of the ith agent is determined by:

\[
X = [x_1, x_2, \ldots, x_K] \text{ For } i = 1, 2, 3, \ldots, K \tag{20}
\]

The following are the different procedures for resolving the OPP problem with the GWO:

1. Read the data of the power system including line data, bus data.
2. Obtain the Connectivity Matrix (A).
3- Initialize the GWO parameters as the Population Size (PS), the maximum number of iterations $I_{t_{\text{max}}}$ and the vector coefficients ($a^*$, $A^*$ and $C^*$).
4- Identify the upper and lower limits of the control variables.
5- Generating an arbitrary population of $N$ agents. For each agent, the initial values are randomly selected between the minimum and maximum values of the control variables.
6- In the OPP problem, the fitness values are calculated for each agent in the population.
7- Select the new leader wolves $X_{\alpha}$, $X_{\beta}$ and $X_{\delta}$ from the repository.
8- Use equations (11) and (12) to calculate the coefficient vector ($\bar{a}$, $\bar{A}$ and $\bar{C}$).
9- Actualize the position of the wolves using equation (18).
10- Find and save non-dominated solutions in the repository.
11- Put $t = t + 1$.
12- Repeat steps 3 to 6 until reaching the end criterion.

8 RESULTS AND DISCUSSION

MATLAB R 2017b software is used to run the simulations. The technical specifications of the computer used to carry out the simulations is the Intel i7 core with 2.4 GHz and 8 GB RAM. The results of the simulation have been obtained by assuming that each PMU contains the maximum number of channels possible while all PMUs are equally expensive.

The proposed method focuses on finding the minimum number of PMUs, to ensure complete monitoring of the system and maximize measurement redundancy (SORI). High SORI values imply too much reliability of the monitoring system for unexpected events.

Table 2 briefly presents the precise specifications of each testing system.
Table 2 – Characteristics of the test system.

<table>
<thead>
<tr>
<th>Test System</th>
<th>Number of Lines</th>
<th>Number of ZIBs</th>
<th>Locations of ZIBs</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE 14-Bus</td>
<td>20</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>IEEE 24-Bus</td>
<td>38</td>
<td>4</td>
<td>11, 12, 17, 24</td>
</tr>
<tr>
<td>NE 39-Bus</td>
<td>48</td>
<td>12</td>
<td>1, 2, 5, 6, 9, 10, 11, 13, 14, 17, 19, 22</td>
</tr>
</tbody>
</table>

Source: Authors.

Table 3 shows the optimal number of PMUs, their positions and the measurement redundancy value in the case without considering ZIBs. In the case of existence of ZIBs, both the number of PMUs, their locations and the SORI value are shown in Table 4. It appears from Tables 3 and 4 that the number of PMUs necessary to ensure a complete monitoring of the network has been decreased when considering the ZIB compared to the base case, which is due to the presence of ZIB.

In the case of NE 39-bus, as an example, there are 13 PMUs in the absence of ZIBs, whereas this number is reduced to 8 in the presence of ZIBs.

To better estimate the performance of the proposed method, the results achieved by the simulations performed with the applied approach are compared to previous studies. The PMUs number and SORI value are compared versus the results achieved from previous studies which have employed different techniques to resolve the OPP problem and considering normal operation and ZIB.

Table 5 summarizes the comparison between the results of the suggested method and those of existing studies. All tested IEEE bus system solutions are compared. The most qualitative solution is the one with the highest SORI, which is worth mentioning once again. As mentioned in this Table, the different studies
compared, even the approach proposed, succeeded in obtaining an identical number of PMUs for all the IEEE bus systems tested. However, the measurement redundancy values are different for some bus systems.

The same remark appears in Table 6 for the ZIB case. However, for the NE 39-bus system, the method proposed succeeded in reducing the number of PMUs needed compared to the result obtained.

<table>
<thead>
<tr>
<th>Test System</th>
<th>Parameter</th>
<th>Proposed Method</th>
<th>BPSO [26]</th>
<th>BPSO [27]</th>
<th>BSDP [28]</th>
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<tr>
<td>IEEE 14-Bus</td>
<td>$N_{\text{PMUs}}$</td>
<td>4</td>
<td>-</td>
<td>4</td>
<td>4</td>
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<tr>
<td></td>
<td>SORI</td>
<td>19</td>
<td>-</td>
<td>19</td>
<td>16</td>
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<tr>
<td>IEEE 24-Bus</td>
<td>$N_{\text{PMUs}}$</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SORI</td>
<td>31</td>
<td>29</td>
<td>31</td>
<td>-</td>
</tr>
<tr>
<td>NE 39-Bus</td>
<td>$N_{\text{PMUs}}$</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SORI</td>
<td>49</td>
<td>50</td>
<td>49</td>
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Source: Authors.

<table>
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<td>3</td>
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<td></td>
<td>SORI</td>
<td>16</td>
<td>15</td>
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<td>$N_{\text{PMUs}}$</td>
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<td>13</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>SORI</td>
<td>32</td>
<td>51</td>
<td>43</td>
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</table>

Source: Authors.

9 CONCLUSION

The OPP problem is solved with the aim of reducing the number of PMUs and improving measurement redundancy, on the basis of SORI values that assess the quality of PMU location in the power system. Two different situations, such as ignorance and consideration of ZIBs, are examined in this paper. A grey wolf optimization (GWO) method, which simulates the behaviour of grey wolves in the wild, has been used as a means of optimization. The proposed technique was tested on three test systems, IEEE 14-bus, 24-bus and NE 39-bus. To verify the results, a comparison has been made with other recent approaches. It appears from the results obtained that the proposed method has reduced the number of PMUs and improved the power system observability. In the next article, the power system will be developed, and applied in case of failure of a device and the line losses.
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