Method of Optimal Placement PMU Placement based on Probabilistic Reliability

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Abstract

PMU configuration in the actual proce ss, due to economic factors, can not configurated sufficient number of PMU to make the system completely observable, the paper studies optimal PMU placement based on incomplete observed for the given number of PMU in grid. After getting configurations, if the solution is not unique, then the system probabilistic reliability index as a reference factors that determine a way for the largest value of probabilistic reliability PMU incremental optimization program, the use of CLMCS flow calculation method to verify the correctness of selected programs and gives the results of various programs and the number of iterations.

Keywords

PMU; Incomplete observed; Optimal placement; CLMCS; Probabilistic reliability.

1. Introduction

With the rapid development of our economy and the continuous reform of electricity market, the continuous expansion of grid has become the development trend of the whole power system.[1,2] It is due to the continuous expansion of this size, which makes the grid accidents annually increasing trend in constantly changing, and this unceasingly increasing speed is continually increasing[3,4]. Because our country is gradually promoting the work of the smart grid, and in the pilot and summing up experience, there are still many problems now. For the advancement of the smart grid, the power grid is also higher and higher to the requirement of real-time, so based on the requirements of real-time feature's security and reliability will be higher [5]. Due to the electrical power system fund factor limit, this article proposes the PMU optimization placement method which is in the situation that the system is not completely observable. In the process of configuration, set the number of PMU device, if the number of optimized configuration scheme is not unique, then take the probability reliability incremental value as determine only metrics of solution scheme. And, the system of different configurations schemes do flow calculation, judge the deviation degree of the flow calculation results, shows the superiority of the selected scheme.

2. Unobservable Depth

2.1 The Concept of Unobservable Depth

Due to the configuration section, the prerequisite of PMU placement is not the same, so the definition of incomplete observed depth is also not the same, no matter how define the concept of incomplete observed depth. As long as the definition is reasonable, it can. The literature [6], Dr. Phadke gives the concept about incomplete observed depth is the most widely. He pointed out that the incompletely observed depth is the largest invisible region in electrical power system contains the number of the bus. In this article, we are using the concept of node incompletely observed depth $\eta(i)$ is the node i, and with its distance is the nearest directly observed nodes or indirectly observed nodes to go through the minimum number of the branch numbers. Will get, the incompletely observed depth values of different nodes are carried on the comparison. Choose the largest value, we take it as the system of the incompletely observed depth η_s, namely:

$$\eta_s = \max\{\eta(i)\}_{i=1}^{n} \tag{1}$$

Figure 1 illustrates incompletely observed depth of each node and incompletely observed depth of the system in the system.

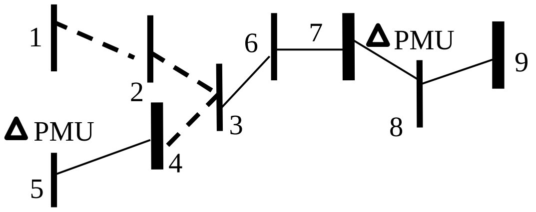

Figure 1. Incompletely observed depth definition schematic.

Through the figure 1, the incompletely observed depth definition schematic shows. If, on the node 5 and 8, each install a PMU devices, with indicates, then the closest nodes with it, 4, 7,9 can be observed indirectly, with the bold line represent, all of the other nodes cannot observed, namely $\eta(4)=\eta(5)=\eta(7)=\eta(8)=\eta(9)$. However, through the other nodes, with recently observed node connecting of branch number, we know, $\eta(1)=3$, $\eta(2)=2$, $\eta(3)=\eta(6)=1$, Therefore, the incompletely observed depth of system is the maximum of in each node incompletely observed depth values, namely $\eta_s = \max\{\eta(i)\}_{i=1}^{9} = \eta(3) = 3$

Among them, the dotted line is a branch which the system incompletely observed depth passes through.

2.2 The Meaning of Unobservable Depth

Because the research of electrical power system incompletely considerable PMU disposition has the practical significance. So said, the proposed unobservable depth is also existence its significance [7,8]. We get the line of electrical power system turn into the π-type equivalent circuit, shown in Figure 2, then analyze the unobservable depth meaning.

In the equivalent circuit diagram, the node j voltage vector can be obtained by calculation, namely:

$$\dot{U}_j = \dot{U}_i - Z\left(\frac{\tilde{S}_i'}{\dot{U}_i}\right) = \dot{U}_i - Z\left(\frac{S_i^* - \frac{1}{2}YU_i^2}{\dot{U}_i^*}\right) \tag{2}$$

Assume that any parameters of the circuit are accurate. If the voltage phasor $\dot{U}_j$ of the node j appears error, then by the equation (2),we can know, the error comes from the voltage phasor $\dot{U}_i$ of the node i and the trend $\tilde{S}_i$ of the branch $i-j$. That is to say, the two phasor value exist error, is not accurate.

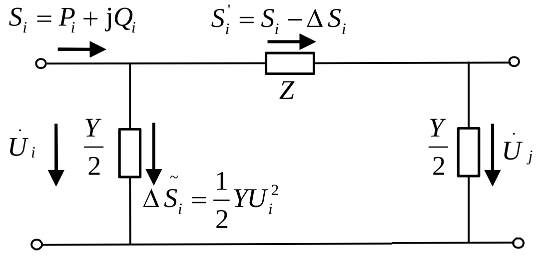

Figure 2.π- type equivalent circuit diagram of the line in the electrical power system.

Through the figure 1 shows that If the voltage phasor value of node 6 and node 3 exists error, then it is caused by the 3-4, 6-7 two branch current error, and the two branch are provided by the power system existing SCADA system. So the node 2 voltage phase value also appears error on the basis of the 3-4 branch error data, and this error will be larger.

The node voltage phasor in power system existence error degree size can be directly reflected through the unobservable depth concept.

3. System Incomplete Observed PMU Optimization Configuration Method

Through the concept of unobservable depth, for the system incomplete observed, PMU optimization placement methods do an introduction. Use the simple method of observability topology to analysis. According to the size of the system unobservable depth value to choose the location of configuration PMU, if the scheme is not the only, then for each configuration scheme do probability reliability index calculation, the maximum value of probability reliability incremental value is corresponding to the optimal allocation scheme as the optimal solution.

System unobservable depth of the minimum value as the initial search PMU position of the objective function:

$$\eta = \min\{\eta_s\} = \min\{\max\{\eta(i)\}\} \tag{3}$$

Probability reliability increment value of the minimum value as the system reliability analysis of the objective function:

$$\max\{PIRV\} = \max\{\frac{\Delta TPRI}{\Delta C}\} \tag{4}$$

The system incomplete observed PMU optimal configuration steps are as follows:

1).Input the electrical power system nodes correlation matrix A, need to configure PMU the number m and system node the number n;

2).The number of initialization configuration scheme t;

3).Make counter $i=1$;

4).Set the node i, and take it as the start configuration PMU node;

5).Using incidence matrix A, to find with the node exists a direct connect relationship the node j, make $\eta(i)=\eta(j)=0$;

6).Search for other nodes $K^{(k\neq i,j)}$ in the system, when it reaches the directly observed node i or indirectly observable node j, through the number of branches l in the shortest path, and make $\eta(k)=l$;

7). Compare the PMU configuration under the node i situation each node unobservable depth value. Choose one of the biggest unobservable depth value as this time configuration of system unobservable depth η_s;

8).When the judge $i=n$,comparing the n different largest value which we obtain in step 7. Output the minimum value of the maximum as a result of the whole system search unobservable depth, at the same time, the number of output $\min\{\eta_s\}$is t, Otherwise, make $i=i+1$, then return to Step 4 to continue the search;

9). Determine the number of configuration scheme $t=1$, if output, and obtain the node i value of $\min\{\eta_s\}$,end, otherwise each scheme carry on the probability reliability assessment.

4. Probability Reliability

4.1 Probability Reliability Evaluation Index

Probabilistic risk assessment method (PRA) is a practical mixture evaluation method, probabilistic methods and deterministic methods are combined by the mixture method, and PRA will appear the accident probability and the accident of the influence degree summarizes as probabilistic reliability index(PRI) . Probabilistic reliability index PRI is equal to the appearance accident probability with the product of the accident influence degree, the PRI is:

$$PRI = \text{Appearance accident probability} \times \text{Accident influence degree} \tag{5}$$

Among them, the extent of the accident produce influence is an impact that the accident for the whole power system on the physical properties.

And, specifies four kinds of reliability index, namely overload probabilistic reliability index (APRI), voltage beyond the upper and lower limit probability and reliability index (VPRI), voltage stability probabilistic reliability index (VSPRI) and cutting load probability reliability index (LLPRI). However, different reliability index values corresponding to different units and different domain. Before we want to the comprehensive analysis the different reliability index, must deal with different indicators at first. after make their respective domain within the boundaries of the same, they can become a composition factors of the comprehensive analysis. The following is the reliability index of after processing, its range all in the same range.

PRA rules of four kinds of reliability index as shown below:

1). Overload probabilistic reliability index (APRI)

$$APRI = \sum_{i\in\{S\}} \Pr obility \cdot \sum_{j=1}^{n} \frac{S_{overload\_j} - S_{\max}}{S_{\max}} \tag{6}$$

Type, $\{S\}$ is a collection of all possible faults in the power system, n for the fault, n is fault i cause the entire super load of the power system the number of all branch, $S_{overload\_j}$ is a load on the super load branch j , $S_{\max}$ is the maximum value that can bear the power capacity on the branch.

2). Voltage beyond the upper and lower limit probability and reliability index (VPRI)

$$VPRI = \sum_{i\in\{S\}} \Pr obility \cdot \sum_{j=1}^{n} \left| \frac{V_{overload\_j} - V_m}{V_m} \right| \tag{7}$$

Type, n is all of the nodes number that fault i can cause the whole power system nodes voltage exceeds the upper limit and the lower limit. $V_{overload\_j}$ is beyond the boundaries the voltage of node j , V_m is the maximum limit or the minimum limit of the node voltage.

3). Voltage stability probabilistic reliability index (VSPRI)

$$VSPRI = \sum_{i\in\{S\}} \Pr obility \cdot VSI_i \tag{8}$$

Type, VSI_i is the voltage stability situation that fault i can cause in the whole power system. If the failure causes the voltage instability, then $VSI_i = 1$; Otherwise, $VSI_i = 0$.

4). Cutting load probability reliability index (LLPRI)

$$VPRI = \sum_{i\in\{S\}} \Pr obility \cdot \sum_{j=1}^{n} \frac{L_{loss\_j}}{L} \tag{9}$$

Type, n is all of the nodes number that fault i can cause the whole power system cutting load, L_{loss_j} is the node j cutting load. L is all of the load in the system.

Values of these four kinds of indicators is [0,1] , then the definition comprehensive probabilistic reliability index (TPRI) for:

$$TPRI = \omega_1 \times APRI + \omega_2 \times VPRI + \omega_3 \times VSPRI + \omega_4 \times LLPRI \tag{10}$$

Type, ω_1 , ω_2 , ω_3 and ω_4 as the weighting factor.

Since in the actual grid, various uncertain factors will make the grid appear different circumstances. More than 4 kinds of reliability index, respectively expounds the size of the different problem reliability extent. According to the actual problem, weighting factor $\omega_1, \omega_2, \omega_3$ and ω_4 are assigned initial value.

4.2 Probabilistic Reliability Assessment Flow

Probabilistic reliability incremental value PIRV, as the PMU optimal allocation scheme reliability index, the probabilistic reliability evaluation process is as follows:

1).A collection of forming PMU optimization configuration feasibility scheme;

2).To calculate the cost of the optimization allocation grid, namely equipment investment CI ocapital perating costs CO and the total cost of investment C;

3).Calculate reliability index of different configuration scheme, $APRI$, $VPRI$, $VSPRI$, $LLPRI$;

4).The weighting factor ω_1, ω_2, ω_3 and ω_4 are assigned. Calculate comprehensive probabilistic reliability index $TPRI$;

5).Calculate probability reliability increment value $PIRV$;

6). Select the most optimal configuration scheme.

The flowchart of system incompletely observable PMU optimization configuration method is shown in figure 3. Figure 4 shows the probabilistic reliability assessment flowchart.

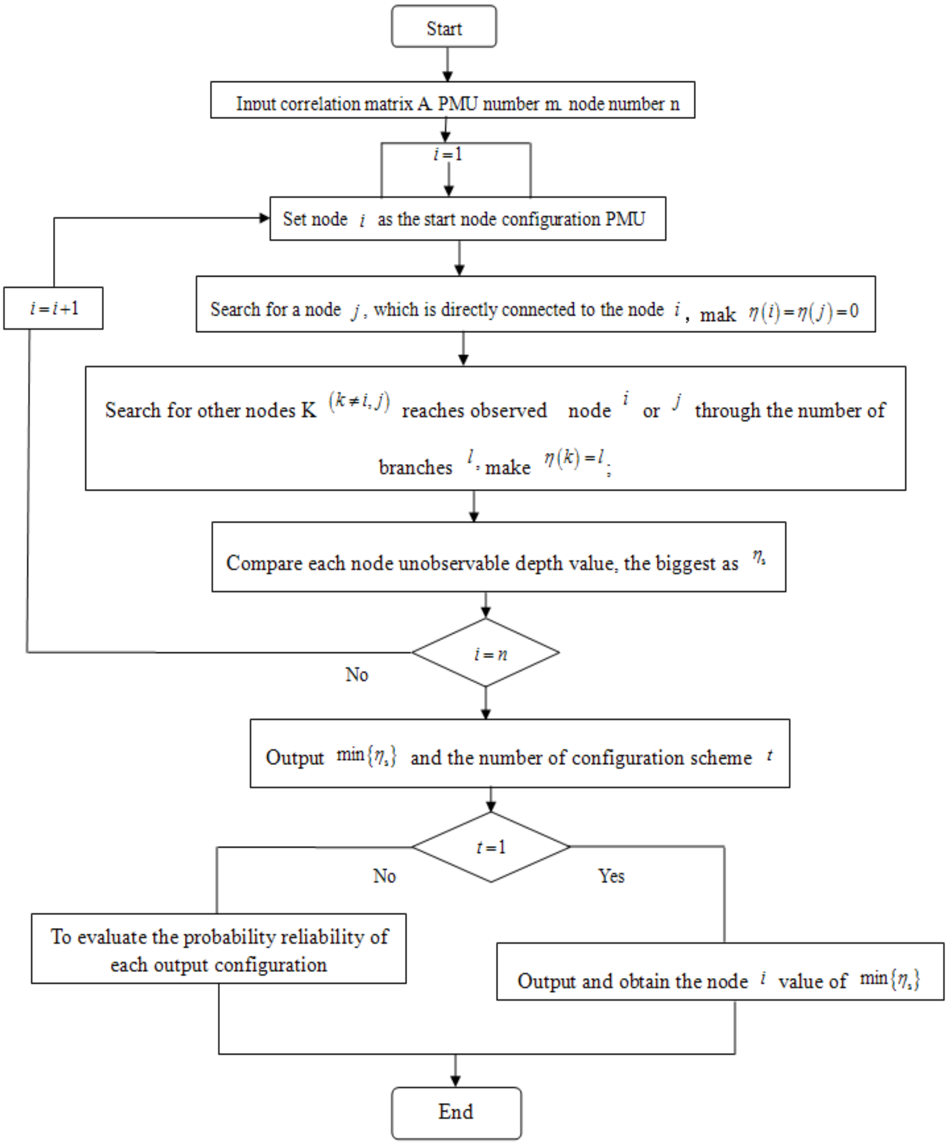

Figure 3. The flowchart of system incompletely observable PMU optimization configuration.

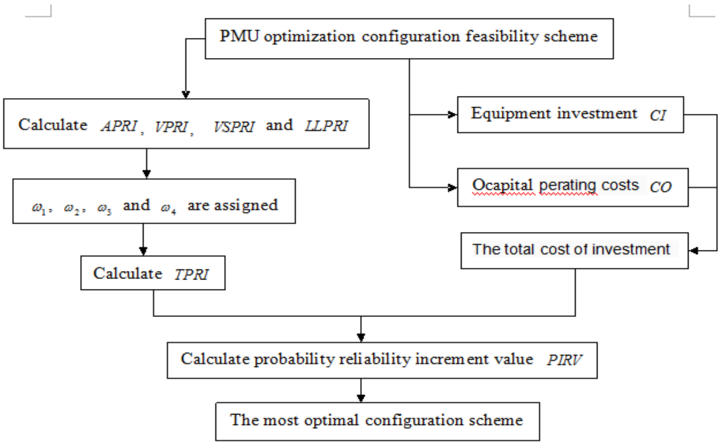

Figure 4. The flowchart of probabilistic reliability assessment

5. Conclusion

This paper puts forward the concept of system unobservable depth, and PMU optimized configuration method in under the system incomplete observed situation is studied. When we configurate one or two PMU devices to system, and for different configuration unobservable depth comparison. If there are a variety of schemes, the minimum unobservable depth among the scheme are the same. Then by calculating the probability reliability evaluation index, selecting the maximum value of the reliability incremental value as the final configuration results. The scheme is unique determined, then use the CLMCS probabilistic power flow calculation method to verify the correctness of the selected configuration scheme, do flow calculation for each scheme, and compares the calculation results. And applied to the IEEE14 node system and New England 39 node system, based on this carried on the simulation. PMU configuration scheme in different locations power flow calculation, comparing the number of iterations. take advantage of CLMCS method calculation deviation situation. Considering the system incomplete observability under the conditions, PMU optimal allocation has practical significance to the grid. In this paper, by using the probabilistic reliability index selection the optimal scheme is taking into account the economic investment case of the system. Apply CLMCS algorithm to verify the correctness of the selected scheme. Due to the outstanding features of the algorithm: The realization of the algorithm is relatively simple, high calculation accuracy; To effectively analyze the input phase correlation between random variables; Each input random variable type will not have constraint effect on the phase correlation; The output variables cases are more comprehensive.

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