Research on Optimal PMU Placement Method based on incomplete observed

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Abstract

PMU configuration in the actual process, 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

At present, the power systems are mostly established on the basis of the Supervisory Control and Data Acquisition (SCADA) system. With a long cycle of data measurement and acquisition of this system, the real-time data of the grid cannot be measured and there is no time mark in the data, so that the information of the same time point cannot be obtained in different locations. However, the emergence of phasor measurement unit (PMU, Phasor Measurement Unit) which is based on the global positioning system (GPS, Global Positioning Systems) can resolve the data synchronization issues. PMU uses the time signal of the GPS to make time stamp on the data which is measured by each node in the electrical power system. It is because of this characteristic that makes the power system dynamic observation possible. PMU device has the advantages of high measurement accuracy, high speed and short time interval for reading data. Because of these advantages, the device is widely studied as soon as this device appears. The most important character of this device is: it can obtain the phase angle of the node by the function of time stamp [1-5].

2. System incomplete observed PMU optimization configuration method

Introduce the methods of incomplete observed PMU optimization placement through the concept of incomplete observed depth. Using the simple method of observability topology analysis, choose the location of configuration according to the size of the system incomplete observed depth value to PMU, if the scheme is not the only, do probability reliability index calculation for each configuration scheme, take the maximum value of probability reliability incremental value which is corresponding to the optimal allocation scheme as the optimal solution.

Take the system incomplete observed depth of the minimum value as the initial search PMU position of the objective function:

$$\eta = \min\{\eta_s\} = \min\{\max\{\eta(i)\}\} \tag{1}$$

Take the maximum value of the probability reliability increment value as the objective function for the system reliability analysis:

$$\max\{PIRV\} = \max\left\{\frac{\Delta TPRI}{\Delta C}\right\} \tag{2}$$

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

1. Input the electrical power system nodes correlation matrix A, the number m of configuring PMU and the node number n of system;
2. The number of initialization configuration scheme t;
3. Make counter $i=1$;
4. Set node i as the starting configuration PMU node;
5. Use incidence matrix A to find the node j which has a direct connect relationship with the node i, make $\eta(i)=\eta(j)=0$;
6. Search for the number of branches l which other nodes K $(k \neq i, j)$ in the system pass through in the shortest path when they reach the directly observed node i or indirectly observable node j, and make $\eta(k)=l$;
7. Compare the incomplete observed depth value of each node under the situation of PMU configuration on node i . Choose the maximum value of incomplete observed depth as the incomplete observed depth η_s of the system configuration this time;
8. When determine $i=n$, compare the n different maximum values which we obtain in step 7. Output the minimum value among the maximum values as the result for searching the incomplete observed depth of the whole system, at the same time outputting the number of $\min\{\eta_s\}$ t . Otherwise, make $\boldsymbol{i}=\boldsymbol{i}+\mathbf{1}$, then return to Step 4 to continue the search;
9. When determine the number of configuration scheme $t=1$, output the value of the node i obtained from $\min\{\eta_s\}$, end, otherwise do the probability reliability assessment on each scheme.

3. The example analysis

Beforehand we set up that the equipment depreciation rate $i=5\%$, the equipment service life is 10 years and the convergence condition of power flow calculation is $\varepsilon=10^{-6}$. When calculating the power flow result deviation of each configuration scheme, the power flow is calculated in the sample size of the regulation for 100 times. In this paper, the IEEE14 node system is researched by being configurated a PMU device. And, the New England 39-node system is researched by being configurated two PMU.

When PMU is installed in different nodes, the calculation result of the system incomplete observed depth is 2, 3, and 4. PMU installed in different nodes, the minimum value of the system incomplete observed depth is 2. We regard 2 as an incomplete observed depth of the whole. So for pre-instaling a PMU device, we have the following five kinds of schemes:

1. If installed on node 2, nodes 1, 3, 4 and node 5 can be indirectly measured;
2. If installed on node 4, nodes 2, 3, 5, 7, 8 and node 9 can be indirectly measured;
3. If installed on node 5, nodes 1, 2, 4 and node 6 can be indirectly measured;
4. If installed on node 6, nodes 5, 11, 12 and node 13 can be indirectly measured;
5. If installed on node 9, nodes 4, 7, 8, 10 and node 14 can be indirectly measured.

Since the scheme is not unique, so we conduct the probabilistic reliability assessment and determine the unique solution. In this article, we will regard probability reliability problems as equal appearing and all appearing, then make $\omega_1=\omega_2=\omega_3=\omega_4=1$, but the size of the reliability is determined by the respective calculation value. Calculation of probabilistic reliability incremental value is shown in table 2.

Through the table 2, the probabilistic reliability incremental value $PIRV$ of scheme 4 is relatively greater. Reliability and economy of power system can be better balanced, then the plan 4 is the optimal scheme.

The system configurated no PMU unit is presented as 0 scheme. The power flow methods are applied to the above six kinds of schemes for comparing the iteration times of power flow calculation. As shown in Figure 5, we can know that iteration times of power flow calculation in solutions 1-5 are less than that in 0 scheme.

Table 1 Different schemes of probabilistic reliability assessment results

Scheme	Δ*TPRI*	Δ*C* (ten thousand)	*PIRV* (1/the thousand)
1	0.010228	15219.30	6.72e-7
2	0.007413	15108.94	4.91e-7
3	0.004238	15004.31	2.82e-7
4	0.011242	15382.81	7.31e-7
5	0.010481	15192.64	6.90e-7

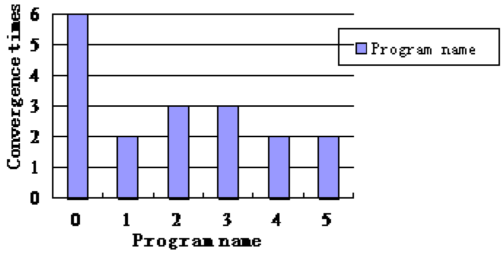
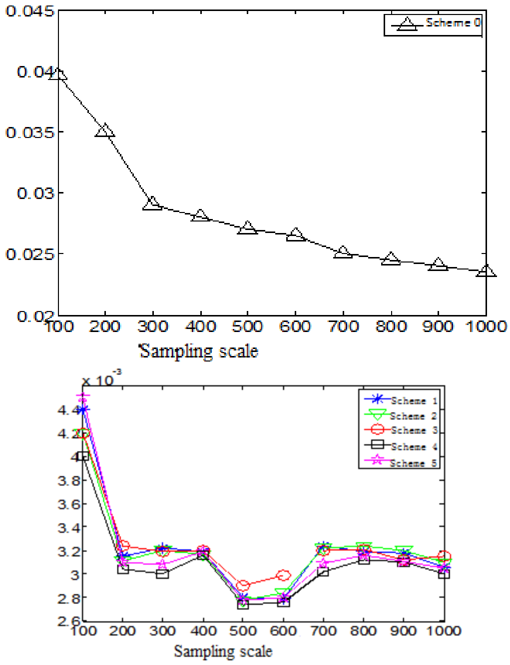
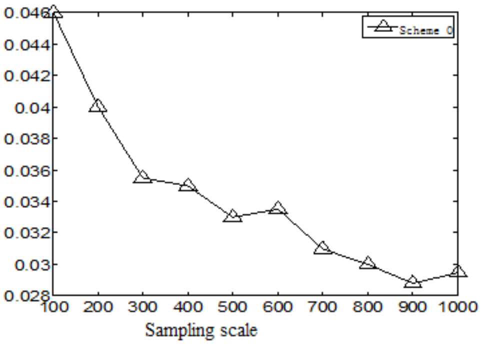


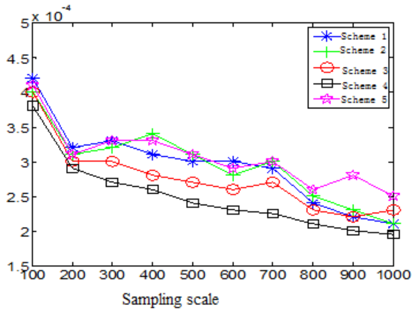
Figure 1. Comparison of iteration times of flow calculation in each scheme.

Figure 6 and 7 are the variation of expected error and standard deviation by using CLMCS method to calculate the voltage amplitude results in above 6 kinds of schemes.



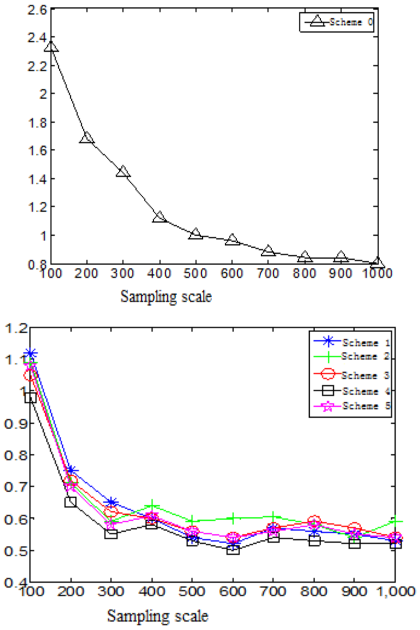
(a) Various schemes using CLMCS of $\bar{\varepsilon}_{E}^{U}$.



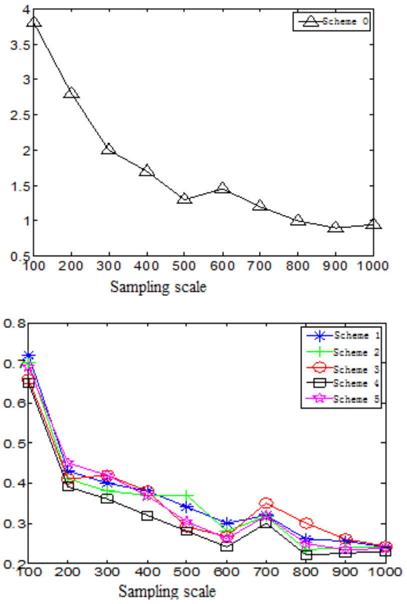


(b) Various schemes using CLMCS of $\bar{\varepsilon}_{\mathrm{D100}}^{U}$ contrast.

Figure 2. Various schemes CLMCS of $\bar{\varepsilon}_{\mathrm{E}}^{U}$ contrast.



(a) Various schemes using CLMCS of $\bar{\varepsilon}_{\mathrm{D}}^{U}$.



(b) Various schemes using CLMCS of $\bar{\varepsilon}_{\mathrm{D100}}^{U}$ contrast.

Figure 3. Various schemes CLMCS of $\bar{\varepsilon}_{\mathrm{D}}^{U}$ contrast.

Table 2 and 3 are the data result of $\bar{\varepsilon}_{\mathrm{E}}$ and $\bar{\varepsilon}_{\mathrm{D}}$ obtained by using CLMCS probabilistic power flow calculation method in various schemes.

Table 2 Comparison of $\bar{\varepsilon}_{\mathrm{E}}$ in various schemes

Scheme		Average Value	Standard Value
0	$\bar{\varepsilon}_E^U/\%$	3.02e-2	3.42e-2
	$\bar{\varepsilon}_E^\theta/\%$	0.78	0.69
	$\bar{\varepsilon}_E^{Q_{ij}}/\%$	1.6	0.79
	$\bar{\varepsilon}_E^{Q_{ij}}/\%$	1.28	1.23
1	$\bar{\varepsilon}_E^U/\%$	3.22e-2	2.94e-4
	$\bar{\varepsilon}_E^\theta/\%$	0.24	6.89e-3
	$\bar{\varepsilon}_E^{Q_{ij}}/\%$	0.27	5.87e-3
	$\bar{\varepsilon}_E^{Q_{ij}}/\%$	0.36	0.0481
2	$\bar{\varepsilon}_E^U/\%$	3.21e-3	2.95e-4
	$\bar{\varepsilon}_E^\theta/\%$	0.31	7.25e-3
	$\bar{\varepsilon}_E^{Q_{ij}}/\%$	0.32	5.99e-3
	$\bar{\varepsilon}_E^{Q_{ij}}/\%$	0.24	0.0513
3	$\bar{\varepsilon}_E^U/\%$	3.21e-3	2.76e-4
	$\bar{\varepsilon}_E^\theta/\%$	0.35	7.48e-3
	$\bar{\varepsilon}_E^{Q_{ij}}/\%$	0.29	6.04e-3
	$\bar{\varepsilon}_E^{Q_{ij}}/\%$	0.33	0.0328
4	$\bar{\varepsilon}_E^U/\%$	2.95e-3	2.50e-4
	$\bar{\varepsilon}_E^\theta/\%$	0.51	6.75e-3
	$\bar{\varepsilon}_E^{Q_{ij}}/\%$	0.19	5.22e-3
	$\bar{\varepsilon}_E^{Q_{ij}}/\%$	0.11	0.0184
5	$\bar{\varepsilon}_E^U/\%$	3.19e-3	3.07e-4
	$\bar{\varepsilon}_E^\theta/\%$	0.19	7.14e-3
	$\bar{\varepsilon}_E^{Q_{ij}}/\%$	0.23	5.96e-3
	$\bar{\varepsilon}_E^{Q_{ij}}/\%$	0.27	0.0502

Table 3 Comparison of $\bar{\varepsilon}_{\mathrm{D}}$ in various schemes

Scheme		Average Value	Standard Value
0	$\bar{\varepsilon}_D^U/\%$	1.19	1.71
	$\bar{\varepsilon}_D^\theta/\%$	2.64	2.12
	$\bar{\varepsilon}_D^{P_{ij}}/\%$	2.77	2.12
	$\bar{\varepsilon}_D^{Q_{ij}}/\%$	3.12	2.11
1	$\bar{\varepsilon}_D^U/\%$	0.64	0.36
	$\bar{\varepsilon}_D^\theta/\%$	0.98	0.71
	$\bar{\varepsilon}_D^{P_{ij}}/\%$	0.88	0.62
	$\bar{\varepsilon}_D^{Q_{ij}}/\%$	0.81	0.55

2	$\bar{\varepsilon}_D^U/\%$	0.65	0.35
	$\bar{\varepsilon}_D^\theta/\%$	0.95	0.69
	$\bar{\varepsilon}_D^{P_{ij}}/\%$	0.84	0.61
	$\bar{\varepsilon}_D^{Q_{ij}}/\%$	0.80	0.52
3	$\bar{\varepsilon}_D^U/\%$	0.64	0.36
	$\bar{\varepsilon}_D^\theta/\%$	0.95	0.68
	$\bar{\varepsilon}_D^{P_{ij}}/\%$	0.83	0.63
	$\bar{\varepsilon}_D^{Q_{ij}}/\%$	0.81	0.53
4	$\bar{\varepsilon}_D^U/\%$	0.95	0.32
	$\bar{\varepsilon}_E^\theta/\%$	0.93	0.66
	$\bar{\varepsilon}_D^{P_{ij}}/\%$	0.81	0.58
	$\bar{\varepsilon}_D^{Q_{ij}}/\%$	0.76	0.49
5	$\bar{\varepsilon}_D^U/\%$	0.63	0.35
	$\bar{\varepsilon}_D^\theta/\%$	0.96	0.70
	$\bar{\varepsilon}_D^{P_{ij}}/\%$	0.84	0.59
	$\bar{\varepsilon}_D^{Q_{ij}}/\%$	0.78	0.53

Through the comparison of figure 2,3 and table 2,3, error value of the power flow calculation results of scheme 4 is shown minimum. Scheme 4 is verified as the optimal solution. This proves the selected best solution is correct.

4. Conclusion

This paper puts forward the concept of system incomplete observed depth, and PMU optimized configuration method under the situation of system incompletely observed is studied. Provision of system configurated one or two PMU devices, the incomplete observed depth of different configuration schemes are compared. If there are a variety of schemes whose the minimum incomplete observed depth are the same, then by calculating the probability reliability evaluation index, we can select the maximum value of the reliability incremental value as the final configuration results. And the scheme is uniquely determined. Then the CLMCS probabilistic power flow calculation method can be used to verify the correctness of the selected configuration scheme, do flow calculation for each scheme, and compare the calculation results. And this method is applied to the IEEE14 node system and New England 39 node system to carry on the simulation. The number of power flow calculation iterations that PMU configurated in different locations are compared. As the same time, taking advantage of CLMCS method, we can calculate deviation situation. Considering the PMU optimal configuration under the situation of system incompletely observability has practical significance to the grid. In this paper, we use the probabilistic reliability index to select the optimal scheme is because of considering the economic investment case of the system. Using CLMCS algorithm to verify the correctness of the selected scheme is due to the outstanding features of the algorithm: The realization of the algorithm is relatively simple, and has high calculation accuracy; the algorithm can effectively analyze the correlation between input random variables; Each type of input random variable will not have constraint effect on the phase correlation; The cases of output variables are more comprehensive.

Acknowledgments

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