Research on Optimal PMU Placement Method Considering Node Failure Rate

Limei Yan [1], Bo Chen [1], Jianjun Xu [1, *], Yibing Xie [2], Mingxia Xie [1]

[1]Northeast Petroleum University, Daqing163318, China

[2]Qingdao Hotel Management College, Qingdao266100, China

Abstract

Not considering the reliability of components, generally, PMU optimal allocation results weren't taken fully account of the possible failure of the grid elements. Based on fully considering the reliability and economy, this article proposes the method of optimal PMU placement by combining the node failure rate and the completely observability of system as constraints. While trying to improve and combine Differential Evolution(DE) Algorithm and Shuffle Frog Leaping Algorithm(SFLA),use speed update strategy and global searching ability of DE algorithm to avoid low accuracy and easy to fall into the local optimum in dealing with problems, in order to improve the performance of the algorithm. The first, considering the node failure rate as constraint in the optimization processes to guarantee the global optimal solution of the power system, at the same time to make the numbers of PMU least. Comparing considering the system failure rate and without considering the system failure rate for IEEE14 node-system and New England 39-node system, which shows that the program of considering system failure rate makes the reliability indices more stable and the hybrid algorithm, instead of the existing optimization methods, which can reduce the number of PMU configuration and achieve completely observability of the system, finally, through the simulation results of Daqing Oilfield grid Xianfeng hyper variable region, it verifies feasibility and validity of the algorithm.

Keywords

Optimal PMU Placement, observability, DESFLA, failure rate, reliability index.

1. Introduction

Since the country is gradually advancing the smart grid work and summing up experience, a lot of problems still exists .Modern power system real-time performance makes greater demands of the security and reliability of power grid. So the problem of safety and stability in power grid is critical. In order to carring on the real-time monitoring and the prompting adjustment to the power network dynamic movement situation, we must measure the system generatrix voltage carries on the observation. Due to the PMU devices in different locations, at the same time can be resolved at that point real-time data synchronization problems [1]. So the device can obtain the real-time data information. However, the PMU price of equipment is high, thus the issue of optimization in power system PMU are widely concerned.

Optimal allocation of PMU is a problem of Multi-restraints, multi-objectives [2]. In recent years, there are many experts and scholars having conducted studies on optimal allocation of the PMU. To most of them, study direction is to ensure optimal PMU placement system complete observable and they have obtained the important research results [3]. R.F.Nuqui, et.al, 2005 proposed the method increased the system in the accident the incompletely considerable possibility. The reference [4-8] uses the immunity genetic algorithm to carry on the optimized disposition to PMU, but the system is not completely observable. Even though most of the researches are based on the system of complete observability, these methods all had not considered actually the system appears breakdown situation, so in this paper, the optimal location of PMU determined by reliability index, using DE differential evolution algorithm and leapfrog algorithm SFLA improved hybrid optimization algorithm, taking

PMU disposition smallest number as objective function. In order to ensure complete observability of power system conditions, improving the speed of convergence of the hybrid algorithm.

2. Problems of pmu optimization

2.1 System observability

Carrying on the analysis through the network topology to the entire power system,if voltage magnitude and voltage phase angle can be measured directly or through the calculation, the node is considered to be observed. Algebra and topology is the two main type of observation of the system [9],simple to say,the topology considerable means through the network node to the observe and analysis.

Using of the rules of the observability system to configuration PMU, determine the system observability rules in reference [10] observability conclusion.

2.2 PMU optimization conditions

On the premise of power system is fully observable, in order to guarantee the power network safety and reliable. This article proposes the consideration of power network node failure rate [11], in another words, first installs PMU unit to the node of the system lack of high expectations. PMU optimization conditions as follows:

a. The first constraint conditions is to meet the complete observability ;

b. The second constraint conditions is main consideing the node failure rate of system. Priority configure the PMU device on the node which the system battery lack of high expectations

c. Put the least number of PMU configuration (reduced economic investment) as the objective function;

d. During the configuration process, select the nodes connected with the high failure rate, the number of outlet up to the node as a candidate node.

2.3 The mathematical model of PMU optimal allocation

This article, optimize configuration the electrical network which has N node. It requires full system observability conditions of all constraints and node failure rates is F_i . All of these constraints, putting the low expectations EENS as reliability index to the value on the node with the highest priority configure the PMU device are used to determine the minimum number n and optimal location collection $P(n)$. Optimization problems can be described as follows:

$$\min y = \sum_{i=1}^{N} x_i \tag{1}$$

$$\sum_{i \in P} f(x_i) \geq \sum_{i=1}^{N} x_i \tag{2}$$

$$F_i = \{F_1, \ldots, F_n\} \tag{3}$$

$$x_i = \begin{cases} 1 & \text{Node } i \text{ configure} \\ 0 & \text{Node } i \text{ not configure the} \end{cases} \tag{4}$$

In this formula, y is the number of PMU configuration, N is the number of nodes in a system.

3. Improvedal gorithms for pmu allocation

3.1 Difference evolution algorithm of Operator restructuring strategy

Differential evolution algorithms is a simple and effective heuristic optimization algorithm which was made by Rainer Storn and Kenneth Price in 1995 [12].It has advantages of the fast astringency, the very good stability and the strong compatibility to the nonlinear equation. The evolution process and the mechanism of DE are showed as follows:

Variation operation

Variation operation of DE algorithm is through adds to the difference vector in the third vector to produce a new variation vector [13].The operator restructuring strategy is applied to variation operation to make the population to generate a new individual to ensure the population Variation operation effectively, variation in operating formula is showed as follows:

$$v_{ij}(t+1)=x_{bj}(t)+F_i(t)\cdot(x_{i1j}(t)-x_{i2j}(t)) \quad (5)$$

$$w_{ij}(t+1)=\left(x_{i3j}(t)+x_{i4j}(t)\right)/2 \quad (6)$$

$$F_i(t)=\beta(e^{\lambda}-1) \quad (7)$$

$$\lambda=\frac{T_{\max}}{T_{\max}+t} \quad (8)$$

in formula, $i=1,\ldots,N_P, j=1,\ldots,D$, N_P is the size of population, D is the dimension of the problems, $F_i(t)$ is adaptive variation in operating factor, λ is control factor, $T_{\max}$ is the maximum number of evolution, t is current evolution algebra, β is a constantion between $[0.2,0.6]$. i, $i1$, $i2$, $i3$, $i4$ are not mutually equal and $i1$, $i2$, $i3$, $i4$ are any positive integer random between $[1,M/2]$, x_b is current optimal position.

The crossover operation

Each cross operation must use the mutation operators to parametric mixture, the resulting vector mixed called test vector. The crossover operation ensure the population diversity and increasing the diversity :

$$u_{ij}(t+1)=\begin{cases} v_{ij}(t+1) & if\,(rand[0,1]\le CR) \\ x_{ij}(t) & else \end{cases} \quad (9)$$

$$CR=CR_{\min}+\frac{(CR_{\max}-CR_{\min})t^2}{T_{\max}{}^2} \quad (10)$$

in formula, $u_{ij}(t+1)$ is the individual variation in operation, CR is the crossover probability factor, $CR_{\max}$ and $CR_{\min}$ are the maximum cross-probability factor and the minimum cross-probability factor, this article take $CR_{\min}=0.1$, $CR_{\max}=1.0$ .Function of the crossover probability factor is well to balance global and local search ability. Guarantee entry to the advantage of local search without getting into the plight of local search to reach the best results global search.

Select operation

Select operation by comparing child and parent individuals keep good individual as the optimization results, select operation equation as follow:

$$x_{ij}(t+1)=\begin{cases} u_{ij}(t+1) & if\,(f(u_{ij}(t+1))\le f(x_{ij}(t))) \\ x_{ij}(t) & else \end{cases} \quad (11)$$

in formula, $x_{ij}(t+1)$ is produces in new generation of individual i -th granule position, f is fitness function value, also is objective function value.

3.2 b. Shuffled Frog Leaping Algorithm

Shuffled Frog Leaping Algorithm（SFLA）is a new optimization algorithm in recent years[14]. Searching mechanisms of SFLA is a group of N frogs, assuming the search space is D dimensional, stochastically produces a frog groups,each frog populations are a solution search space. Using $X_i=(x_{i1},x_{i2},\ldots,x_{iD})$ to express the i -th frog to calculate the fitness value of each individual and carries on descending sequence sorting. After sorting the population is divided into M subgroups. And each group needs leapfrog optimization operation. Every subgroup evolution iteration needs to determine the most superior individual X_b ,the worst individual X_w and the most superior individual in groups X_g ,then it carries on the position renewal operation to the worst individuals of sub groups X_w ,the location update formula is showed as follows:

$$d(t)=rand(0,1)\left(X_b(t)-X_w(t)\right) \quad (12)$$

$$X_w(t+1)=X_w(t)+d(t) \quad (13)$$

in formula, $d(t)$ is stride length of frog migration and it moves a step to meet $-d_{\max} \le d(t) \le d_{\max}$, $d_{\max}$ is the maximum stride length of frog may moves. It should calculate $f(X_w(t+1))$ and $f(X_w(t))$,then it carries on the comparison judgment,if $f(X_w(t+1)) \ge f(X_w(t))$, $X_w(t+1)$ replaces $X_w(t)$,while renews $X_b(t)$, $X_w(t)$ and $X_g(t)$; If $f(X_w(t+1)) < f(X_w(t))$, $X_g(t)$ replaces $X_w(t+1)$. Continuelly it carries out the position renewal formula,if $X_w(t+1)$ is not improved,it randomly generates a new $X'_w(t+1)$ to replace $X_w(t)$,and it carries on the iterative computation above step until each sub group sets up the iteration number. When the M sub groups complete the iteration number set, all the individual population will be remixed, then it will calculate the entire group of individual fitness value in descending order and regrouping, it needs local search and repeats the evolutionary operation after the grouping. SFLA will be circulated until it reaches the final optimization problems [15].

3.3 Modified hybrid optimization algorithm

In this article, the SFLA location update strategy is applied to DE algorithm,using leapfrog update system to update the location of the individuals in the population,then carrying on the speed renewal formula of DE algorithm to the grouping various subgroups overlapping and the choice operation,in order to complete the whole process of the optimization. The mixed optimization algorithms of the basic steps are showed as follows:

Enter the basic data of grid such as node loads Etc.;

Carrying on the failure rate computation and the reliable target computation to each node of electrical network,selected the node that electric quantity insufficient expected value EENS as initial configuration node;

Initialization parameters ,set up entire size of population N ,the largest evolution algebra of population and subgroups $T_{\max}, t_{\max}$, DE algorithm and related parameters of SFLA,including the maximum and minimum crossover probability $CR_{\max}, CR_{\min}$,control factor λ ,variation probability factor F .And set up counter $t=0, T=0$;

Calculating the value of fitness optimization,then descend order for fitness value and divide into groups for the individual after arrangement ;

Defined X_b, X_w, X_g , update location according to formula(19)(20)in SFLA algorithm;

Comparing new X_w and original X_w ,if new X_w not better than original X_w, X_g replaces X_b ,then updating location according to Formula(19)(20)in SFLA algorithm. If better than original X_w, carry on step (8);

Comparing locations updated X_w and previous generation X_w,if locations updated X_w not better than previous generation X_w,randomly generate a new X_w.If better , carry on Step (8);

Using randomly generated X_w replaces original X_w;

Judging if the generated sub groups reaches $t_{\max}$ .If not,it will transfer to the(5)and set up $t=t+1$.If reaches the target, the individual will be remixed and resorted;

Carrying on speed renewal of the DE algorithm variation operation to the result of previous step .And making crossover operation and choice operation of DE algorithm;

Makes $T=T+1$,judging if the entire population reaches $T_{\max}$ .If reaches it,outputting the results. If not reaches it , go to step(4) to continue the operating.

4. Example analysis

This article apply the DESFLA hybrid optimization algorithm of considering node failure rate to the IEEE14 and New England 39-node system to verify its accuracy. Then apply it to actual power to prove the feasibility and effectiveness of the algorithm

To test the feasibility and effectiveness of this algorithm, the algorithm is applied in practice in Daqing Oilfield grid Xianfeng hypervariable region. Due to complexity of power grid, Xianfeng hypervariable region is simplified into a dotted-line chart which is showed in Figure1.

Based on the collection of basic parameters in actual grid,calculate the node failure rate of Daqing Oilfield grid Xianfeng hypervariable region as shown in table 1.Calculate the reliability failure rate of without considering and considering respectively, the results as shown in table 2.Considering the system node failure rate is more stable than without. So the algorithm is correct.

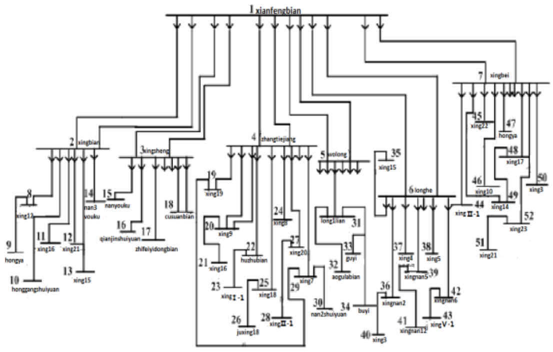

Fig1 Daqing Oilfield grid Xianfeng hypervariable region

Tab 1. Node failure rate of Daqing Oilfield grid Xianfeng hypervariable region

node	failure rate	node	failure rate	node	failure rate
1	0.1579	19	0.1332	37	0.1482
2	0.1568	20	0.4847	38	0.1556
3	0.1538	21	0.1256	39	0.2614
4	0.1814	22	0.1425	40	0.1584
5	0.1046	23	0.0238	41	0.1812
6	0.0793	24	0.0304	42	0.1485
7	0.3091	25	0.1931	43	0.1354
8	0.2507	26	0.4624	44	0.1647
9	0.2538	27	0.2840	45	0.1541
10	0.0238	28	0.1576	46	0.1256
11	0.1623	29	0.4521	47	0.1682
12	0.0819	30	0.2131	48	0.1654
13	0.1331	31	0.3305	49	0.1912
14	0.0358	32	0.1406	50	0.1684
15	0.1378	33	0.2045	51	0.1518
16	0.2461	34	0.1532	52	0.3564
17	0.0573	25	0.1684		
18	0.0742	36	0.2052		

Tab 2. Comparison o Daqing Oilfield grid Xianfeng hypervariable region reliability indices considering failure rate and not

node	EENS （MWh/year）		node	EENS （MWh/year）	
	considering failure rate	not considering failure rate		considering failure rate	not considering failure rate

1	5.1461	2.1521	27	7.8546	0.4492
2	2.1820	1.2482	28	2.0542	0.2542
3	2.0186	1.9842	29	10.2451	1.0204
4	1.0725	1.0028	30	6.1187	3.1581
5	0.5921	0.1546	31	9.1554	0.5758
6	0.7526	0.3489	32	5.5171	2.1812
7	6.1582	0.1647	33	3.1810	2.4428
8	5.1581	3.1532	34	7.1452	5.0164
9	2.0446	1.5108	35	0.1142	0.0216
10	0.1142	0.0521	36	9.1454	0.0518
11	0.5813	0.3514	37	2.0547	0.2542
12	0.5174	0.2251	38	2.2465	1.0216
13	2.7418	0.4281	39	8.1528	0.2547
14	1.1786	0.9925	40	1.0546	0.0546
15	0.4182	0.1514	41	0.6513	0.0065
16	1.0549	0.9931	42	0.5512	0.1546
17	0.4824	0.1547	43	2.1892	1.1748
18	0.8821	0.1182	44	1.0482	1.0028
19	2.4475	1.4251	45	1.4827	1.0477
20	15.1518	1.0223	46	0.6542	0.1185
21	6.1852	2.1842	47	8.0450	2.0541
22	4.1812	0.4624	48	6.1064	1.0514
23	5.1542	2.1892	49	0.1827	0.0119
24	2.0482	1.0571	50	0.5743	0.4447
25	8.1247	1.0042	51	5.0512	2.0462
26	0.1524	0.0027	52	8.4824	1.4187

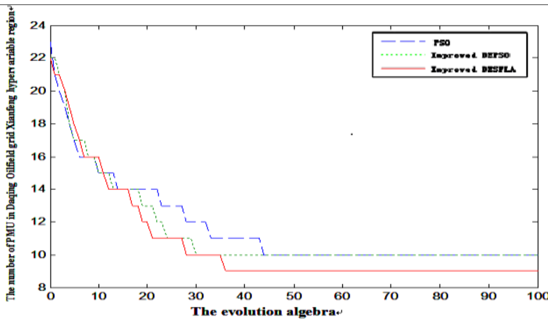

Fig 2. Comparison of DESFLA, DEPSO and PSO for Daing Oilfield grid Xianfeng hypervariable region

Tab 3. Comparison of optimal placement scheme of PMU for Daqing Oilfield grid Xianfeng hypervariable region

configuration methods	time-taken /s	number of PMU	installation node of PMU
DESFLA	1.541	9	7 20 25 27 29 31 36 39 52
DEPSO	1.982	10	7 18 20 24 27 31 36 39 44 52
PSO	4.161	10	4 20 24 25 29 31 36 39 50 52

As shown in table 3 and figure 2,through using the confirmation of the three kind of optimized algorithms to prove that the scheme is feasible in the actual power system. And the results show that the method can reduce the number of PMU configuration. So the scheme is effective.

5. Conclusion

This article presents a optimization algorithm of PMU which considers system failure rate,combining with the failure rate and system observability, using improved differential evolution and DESFLA of PMU hybrid optimization algorithm to optimize configuration. It comes to the conclusion:

Compared with the studied optimization problems,this article considers the factor of system node failure rate and makes failure rate and the system complete observability combine.It is more comprehensive in the process of configuration factors.

Compared with other optimization algorithms, this article combines the improvement of difference evolves the DE algorithm and the frog jumps the algorithm SFLA,and applies SFLA location update formula to DE algorithm. The outstanding advantages of this algorithm are not only to eliminate the number of PMU configuration but also to reduce the calculation time compared with other optimization algorithms.Make optimization procedure avoid local optimal solution so that solve efficiency is clearly improved,to achieve the purpose of the optimizing allocation .

Considering the fault conditions of the system nodes,we can determine the location of the PMU installation according to the calculation of reliability index EENS. Even in guarantee system can realize completely observable constraints, through the collection and analysis of probability of node failure rate factors change node configuration PMU, determining the unique configuration.

Optimized strategy in this article mainly uses node the failure rate, network system topology and observability factors and so on. Set the larger probability to large node of the reliability index EENS. The demonstration of standard-node system verifieies the correctness of this algorithm .The verified from actual network indicates that the method is feasible, effective, and configurations to decline economic investment for a network installation.

Acknowledgment

This work was supported by Scientific Research Fund of Heilongjiang Provincial Education Department (NO: 12541071).

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