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A Genetic Clustering Method for SUC Problem under Uncertainty in Daily Net Loads

Zhenhua Cai
[1]*Hunan City University, Key Laboratory Energy Monitoring and Edge Computing of Smart City, Yiyang, China*
[2]*Hunan City University, Key Laboratory Energy Monitoring and Edge Computing of Smart City, Yiyang, China*
Corresponding Author:Lixiong Li

ABSTRACT

As the increasement of wind power penetration in power systems,the impact of fluctuationandintermittence onsystemsbrought by wind energy leads to computational accuracy and complexity problems foroptimaloperationcost solution in daily net load scenarios. To decrease computational complexity while maintaining adequate accuracy for the stochastic unit commitment problem (SUC), this paper presents a genetic clustering algorithm. Firstly, a sequence of severely changed net load values duringdayandnight time periods is chosen as clustering index, secondly, the genetic clustering algorithm was used to reduce the scenarios, through which we can obtain the reduced scenarios and their corresponding probabilities. Afterwards, a process of CPLEX was introduced to solve the SUC problem in the full scenarios and the reduced scenarios, then a metric based on the optimal results in SUC under the two kinds of scenarios is adopted, the test result shows the effectiveness of the proposed algorithm.

KEYWORDS;*daily net load scenarios, clustering index, genetic clustering algorithm*

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I. INTRODUCTION

With the idea of sustainable development increasing, more types of renewable power generation energy are emerging, such as wind power, solar energy, geothermal energy and et al. The main stream energy type used is wind power which becomes a large component of modern electric power as low investment and high efficiency properties. However, considering the daily load variation and the randomness of wind power that will bring up generation uncertainty, obtaining efficientlythe optimal solution for SUC while maintaining adequateaccuracywithinmultiple scheduling cycles (e.g. month, year or even longer periods for SUC) becomes an urgent concern to system operators. Up to now, the useful mathematical method accountingfor model uncertainty is scenario analysis. there are several ways to generate load scenarios in previous literatures, A detailed review of scenarios generation was elaborated in[1], In[2], load scenarios was generated based on a weather forecast available on the previous day, meanwhile, the planning scenario generation method based on clustering algorithm was proposed in[3],which took account of time series operation scenarios generated by Monte Carlo simulation. Gaining the numerous of simulated scenarios in terms of existing methodologies, scenario reduction algorithms are always introduced to reduce the number of scenarios, which can not only maintain a good precision but also an adequate time cost for SUC solution. these methods determine a subset of scenarios and calculate probabilities for new scenarios so that the reduced probability measure is closest to the original probability measure in terms of a certain probability distance between the two measures. To verify normal power flow for power flow examination in transmission expansion planning, Paper [4] presented an extreme scenario reduction method to retain typical extreme scenarios, where more features of scenario reduction results were maintained. At the same time, paper[5] gave a new heuristic scenario reduction method termed forward selection in recourse clusters to alleviate the computational burden of the Net load scenarios in the stochastic unit commitment problem, while A new scenario reduction method moment-based scenario reduction techniques was illustrated in [6] for hydro uncertainty, test results shows that scenario reduction provided optimal capacity expansion plans whose investment plus expected operational costs were cheaper than the deterministic one. However, scenarios generation method usually generates scenarios in terms of the specific distribution characteristic, Actually, scenarios may sufferfrom properties deterioration due to emergencies such as turbulence caused by wind or demand and et al. viewing this, this paper adopt net load scenarios (power load minus wind power) acquired by statistic method of a practical period to model uncertainty, Subsequently, a new genetic clustering algorithm is devised to reduce the net load scenarios which owns the property of saving time. Inorder to verify the degree of accuracy and time cost, a metric to evaluate the optimal solution of the stochastic unit commitment (SUC) problem under the detailed and reduced scenarios are explored.The structure of this paper is organized as below, the new genetic clustering algorithm and the stochastic unit commitment problem is depicted in detail in section II. the solutions of stochastic unit commitment problem under the reduced load scenarios and the detailedscenariosare compared in section III.

II. APPLICATION OF GENETIC CLUSTERING ALGORITHM

Clustering Indicators

Since daily load curve have the characteristic of peak times in daytime and valley times at night, and the windpower has inverse features in corresponding periods, choosing these equivalent net load values at these corresponding periods as clustering indicators for load scenario is reasonable, which is also valuable obviously to the contribution of the optimal cost solution in stochastic unit commitment problem.

Scenario Generation

Over the years, A great deal of methods to generate scenarios are emerging, the theoretical methods to generate scenarios always have a direct disadvantage of unrealistic, and incapable of coping with emergency situation of any day, this paper take actual measured net load for many days in consideration, among which the net load series of each day is called a scenario series.

Scenario Reduction

Traditional net load scenarios of days could intense the computation cost, thus, this paper put forward a new genetic clustering algorithm for Scenario Reduction, which is based on the principle of genetic algorithm[7], the scenario similar to others are clustered into one new scenario according to the distance between them in the original full scenarios, the new net load scenario has the value and probability which is the average of the original ones and the sum of the primitive probabilities respectively. the steps of the genetic clustering algorithm for scenario reduction are expressed as follows:

Step 1: generate initial population comprising of M individuals, each individual denotes a kind of classification scheme of I net load scenarios, each series of net load scenario in the position of individual are fixed, the classification indexes of scenarios in an individual can changed by genetic clustering algorithm though subsequent steps.

Step 2: adopt fitness to evaluate the good or bad classification property of individual. For the sake of finding an appropriate way to assess the individual, the following formulations are implemented, the center of category iin each individual is calculated by the following equation:

$$\overline{X^{(\omega_i)}} = \frac{1}{N_i}\sum_{k=1}^{N_i} X_k^{(\omega_i)} \qquad (1)$$

Where $N_i$is the total number of category$i$(i=1,2,…c), c is the clustering index, $X_k^{(\omega_i)}$ is the k scenario belonging to category i. The distance between each scenario and their center in a category$i$is：

$$D_i = \sum_{j=1}^{N_i} \left\| \mathrm{X}_j^{(\omega_i)} - \overline{X^{(\omega_i)}} \right\|^2 \qquad (2)$$

Then, evaluation value of individual$i$ is obtained according to the following formula:

$$E_i = \sum_{i=1}^{C} D_i \qquad (3)$$

However, to avoid the problem of over adaption and dis-adaption of individual i, evaluation value is revised by:

$$RE_i = \alpha(1-\alpha)^{\beta-1} \qquad (4)$$

Where $\alpha$is a constant from 0 to 1, $\beta$is the sorting number of $E_i$in an ascend order.

Eventually, thefitnessvalue of the individual$i$ is represented by:

$$CF_i = \frac{\sum_{k=1}^{i} RE_i}{S} \qquad (5)$$

Where $CF_i = \sum_{i=1}^{M} RE_i$.

Step 3: record the best individual and the worst individual in current generation, generate a crossover bit randomly with a probability P_c in each pair of individuals, and communicate the category index of them until all of the individuals are chosen completely.

Step 4: mutate each bit of the individual according to the probability P_m with category index, generate the new individuals.

Step 5: if the number of cycles reach the maximum number of iterations, output the optimal category results, calculate the average value of net load scenarios and the corresponding probability in the same category, otherwise, go to step 3.

Objective Functionof Stochastic Unit Commitment Problem

A generation company always aims to minimize its total expected generation cost as:

$$\min F = \sum_{s=1}^{S} P_s \sum_{i=1}^{N} \sum_{t=1}^{T} \{ f_i(x_t^{i,s}) u_t^{i,s} + g_i(u_{t-1}^{i,s}, u_t^{i,s}) \} \tag{6}$$

Where $P_s$is the probability of scenario *s*, $x_t^{i,s}$ is the output power of unit *i* in time interval *t* under scenario *s*, $f_i(x_t^{i,s})$ is the operation cost of unit *i*, which can be represented by a quadratic function of output power $x_t^{i,s}$, $f_i(x_t^{i,s}) = a_{i0} + a_{i1} x_t^{i,s} + a_{i2} (x_t^{i,s})^2$, a_{i0}, a_{i1}, $a_{i2}$are operation parameters of unit *i*, $u_t^{i,s}$ is the status of unit*i* in time interval t under scenario s (i.e.1 denotes on, 0 denotes off). $g_i(u_{t-1}^{i,s}, u_t^{i,s})$ is the start-up cost of unit *i*which only exists when a unit is transformed from status 0 to 1 in neighboring timeintervals.

Power Balance Constraint

Considering the thermal unit operation cost and characteristic, a unit must keep in an off status and on status for continuous intervals.

$$\sum_{i=1}^{N} x_t^{i,s} = d_t^s, \; t = 1, \cdots, T, \; s = 1, \cdots, S \tag{7}$$

Where d_t^s is the net load demand under scenario *s*.

Minimum Startup/Shutdown Time Constraint

Considering the thermal unit startup cost and characteristic, a unit keeps its off status and on status forcontinuous time intervals, thus, the following constraint are formulated:

$$u_t^{i,s} - u_{t-1}^{i,s} \le u_\tau^{i,s}, \; \tau = t+1, \cdots, \min\{t + L_i - 1, T\}, i = 1, \cdots, N, \; t = 2, \cdots, T, \; s = 1, \cdots, S \tag{8}$$

$$u_{t-1}^{i,s} - u_t^{i,s} \le 1 - u_\tau^{i,s}, \; \tau = t+1, \cdots, \min\{t + l_i - 1, T\}, \; i = 1, \cdots, N, \; t = 2, \cdots, T, \; s = 1, \cdots, S \tag{9}$$

Where$L_i$and l_i are the minimum startup and minimum shutdown time for unit*i* respectively.

Power Output Constraint

To keep unit within its safe operation range, power output constraint isemphasized as:

$$q_i u_t^{i,s} \le x_t^{i,s} \le Q_i u_t^{i,s}, \; i = 1, \cdots, N, t = 1, \cdots, T, \; s = 1, \cdots, S \tag{10}$$

Where $Q_i$and q_i are the maximum and minimum power output for unit *i*respectively.

III. CASESTUDY

Data Illustration

The population size is set to 200, the crossing probability is 0.6 and the mutation probability 0.05, the constant α is 0.6, due to the clustering result no longer changes as the maximum number of iterations reach 50, the maximum number of iterations is set to 50. Theclustering number is selected as 3. In this section, A generation company comprising of 10 thermal units is under consideration, the detailed parameters to cope with the aforementioned SUC can be seen in table literature[7]. At the same time, considering the compatibility of the net loads in reality. The practical net loads are scaled down from the original net loads in the proportion of 3%, thus, a nine net loads data are employed in table I. In thispaper, all the numerical experiments are run with CPLEX on a PC with Intel Core i7 microprocessor.

Result Comparison

The comparison of SUC problem under detailed scenarios and reduced scenarios is shown in table 3, it can be seen that the SUC problem under reduced scenarios is 133.3$ less than that under the detailed scenarios, however, the difference between them are minor enough and can be dismissed, but the time-consuming of the SUC under reduced scenarios is nearly 2 minutes less than that of detailed scenarios, which verifies the high efficiency of the proposed clustering algorithm.

	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	Scenario9
1h	1010.91	744.9096	970.0366	954.1352	923.162	681.0419	680.9111	818.4289	794.6654
2h	949.6507	752.3824	981.6743	911.5152	904.1454	679.5024	664.3953	701.9003	766.1203
3h	913.3441	764.7637	969.1148	895.1536	872.952	660.3096	655.5799	685.211	754.1064
4h	867.6842	774.3372	945.7542	886.5472	863.4541	665.8383	641.6803	687.2438	776.9222
5h	884.9198	821.4994	944.4027	879.2525	855.0253	660.3706	684.8616	695.5264	768.0714
6h	892.937	833.4496	958.454	892.2105	862.4208	647.5536	689.1372	730.6413	755.0541
7h	900.2776	861.2349	977.7588	912.8799	908.5772	658.0609	731.9984	756.6856	770.2608
8h	964.5858	932.1272	1011.554	932.6373	906.8684	641.5816	751.4892	763.9737	746.9397
9h	1070.904	1049.105	1144.059	1063.585	996.2257	649.3433	885.0707	773.9099	758.14
10h	1104.554	1086.011	1178.153	1098.989	983.1179	585.2997	912.5997	803.1755	778.6879
11h	1101.667	1050.187	1136.359	1071.469	952.2794	639.2793	886.4767	816.5291	775.1268
12h	1049.349	1012.035	1106.313	1044.758	930.1055	667.3286	924.0053	850.0932	767.0982
13h	937.4479	974.3565	1096.24	1048.768	930.1852	674.8049	931.0222	891.0218	761.0401
14h	834.5812	938.7752	1075.747	1026.442	910.1568	642.3992	880.5109	907.321	760.8388
15h	793.3321	949.6569	1052.373	1022.626	895.7758	646.655	862.2703	906.5691	764.6388
16h	762.9321	964.8352	1058.044	1021.858	912.943	669.0864	859.1609	895.369	747.5597
17h	791.0087	1024.672	1084.576	1051.525	926.34	678.3179	852.7001	906.5911	748.5905
18h	829.2542	1075.785	1090.528	1059.361	934.584	696.1255	863.9264	919.0773	762.0871
19h	972.2326	1205.842	1193.839	1180.957	1024.169	786.9423	964.9071	943.5475	796.7822
20h	958.287	1201.155	1180.403	1170.739	982.2269	722.5948	959.4608	920.3622	733.9935
21h	978.628	1221.159	1166.217	1164.246	948.6261	679.7121	942.1262	899.551	737.2844
22h	988.3467	1229.195	1169.863	1162.895	871.8745	663.6001	923.6705	898.3983	731.2293
23h	913.4747	1141.935	1106.364	1087.111	801.736	671.1244	851.7513	860.2102	712.2105
24h	810.076	1026.4	1001.776	999.82	692.7513	687.6456	810.546	830.9859	706.0489

Table 1 The detailed net loads scenarios

	Scenario1	Scenario2	Scenario3
1h	743.7945	877.9098	949.1113
2h	706.7564	851.0166	932.445
3h	689.9842	839.0539	912.4068
4h	698.9607	821.0107	898.5852
5h	696.0848	853.2096	892.8935
6h	695.2007	863.1933	904.3618
7h	710.7671	880.7563	933.072
8h	698.5192	948.3565	950.3532
9h	707.6841	1060.005	1067.957
10h	688.1157	1095.283	1086.753
11h	717.5536	1075.927	1053.369
12h	737.9622	1030.692	1027.059
13h	750.4179	955.9022	1025.064
14h	738.2396	886.6782	1004.115
15h	741.1295	871.4945	990.2583
16h	745.2754	863.8837	997.615
17h	752.9544	907.8404	1020.814
18h	768.3539	952.5196	1028.158
19h	828.5536	1089.037	1132.988
20h	774.8863	1079.721	1111.123
21h	749.0649	1099.894	1093.03
22h	739.207	1108.771	1068.211
23h	728.6674	1027.705	998.4037
24h	728.0815	918.238	898.1158

Table 2The reduced net loads scenarios

	Cost of SUC ($)	Time(min)
Detailed Scenarios	472677.65	2.43
Reduced Scenarios	472544.35	0.58

Table 3 Cost comparison of SUC

IV. CONCLUSION

This paper proposes a genetic clustering algorithm to deal with the SUC problem, the algorithm can effectively reduce the daily net scenarios by combining the similar ones. By such method, an outstanding resultwith reduced scenarios is obtained which is nearly the same with the SUC problem with the detailed scenarios but shows a better time efficiency, this method can provide a theory basis to address the uncertainty in daily and is also helpful for real-time scheduling.

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