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Optimal Operation of Wind Power Plants Considering the Constraints and Accidental Events by Means of Particle Swarm Optimization (PSO) Algorithm

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Abstract

Typically, wind power plants are structured in distant areas and distinct geographic conditions, and they are of great importance and sensitivity. Due to the alterable and irregular nature of wind speed, frequently, induction generators are used in wind turbines in order to convert wind energy to electrical energy. Optimal utilization of power plants is one of the most important issues in power systems utilizing and it has a lot of complexity due to the many constraints and parameters raised in it. The purpose of this research is the optimal utilization of the power plants by considering the constraints of the networks. Wind power plants have also been used as electric power generation units. Due to the uncertainty in the wind existence and the probability of the units' emergency shutdown exit, Spinning Reserves have been used to institute the reliability of the system. In this study, a safe way has been presented to allocate reserve, so that according to the existing scenarios of wind, the worst scenario has been considered for allocating the reserve. The main criterion for LOLP reliability checking has been added to the system constraints in order to achieve the desired reliability of the power system. Another case studied in this study is the consideration of the effect of breaking loads on the spinning reserve of units and, ultimately, on the overall cost of the system. Also, in this study, a powerful intelligent method that is called the Particle Swarm Optimization (PSO) has been used to solve this problem.

Keywords: Intelligent Algorithms, Unit Commitment (UC), Load Reserve, Spinning Reserve, Reliability

Introduction

Since the main purpose of utilizing power systems is minimizing costs; consequently, since the past years, special attention has been paid to renewable energy sources such as wind. On the other hand, the unpredictable nature of this energy source has led power system operators to invent the appropriate control and corrective methods in order to utilize it and the researchers conducted extensive researches in this regard. Among the control measures to control the wind turbines production, using advanced gearboxes can be mentioned that can be used to have a relatively constant speed on the shaft by changing the wind speed. Of other methods of speed controlling and the production of wind turbines, is the Pitch Angle Ratio.

Wang et al. (2013) have solved the PBUC problem by taking into account the sources of wind production by means of a randomized programming method. This reference has used the two-stage stochastic programming, that its first step is allocated to submitting the price suggestions by fossil fuel power stations, and in the second stage, it is attempted to maximize the use of wind power plants by using the submitted price suggestions, so that the total cost of the system is minimized.

Wang et al. (2011) have entered the source of the wind with a security constraint into the problem. This problem has used the Benders Decomposition Method. So that, first, the problem has investigated the feasibility of the answer, with the purpose of minimizing the cost of solving the problem, then in line with considering the wind scenarios setting and available reserves. In the event that the existing answer is not feasible, by using the Benders Cuts, the problem will be limited and the mentioned impossible section is omitted, and then returns to the initial problem.

The two recent references have not considered the penetration rate of wind resources significant in the network. While Tuohy et al. (2009) have solved the problem of units' participation planning by taking into account the significant influence of wind resources in the

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network. This reference has used the multi-stage stochastic programming. By multi-stage, we mean that this reference has solved the problem in a two-stage, three-stage, and four-step process. In this way, as we approach the utilization time, we will update the information and will add a new stage to the previous stages.

Daneshi and Srivastava et al (2010) have used this idea and saved the surplus power in the compressed air storage. Fuel and contamination constraints are of the constraints considered in this study. But this research, like many other studies, did not consider the network. Also, due to the use of a deterministic algorithm, it has been forced to linearize the cost function of the thermal unit, which leads to the approximation.

Chen et al. (2008) have considered a wind power plant in an isolated power system, for example, in a micro-grid with a communication line can Exchange with an upstream power network. In this reference, in order to balance the production and consumption, in case of the surplus power of the wind power plant, sells it to the upstream power network and, in case of power shortage; purchases power from the upstream network power.

Some of the references (A. Khodaei and Shahidehpour, 2010; Q. Wang et al., 2013) also have considered the transmission lines switching for optimal energy distribution. At the same time, in this research, winds and breaking loads have been considered, and ultimately the intelligent solution of the problem will be considered in this regard.

Research Method

In this research, a modeling wind farm has been used. This wind farm has 50 wind turbines. The output rate for this wind farm is 0.02. The capacity of each wind power unit is also 0.2 megawatts. In the proposed system turbine, the wind turbine is the main energy generator and priority is given to meet demand.

In this research, the unit commitment problem with the aim of supplying the load for the next 24 hours has been investigated. Due to the consideration of wind power plants in the problem, the uncertainty in production has been entered into the problem. On the other hand, because the realization of the load is considered with a certain reliability criterion; accordingly, this uncertainty should be compensated in some way. The solution is considering a spinning reserve.

Another reserve resource that is considered in this study is the breaking loads. This bundle of loads can be cut by the operator's announcing in return for receiving a predetermined amount of money. Another key factor in determining the amount of reserve is the reliability level which indirectly affects. The considered reliability criterion in this research is the LOLP criterion. In other words, a certain amount of this index must be fulfilled at all times.

In this research, the network and its constraints, such as the scope of the bus bar voltage and the capacity of the lines are considered, and in fact, despite this constraint, the load has been got from the distribution network. The third part of the constraints contained in this problem includes technical constraints of generators. This constraint includes the minimum and maximum output, the maximum rate of production increase or decrease, the maximum amount of production at on and off time intervals. In this study, the proposed mathematical model for the problem is applied to a standard system. The intended system is IEEE 6-bus. The system information will be presented and then the results of applying the Particle Swarm Optimization to the unit commitment problem will be presented.

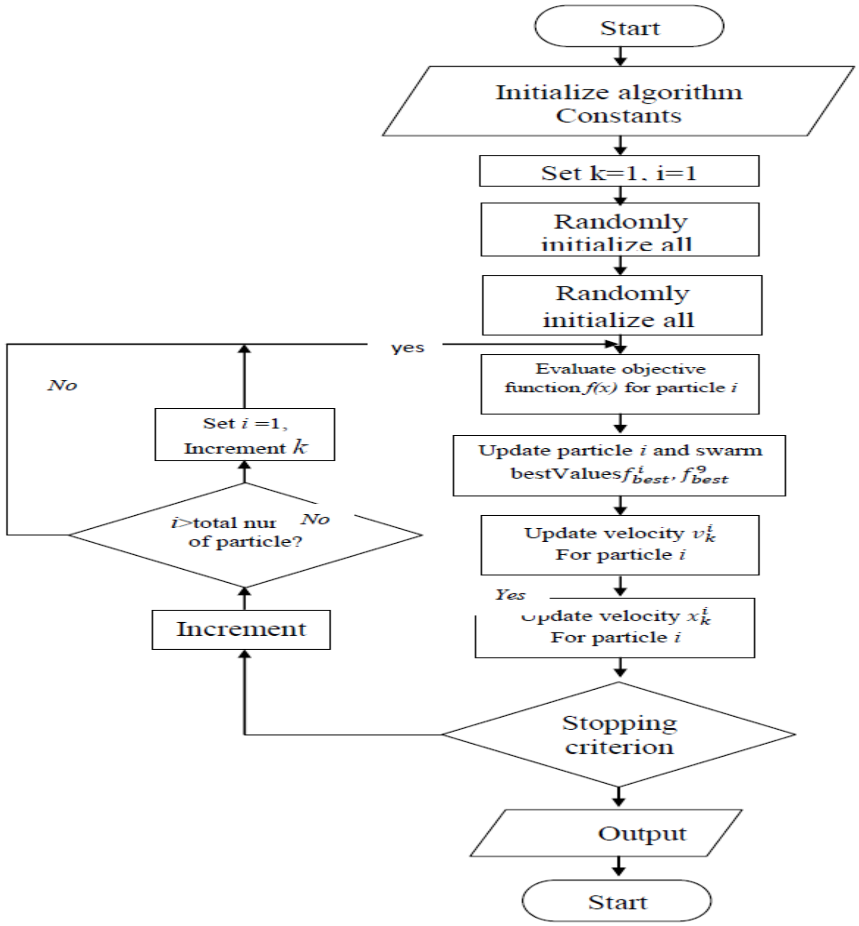

Fig. 1: PSO Algorithm Flowchart

Research Results

The simulations have been carried out in 3 different modes, thus the results of each section have been separately presented and eventually compare to each other to reveal the effect of the wind power plant and the breaking loads in the problem.

1. *Simulation without considering the breaking load and the wind power plant*

The obtained results have been presented in Tables (1) to (4). The total cost, in this case, is 9,806,845$. It takes 2.64 seconds to solve this problem. Also, the considered reliability index (LOLP) is equal to its maximum level, because, in order to increase it, we need to increase the reserve resources, which means an increase in overall cost, since the optimization problem seeks to minimize the costs, it will increase the mentioned index as much as possible.

Table 1- Sequence of units off and on modes

Unit Number / Hour	1	2	3
1	1	1	1
2	1	1	1
3	1	0	1
4	1	0	1
5	1	0	1
6	1	0	1
7	1	0	1
8	1	1	1
9	1	1	1
10	1	1	1
11	1	1	1

12	1	1	1
13	1	1	1
14	1	1	1
15	1	1	1
16	1	1	1
17	1	1	1
18	1	1	1
19	1	1	1
20	1	1	1
21	1	1	1
22	1	1	1
23	1	1	1
24	1	1	0

Table 2- Unit Production Rate

Unit Number / Hour	1	2	3
1	126.33	42.352	10
2	140.71	17.371	10
3	141.84	0	20
4	157.83	0	20
5	138.16	0	20
6	143.66	0	20
7	166.86	0	10
8	148.28	34.581	11.340
9	189.67	10	10
10	190.20	14.259	17.08
11	219.68	10	13.496
12	181.74	49.070	10
13	216.37	10.655	20
14	112.08	16.386	20
15	211.60	12.224	20
16	215.13	15.767	20
17	217.51	33.606	20
18	220	11.68	20
19	212.93	17.956	20
20	21,586	16,233	10
21	218.05	14	10
22	203.73	17.949	10
23	179.15	15.911	10
24	190.69	10	0

Table 3- Reserve amount of each unit

Unit Number / Hour	1	2	3
1	52.352	57.647	10
2	27.731	82.268	10
3	20	0	0
4	20	0	0
5	20	0	0
6	20	0	0
7	10	0	10
8	45.921	65.418	8.6598
9	20	90	10
10	29.799	85.740	292
11	.3167	90	6.5033
12	38.250	50.929	10
13	3.6254	89.344	0
14	36.386	83.613	0
15	8.3946	87.775	0

16	4.8674	84.232	0
17	2.4860	66.394	0
18	0	88.32	0
19	70.660	82.044	0
20	4.1338	83.766	10
21	1.95	86	10
22	16.269	82.050	10
23	25.911	84.088	10
24	10	90	0

Table 4- A total reserve of 3 units

Hour	Reserve Rate	Hour	Reserve Rate	Hour	Reserve Rate
1	120	9	120	17	68.88
2	120	10	118.46	18	88.32
3	120	11	96.82	19	89.11
4	120	12	99.18	20	97.9
5	120	13	92.97	21	97.95
6	120	14	120	22	108.32
7	120	15	96.17	23	120
8	120	16	89.1	24	120

In the study system, due to the small size of the system per hour, we can calculate the loss of load by comparing the production power of one unit and the total reserve of two other units. From the LOLP indicator perspective, storage is not needed in units 2 and 3. However, in terms of the LOLE indicator, that the amount of lost load is involved in it, maximum storage power is required in all units.

On the other hand, summing the total power generation and storage power of units per hour leads to this observation that this summation is lower than the maximum power of the units. Due to the fact that other units produce a total of 45,921 megawatts, since the objective of this work is to minimize the LOLP, so other plants loss states should be supplied as much as possible by the remaining units' reserves. The method of getting the best answer in this simulation is shown in Fig. 2.

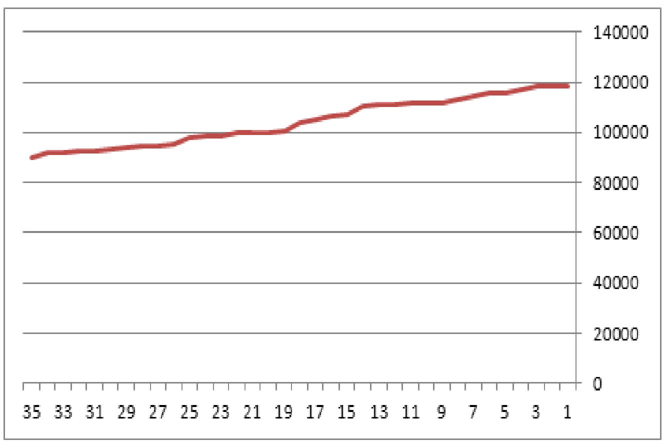

Fig. 2: The process of getting the best answer

2. *Regardless of the breaking load and considering the wind power plant*

The results of the simulation of the system to solve unit commitment problem, regardless of the breaking loads, but the presence of wind power plants are presented in Tables (5) to (8).

Table 5- Sequence of on and off state of the units

Unit Number / Hour	1	2	3
1	1	1	1
2	1	0	1
3	1	0	1
4	1	0	1
5	1	0	1
6	1	0	1
7	1	1	1

8	1	1	1
9	1	1	1
10	1	1	1
11	1	1	1
12	1	1	1
13	1	1	1
14	1	1	1
15	1	1	1
16	1	1	1
17	1	1	1
18	1	1	1
19	1	1	1
20	1	1	1
21	1	1	1
22	1	1	1
23	1	1	0
24	1	0	1

Table 6- Units production rate

Unit / Number Hour	1	2	3	Wind
1	129.16	32.235	8.3007	8.99
2	139.59	0	20	8.93
3	133.81	0	19.196	8.83
4	139.18	0	20	8.68
5	129.6	0	20	8.56
6	135.13	0	20	8.56
7	128.08	40.334	20	8.44
8	164.19	11.656	20	8.36
9	153.47	37.911	10	8.28
10	183.25	19.979	10	8.31
11	194.27	20.609	10	8.30
12	218.49	10	10	8.17
13	218.4297	10.5103	10	8.09
14	218.30	11.930	10	8.23
15	215.75	20	10	8.08
16	212.76	30	10	8.14
17	215.77	16.971	20	8.37
18	213.2	10	20	8.48
19	200.21	22.733	19.426	8.52
20	197.89	18.874	15.806	8.52
21	200.75	13.256	19.537	8.5
22	178.92	27.831	16.096	8.83
23	161.82	34.367	0	8.88
24	181.71	0	10	8.98

Table 7- Reserve amount of each unit

Unit / Unit Number	1	2	3
1	40.536	67.764	11.699
2	20	0	0
3	19.196	0	0.8039
4	20	0	0
5	20	0	0
6	20	0	0
7	60.334	59.665	0
8	31.656	88.343	0
9	47.911	62.088	10
10	29.979	80.020	10
11	25.729	79.390	10
12	1.5021	90	10
13	1.5703	89.489	10
14	1.6906	88.069	10
15	4.25	80	10
16	7.24	70	10
17	4.2217	83.028	0
18	68	90	0
19	19.789	77.266	0.5739

20	22.100	81.125	4.1938
21	19.243	8.,743	0.4629
22	41.077	72.168	3.9039
23	34.367	65.632	0
24	10	0	10

Table 8- Total amount of reserve

Hour	Reserve Rate	Hour	Reserve Rate	Hour	Reserve Rate
1	120	9	120	17	8,725
2	120	10	120	18	968
3	120	11	115.12	19	97.63
4	120	12	101.50	20	107.42
5	120	13	101.06	21	106.45
6	120	14	99.76	22	117.15
7	120	15	94.25	23	120
8	120	16	87.24	24	120

The utilization cost, in this case, is equal to 92184.34$ and it takes 3.89 seconds to solve it. In this case, the way of getting the answer is as shown in Fig. 3.

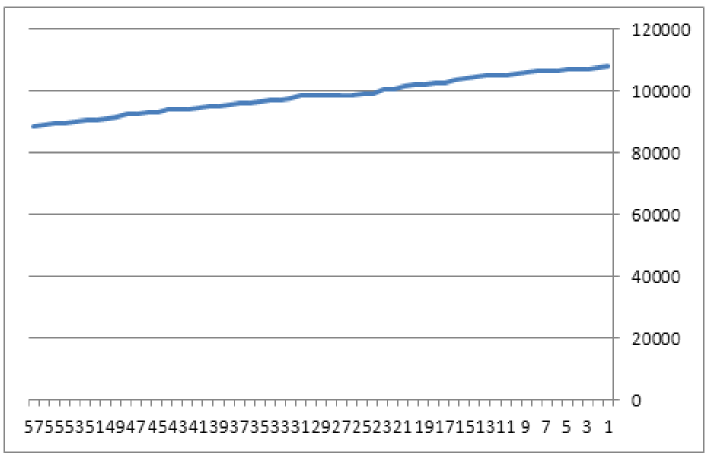

Fig. 3: The process of getting the answer

3. Considering the breaking load and wind power plant

The results of the simulation of the system to solve the unit commitment problem regardless of the interruptible loads, but the presence of wind power plants are presented in tables (9) to (12).

Table 9- Sequence of on and off states of the units

Hour \ Unit Number	1	2	3
1	1	1	1
2	1	1	1
3	1	1	1
4	1	1	1
5	1	1	1
6	1	0	1
7	1	0	1
8	1	0	1
9	1	0	1
10	1	0	1
11	1	1	1
12	1	1	1
13	1	1	1
14	1	1	1
15	1	1	1
16	1	1	1
17	1	1	1

18	1	1	1
19	1	1	1
20	1	1	1
21	1	1	1
22	1	1	1
23	1	1	1
24	1	1	1

Table 10- Units production rates

Unit / Number Hour	1	2	3	Wind
1	136.88	21.311	11.504	8.99
2	130.70	15.710	13.107	8.93
3	112.82	12.935	19.249	8.83
4	119.45	10	19.722	8.68
5	126.71	12.886	10	8.56
6	135.60	0	19.256	8.56
7	151.81	0	16.61	8.44
8	167.79	0	18.06	8.36
9	184.84	0	16.547	8.28
10	198.87	0	14.357	8.31
11	185.80	19.072	20	8.30
12	182.48	30.901	19.263	8.17
13	204.30	15.567	19.066	8.09
14	199.76	21.151	19.322	8.23
15	210.69	15.053	20	8.08
16	217.51	15.246	20	8.14
17	220	12.75	20	8.37
18	212.87	10	20	8.48
19	181.11	41.258	20	8.52
20	194.57	19.962	20	852
21	203.69	10.534	20	8.5
22	202.21	10.211	20	8.83
23	167.65	10.876	20	8.88
24	161.44	13.096	17.168	8.98

Table 11- Reserve rate of each unit

Unit / Unit Number	1	2	3
1	32.815	78.688	8.4959
2	28.817	84.289	6.8930
3	32.185	87.064	7504.
4	29.722	90	.2772
5	22.886	87.113	10
6	19.256	0	.4740
7	16.61	0	3.39
8	18.06	0	1.94
9	16.547	0	3.4529
10	14.537	0	5.6422
11	34.192	80.927	0
12	37.514	69.098	.3770
13	15.694	84.432	.9333
14	20.234	78.848	.6777
15	9.3037	84.946	0
16	2.4861	84.754	0
17	0	87.25	0
18	7.1276	90	0
19	38.888	58.741	0
20	25.426	80.033	0
21	16.308	89.465	0
22	17.784	89.788	0
23	30.876	89.123	0
24	30.265	86.903	2.8316

Table 12- Total reserve rate

Hour	Reserve Rate	Hour	Reserve Rate	Hour	Reserve Rate
1	120	9	120	17	87.25
2	120	10	120	18	97.127

3	120	11	115.12	19	97.63
4	120	12	107.35	20	105.46
5	120	13	101.06	21	105.77
6	120	14	99.76	22	107.57
7	120	15	94.25	23	120
8	120	16	87.240	24	120

By investigating the results, it can be seen that there is a very small difference in the amount of production and hours when the system is on only at 8 o'clock for steam generator number 2. The total cost, in this case, is $ 88705.02 and it takes 3.98 seconds to solve the problem. The process of getting the answer, in this case, is shown in Fig. 4.

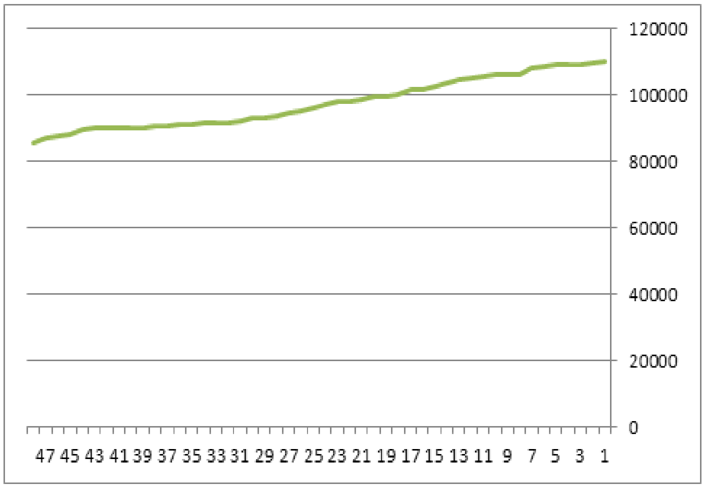

Fig. 4: The process of getting the answer

Conclusion

By means of analyzing the results in the three studied cases, there is such a trend in studies that, the new production source entering (wind power plant in Mode 2), leads to the significant difference in productions and the total cost has fallen almost 6%. In other words, due to the fact that the wind power plant is a cheaper source compared with the thermal power station, the algorithm has used it as much as possible. In the following, with the arrival of a new source for reserve, it was found that the reserve level of the thermal power station was lower in some hours. Here, due to the increase in the number of the algorithm variables, the load reserve level was removed from the algorithm variable mode and generated it randomly, to the extent that it has the lowest cost, since the load reserve level is much lower than the units generated power, it does not have a significant impact on reliability and as a result, and it does not lead to the shutdown of any unit and only imposes additional costs on the system.

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