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Adaptive Teaching Learning Based OptimizationAlgorithm for Solving Unit Commitment Problem with Wind Farm

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Abstract: Now a day's electrical power system is suffering from many dificulities like limited availability of thermal generation, increasing power demand as well as fuel cost. Unpredictable load demand becomes more challenging for power system operator in case of thermal wind system due to fluctuations of wind energy. Smart grid system plays a vital role in reducing the problems associated with existing popwer system with intelligent computational techniques. In this paper, integration of wind farm ia presented to overcome the problems associated with power system. The classical unit commitment problem is modified by penetrating the cost model of fluctuating wind power. Teaching Learning Based Optimization algorithm is used to find the solution of this modified optimization problem for 10 unit system. Unit commitment in smart grid environment shows a significant reduction in the total cost.

Keywords*: Unit Commitment, TLBO, Wind Farm Power system optimization*

1. Introduction

In future electricalpower system must have a capability to supply the continuously increasing and volatile load demand.The larhe penetration of wind farm with high degree of valatality makes more challenging for power system operators. The optimum unit commitment of generating units with wind farm could be the one of the solution to minimize the probles associated with power system. The optimum unit commitment problem in power system is developed to arrive at the best combination of power generation from all the available generator units and wind farm, while satisfying the system constraints such as power balance, generator capacity limits, and transmission line limitations.The optimum unit commitment is generally carried out in real-time, and adjustments are done to respond the load demand with changes in wind availability.Overall, the optimum unit commitment is an essential tool for power system operators, and itbecomesmore important as the load demand is continuously increasing. The power system operators con reduce the overall operating cost using optimum unit commitment with the system reliability and stability. Traditionally, unit commitment i. e. generation scheduling is a mixed integer optimization problem which decides when to start-up and shut down the generating over a scheduled time to minimize the operating cost while satisfying the load demand and multiple constraints[1-2].

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Many researchers have developed several optimization techniques to solve unit commitmentproblem. The traditional UC methods include priority list method [3-4], dynamic programming [5-6], mixed-integer programming [7]. The classical priority list method is providing solution with higher generation cost. Dynamic Programmingmethod is having problem ofdimensionality which increases the total computation time with increase in the generation units. LR method has convergence problem and generates poor quality solution.Recently, the researchers are developed different optimization algorithms which are artificial intelligence based and derived from natural phenomena. Many numerical techniques have been tried to solve optimum Unit Commitment problem such as linear programming and nonlinear programming (NLP) [10– 14], Recently, some methods based on meta-heuristics approach are also available such as genetic algorithm (GA) [8-9], adaptive genetic algorithm (GA) [10], tabu search [11], ant colony optimization (ACO) [12], artificial bee colony algorithm [13], particle swarm optimization (PSO) [14–16],

Now days, the penetration of renewable energy sources are developed some more challenges to unit commitment. In [17] author has presented Unit Commitment Optimization Considering Spatial Correlation of Wind Farms. The effect of frequency deviation with wind farm is presented in [18]. Wind power forecasting uncertainty is explained in [19]. Unit commitment with wind farm using different optimization techniques like glowworm metaphor algorithm [20], quantum-inspired binary gravitational search algorithm [21], Improved gravitational search algorithm [22] and Teaching Learning based optimization algorithm [23] are also available in the literature Also the new approach for unit commitment considering demand side resources is presented in [24].In this paper Adaptive TLBO algorithm is proposed to solve Unit Commitment Problem in presence of wind farm.

2. Problem Formulation

The basic target is to minimize the operating cost of thermal units using optimization process as operational cost of wind farm is very low and can be neglected. Therefore objective function composed of operating cost, startup cost and shutdown cost.

2.1. Objective function

The objective function is formulated to minimize the fuel cost for a day. This is having an addition of fuel cost of all generating units for 24 hours. The total cost including fuel cost, start-up cost and shutdown cost is considered to minimize the total generation cost of all thermal units as represented in Eq. 1 and considered as objective function for the UC problem [15].

$$min\ Z = min \sum_{j=1}^{H} \sum_{i=1}^{N} \{CiPG_{i,j} + SUC_{i,j}.[1 - u_{(i,j-1)}]\} u_{i,j} + SDC_{i,j} \quad ...1$$

Where

Z - The total operating cost to be minimize

$CiPG_{i,j}$ - Fuel cost for ith unit at j^{th} hour

$SUC_{i,j}$ - Start-up cost of ith unit at j^{th} hour

$SDC_{i,j}$ - Shut down cost of i^{th} unit at j^{th} hour

$u_{i,j}$ - On/Off status of i^{th} unit at j^{th} hour

H - Total number of hours

N - Total number of thermal units

2.1.1. Fuel cost function

Eq.1 contains three terms, the first term is fuel cost. This is calculated using Eq.2 for each generator depending on power generated by it.

$$C_i(PG_{i,j}) = a_i + b_i.PG_{i,j} + c_i.PG_{i,j}^2 \quad ...2$$

Where

ai, bi, ci - Cost coefficients for the ith generator

PGi,j - Power generated for ith generator at jth hour

2.1.2. Start-up cost

To start the thermal unit, some parameters are required so set initially. The cost required to set these parameters is known as start-up cost. Further this cost is divided into hot start-up cost and cold start-up cost. Eq.3.3 represents the start-up cost of generation unit.

$$SUC_i = \begin{cases} HSUC_i t_i^{off} \leq t_i^{down} + t_i^{cold} \\ CSUC_i t_i^{off} > t_i^{down} + t_i^{cold} \end{cases} \quad ...3$$

Where

SUCi - start-up cost of thermal unit i,

HSUCi - hot start-up costs for ith thermal unit ($/h)

CSUCi - cold start-up costs for ith thermal unit ($/h)

t_i^{off}- time of Off state for ith thermal unit at jth hour

t_i^{down} -time of downstate for ith thermal unit at jth hour

t_i^{cold}- time taken for the cooling state of ith thermal unit

2.1.3. Shutdown cost

As value of shut down cost is very small as compared to start-up cost so this cost is not considered in further calculation neglected

2.2. Constraints

The optimization problem presented by eq. 1 has following constraints.

2.2.1. Power balance constraint

Power balance constraints considering Thermal units and Wind powercan be represented by Eq.4.

$$PG_{(i,j)} + PW_{(j)} = LD_j \quad ...4$$

2.2.2. Spinning reserve Constraints

Spinning reserve constraints with wind farm is represented by Eq.5.

$$PG_{(i,j)}^{max}.u_{(i,j)} + PW_{(j)} \geq LD_j + Sr_j \quad ....5$$

2.2.3. Thermal power generation limits

The power generated by each Thermal unit should be within its minimum and maximum limits. This can be mathematically represented by Eq.6.

$$u_{(i,j)}.PG_{(i,j)}^{min} \leq PG_{(i,j)} \leq PG_{(i,j)}^{max}.u_{(i,j)} \quad ...6$$

3. Adaptive Teaching Learning Based Optimization Algorithm

The TLBO algorithm is modified to make the decision regarding TURN ON / OFF for the generating units. The modified TLBO algorithm is called as Adaptive Teaching Learning Based Optimization algorithm. In this algorithm, like basic TLBO algorithm the population is developed for all the available units in the power system.The proposed Adaptive TLBO algorithm generates the population for all available units with half of its actual lower limit for each generator. The optimization is carried out for pre-determined iterations using teacher's phase of the algorithm. At the end of teacher phase the solution is available for all the generator units. The result shows that the units contributing minimum load i.e. near to half of its lower limit has higer generation cost. Thus teachers phase selects the units that must be TURN OFF. The solution is further optimized using learners phase. In this phase, the population is developed only for the units which are sharing maximum load that means the population is not developed for the units contributing the load demand near to half of their lower limit. The population is developed taking consideration of equality constraint i.e. total power generated is equal to or greater than the total load demand. Then the optimisation is carried out for the predetermined iterations of learners phase. This process is repeated to get a global optimum solution using adaptive TLBO algorithm. To validate the effectiveness of proposed Adaptive TLBO algorithm a 10-unit test system is considered.

4. Results and Discussion

To validate the effectiveness of proposed Adaptive TLBO algorithm a case study with 10 - unit system is considered. The generation data of a 10 - unit system along with generator parameters, upper and lower limits and ramp up/down cost is presented pn Table - 1. The objective function, constraint functions are modeled using m-file in MATLAB environment. Initially the optimization is carried out using Adaptive TLBO algorithm for different load demands as per Table –2 without considering wind power. Then the objective function is optimized using proposed algorithm for the same load demand with available wind power as per Table -3. Tresults obtained using Adaptive TLBO algorithm without and with wind farm is tabulated in Table –4 and Table – 5 respectively. These results show that Adaptive TLBO algorithm is capable to take the ON/OFF decision for generator units. The results also indicate that the units G7 and G8 are rarely turned ON whereas the units G9 and G10 are never turned ON as these units are higher generation cost. The average generation cost for a day without wind farm is 20.12$/MW whereas the integration of wind farm drop down this cost to 18.42$/MW producing a savings of $45999/day. The total fuel cost for the period of 24 hours according to available load demand is 542769 $ whereas with integration of wind farm it comes down to 496769. This profit can be improved by utilizing wind energy during peak hours but wind energy is naturally available so it must be utilized during its availability.The results obtained using proposed method is compared with other methods in Table -5, which clears that the Adaptive TLBO algorithm is a reliable to solve optimum unit commitment problem.

Table 1: 10 - unit system parameters

Unit	P_G^{max} (MW)	P_G^{min} (MW)	a ($)	b ($/MWh)	C ($/MWh$^{2)}$	RU (MW)	RD (MW)	HSC ($)	CSC ($)
1	455	150	1000	16.19	0.00048	152.5	152.5	4500	9000
2	455	150	970	17.26	0.00031	152.5	152.5	5000	10,000
3	130	20	700	16.60	0.00200	55.0	55.0	550	1100
4	130	20	680	16.60	0.00211	55.0	55.0	560	1120
5	162	25	450	19.70	0.00398	68.5	68.5	900	1800
6	80	20	370	22.26	0.00712	30.0	30.0	170	340
7	85	25	480	27.74	0.00079	30.0	30.0	260	520
8	55	10	660	25.92	0.00413	22.5	22.5	30	60
9	55	10	665	27.27	0.00222	22.5	22.5	30	60
10	55	10	670	27.79	0.00173	22.5	22.5	30	60

Table 2: Load demand

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Power (MW)	700	750	850	950	1000	1100	1150	1200	1300	1400	1450	1500
Hour	13	14	15	16	17	18	19	20	21	22	23	24
Power (MW)	1400	1300	1200	1050	1000	1100	1200	1400	1300	1100	900	800

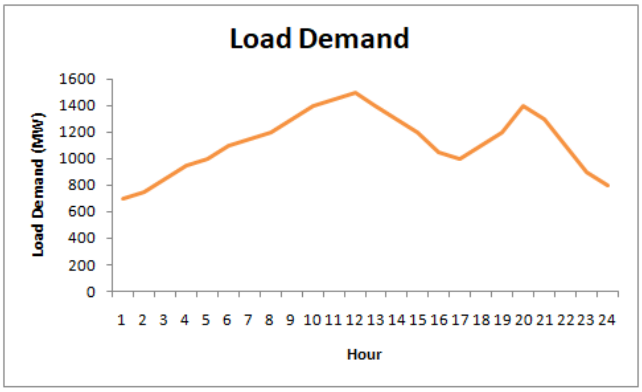

Fig. 1. Load Demand

Table 3: Forecasted wind Power

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Wind Power (MW)	82	110	81.4	108.8	138.1	103.5	91.2	71.3	64.9	88.1	66	103.5
Hour	13	14	15	16	17	18	19	20	21	22	23	24
Wind Power (MW)	56.5	134.1	88.7	83.4	116.1	134.7	130.5	118.3	100.1	100.1	85	48.3

Table 4 :Result obtained for 10 unit system with Adaptive - TLBO Algorithm

Hr	Total Demand	G_1	G_2	G_3	G_4	G_5	G_6	G_7	G_8	G_9	G_{10}	Cost
1	700	455	245									13683
2	750	455	295									14554
3	850	455	395									16302
4	950	455	365	130								18669
5	1000	455	415	130								19544
6	1100	455	385	130	130							21880
7	1150	455	435	130	130							22755
8	1200	455	455	130	130	30						24150
9	1300	455	455	130	130	131						26186
10	1400	455	455	130	130	162		69				29226

11	1450	455	455	130	130	162	80	38				30584
12	1500	455	455	130	130	162	80	33	55			32542
13	1400	455	455	130	130	162	68					28768
14	1300	455	455	130	130	130						26185
15	1200	455	455	130	130	30						24151
16	1050	455	335	130	130							21005
17	1000	455	285	130	130							20133
18	1100	455	385	130	130							21879
19	1200	455	455	130	130	30						24151
20	1400	455	455	130	130	162	68					28768
21	1170	452	453	126	130		10					23169
22	1100	455	385	130	130							21879
23	900	455	445									17178
24	800	455	345									15427
	Total Generation Cost											542769

Table 5 :Results obtained using Adaptive TLBO for 10 unit system with wind farm

Time (Hr.)	Load Demand	Wind Power	Thermal power output(MW)										Fuel cost ($)
			G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	
1	700	82	454.9	163.0	-	-	-	-	-	-	-	-	12257
2	750	110	454.9	185.0	-	-	-	-	-	-	-	-	12639
3	850	81.4	454.9	313.6	-	-	-	-	-	-	-	-	14879
4	950	108.8	454.9	386.4	-	-	-	-	-	-	-	-	16147
5	1000	138.1	455	406.9	-	-	-	-	-	-	-	-	16510
6	1100	93.7	454.9	454.9	0	59.99	36.34		-	-	-	-	20201
7	1150	103.5	455	454.4	0	120	16.504	-	-	-	-	-	20817
8	1200	91.2	454.9	454.9	0	129.99	68.82	-	-	-	-	-	22038
9	1300	71.3	454.9	454.9	59.97	129.99	128.74	-	-	-	-	-	24968
10	1400	64.9	455	454.4	120	130	161.98	13.18	-	-	-	-	27344
11	1450	88.1	454.9	454.9	129.9	129.96	161.99	29.96	-	-	-	-	27894
12	1500	66	454.9	454.9	129.9	128.47	161.94	39.96	26.23	37.9	-	-	30951
13	1400	56.5	454.9	454.9	129.9	129.99	161.99	11.53	-	-	-	-	27479
14	1300	134.1	454.9	452.4	128.4	130	-	-	-	-	-	-	23034
15	1200	88.7	454.9	396.3	129.9	130	-	-	-	-	-	-	22077
16	1050	83.4	454.1	381.6	-	129.98	-	-	-	-	-	-	18928
17	1000	116.1	454.9	298.9	-	129.99	-	-	-	-	-	-	17483

18	1100	134.7	454.9	380.4	-	129.9	-	-	-	-	-	-	18905
19	1200	130.5	454.9	424.5	59.99	129.94	-	-	-	-	-	-	21382
20	1400	118.3	455	455	119.9	129.96	-	-	89.96	31.81	-	-	26273
21	1170	100.1	454.8	454.8	129.7	129.85	30.61	-	-	-	-	-	24150
22	1100	100.1	454	286.8	128.3	129.97	-	-	-	-	-	-	20133
23	900	85	455	360	-	-	-	-	-	-	-	-	15689
24	800	48.3	455	296.7	-	-	-	-	-	-	-	-	14584
Total Cost = Fuel cost + Start-up cost (496769.50 $+3110$ = 499879.5 $)													496769

Table 6 : Comparison of total generation cost for 10-unit system with wind

Sr. No.	Method	Generation cost ($)
1	TLBO [62]	542769
2	BPSO [44]	516778
3	BGSA [44]	517736
4	Improved gravitational search algorithm [44]	515036
5	Adaptive TLBO	496770

5. Conclusion

This paper presents the application of Adaptive TLBO algorithm for Unit Commitment problem in presence of wind farm. The Unit Commitment problem is formulated as constrained non-linear optimization problem for minimization of total operating cost of Thermal units. The optimum solution is obtained using Adaptive TLBO algorithm for 10 - unit test system with and without integration of wind farm. The results obtained satisfy the equality as well as non-equality constraints. Overall, the results demonstrates that Adaptive TLBO algorithm gives optimum solution to Unit Commitment problem, and also offers reliable and accurate results for power system operators seeking to minimize generation costs while meeting the demand requirements.

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