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Economic Operation of Pumped Hydro Storage Plant using Teaching Learning Based Optimization (TLBO) Algorithm

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Abstract *- Wind energy generations are expected to have a vital role in the near future. However, the power output from the wind farm is random and intermittent in nature. Therefore, the wind power generation poses many challenges to the power system operation. Due to randomness, if the total wind generation is less than the contract, the farm owner has to pay the penalty. One of the best solutions to overcome this problem is to install energy storage system. Out of all energy storage technologies pumped hydro storage (PHS) is available for large storage. In this paper, an effective use of pumped hydro storage (PHS) power plant is presented to meet peak demand considering availability based tariff.*

Key Words: wind farm; pumped hydro storage (PHS); availability based tariff

1. INTRODUCTION

Nowadays, rapidly increasing energy demand creates more energy crisis. To solve these energy crises, renewable energies, such as the wind, are becoming more popular. Wind power generation is the rapidly developing power technology and will play an important role in the power sector. However, randomness and fluctuation of wind power are the crucial challenges in the wind power generation. These can cause instability of wind power output. This, in turn, leads to difficulty in formulating generation scheduling and dispatching of electrical power.

In power system, one of the prominent issues is the unit commitment (UC) problem for daily economic planning and operation. Main objective to solve such problems is to obtain an optimal scheme to meet the power demand at minimum fuel cost. The integration of renewable energy sources such as wind into UC has become a challenging task due to its intermittent nature and difficult to predict. Negative impacts of wind can be mitigated by installing energy storage system in the grid. Among all the energy storage techniques, pumped hydro storage (PHS) is available for large storage. PHS consists of two water reservoirs, during low electricity demand period, water from the lower reservoir is pumped to upper reservoir using excess wind energy. The electricity is generated using stored water in the upper reservoir to meet peak demand

Many researchers have presented different methods for economic scheduling of hybrid system considering wind farm and pumped hydro energy storage systems[2-4]. A unit commitment problem considering thermal units and wind farm and pumped hydro energy storage is presented in [1]. The Binary Particle Swarm Optimization (BPSO) algorithm is proposed to find the optimum schedule scheme. The optimum unit commitment problem is also presented considering energy demand, economics and environmental constraints [7]. The application of hybrid Particle Swarm Optimization [8] and enhanced hybrid Particle Swarm Optimization [9] algorithm is presented for unit commitment problem.

The growing economy with corresponding increase in power demand causes more challenges in power sector of developing countries. The unit commitment problem is formulated considering frequency with availability based tariff and presented as Indian example [10]. The hybrid wind–hydro power generation appears to be an attractive solution for isolated, autonomous electric grids in order to increase the wind energy penetration and cost-effectiveness [14]. The authors have presented a numerical methodology for optimum sizing of the various components of a reversible hydraulic system designed to recover the electric energy that is rejected from wind farms due to imposed grid limitations. The algorithm is applied to study a practical case using time variation data of rejected power from a number of wind farms installed in the island of Crete, Greece [11].

The problem is formulated to maximize the profit using frequency based pricing environment in a day ahead electricity market [17]. In these methods, all the units are scheduled on hourly basis. i.e. the load demand is considered constant for each hour. A unit commitment problem considering thermal units and wind farm and pumped hydro energy storage is presented in [16].

Several traditional methods and meta-heuristics optimization techniques were employed to solve UC problem in the literature. Recently, a simple optimization technique, namely, Teaching-learning based optimization (TLBO) algorithm is developed with a novel concept of teaching and learning process in a class. The TLBO algorithm has been successfully applied in different power system problems of economic load dispatch, optimum relay coordination and optimal power flow. This motivates the authors to use TLBO to solve UC problem of power system.

This paper is organized in 4 sections. Section – I introduce the need of unit commitment problem. Section – II deals with UC Problem formulation along with the cost model of wind power and PHS subject to several constraints. Brief information of Teaching–learning based optimization (TLBO) algorithm and its implementation for UCP is provided in Section – III. Section – IV deliberates the simulation results and comparisons of different scenarios are considered. The conclusion is drawn in the final section.

1.1 PROBLEM FORMULATION

Basic objective of this optimization process is to minimize the operating cost. Since cost of wind and pumped hydro energy storage units is mainly reflected in the construction (no fuel cost) Therefore objective function do not consider wind and PHES units.

Objective function

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

Where

Z is the total operating cost to be minimize. Fuel cost of thermal unit is given by $CiPG_{(i,j)}$;$SUC_{(i,j)}$is the startup cost;$PG_{(i,j)}$is the output power generation of ith unit at jth hour.$u_{(i,j)}$ is a 0-1 decision variable for ith unit at jth hour. 1 means ON state and 0 means OFF state of the unit. Number of available thermal units and hours are given by N and H respectively.

Fuel cost of thermal unit is characterized as

$$CiPG_{(i,j)} = aiPG^2_{(i,j)} + biPG_{(i,j)} + ci \quad (2)$$

Where ai, bi and ci are the fuel cost coefficients for unit i.

Second term of equation (1) describes a start-up cost of each generating unit

Constraints:-

1. Power balance constraint:-

   Power balance constraint requires the total accumulation of power generated from thermal ($PG_{(i,j)}$), wind turbine($PW_{(j)}$) and PHS units must satisfy the load demand (LD_j)and is described as

$$PG_{(i,j)} + PW_{(j)} + PG^{PHS}_{(j)} - PP^{PHS}_{(j)} = LD_j \quad (3)$$

2. Spinning reserve Constraints:-

   To ensure power system stability and reliability, adequate spinning reserve is required to meet the system load requirement.

$$PG^{max}_{(i,j)}.u_{(i,j)} + PW_{(j)} + PG^{PHS}_{(j)} \geq LD_j + PP^{PHS}_j + Sr_j \quad (4)$$

   Where $PG^{max}_{(i,j)}$the upper limit of is the power output of unit I; Sr_j is the spinning reserve requirement in hour j.

3. Thermal power generation units

$$u_{(i,j)}.PG^{min}_{(i,j)} \leq PG_{(i,j)} \leq PG^{max}_{(i,j)}.u_{(i,j)} \quad (5)$$

4. PHES Generation power and pumping power constraints are given by

$$PG^{PHS}_{min} \leq PG_{(g,j)} \leq PG^{PHS}_{max} \quad (6)$$
$$PP^{PHS}_{min} \leq PP_{(p,j)} \leq PP^{PHS}_{max} \quad (7)$$

5. PHES reservoir capacity constraints
   E^0_U and E^0_L are the initial equivalent electricity of upper and lower reservoir. Equivalent electricity sum of both upper and lower reservoir is E^0 at jth hour. $E_{U,j}$and$E_{L,j}$ are the equivalent electricity of upper and lower reservoir for jth hour.E_{Umax} andE_{Lmax} are the maximum of equivalent quantity of electricity

$$E^U_0 - \sum_{j=0}^{h} PG^{PHS}_{(g,j)} + \eta \sum_{j=0}^{h} PP^{PHS}_{(p,j)} \geq 0 \quad (8)$$
$$E_{U,j} + E_{L,j} = E^0 \quad (9)$$
$$E_U \leq E_{Umax} \quad (10)$$
$$E_L \leq E_{Lmax} \quad (11)$$

1.2 TEACHING LEARNING BASED OPTIMIZATION TECHNIQUE (TLBO)

TLBO is a teaching-learning process based algorithm proposed by R. V. Rao et al [18]. This is related to the effect of influence of a teacher on the output of students in a class. The algorithm describes two basic modes of the learning: (i) through classroom teaching (known as teacher phase) and (ii) interacting with the other students (known as learner phase). In this optimization method a group of students is considered as population and different subjects offered to the student is considered as different design variables of the optimization problem. Student's result is analogous to the 'fitness' value of the optimization problem. The best solution in the entire population is considered as the teacher. The design variables are actually the parameters involved in the objective function of the given optimization problem. The working of TLBO is divided into two parts, 'Teacher phase' and 'Learner phase' [18].

A. Teacher Phase:

During this phase a teacher tries to increase the mean result of the class in the subject taught by him or her depending on his or her capability. At any iteration i, assume that there are 'nd'number of subjects (i.e. variables), 'ps' number of students (i.e. population size, k=1,2,...,ps) and Mean$_{j,I}$ be the mean result of the students in a particular subject ' j ' for j= 1,2,...,nd. The best overall result Xtotal-kbest,I considering all the subjects together obtained in the entire population of students can be considered as the result of best student kbest. However, as the teacher is usually considered as a highly qualified person who trains students so that they can have better results, the best student identified is considered by the algorithm as the teacher. The difference between the existing mean result of each subject and the corresponding result of the teacher for each subject is given by,

$$\text{Difference\_Mean}j,k,i = ri*(Xj,kbest,i - TF*Meanj,i) \quad \ldots (12)$$

Where, Xj,kbest,iis the result of the best student (i.e. teacher) in subject *j*. *TF* is the teaching factor which decides the value of mean to be changed, and 'ri' is the random number in the range [0, 1]. *TF* is a teaching factor, the algorithm is found to perform much better if the value of TF is either 1 or 2 and hence to simplify the algorithm, the teaching factor is suggested to take either 1 or 2. Based on the Difference_Meanj,k,i, the existing solution is updated in the teacher phase according to the following expression.

$$X'j,k,i = Xj,k,i + \text{Difference\_Mean}j,k,i \quad \ldots(13)$$

Where, X'j,k,iis the updated value of Xj,k,i. Accept X'j,k,iif it gives better function value. All the accepted function values at the end of the teacher phase are maintained and these values become the input to the learner phase. The learner phase depends upon the teacher phase [18].

B. Learner phase

Students increase their knowledge by interaction among themselves. A student interacts randomly with other students for enhancing his or her knowledge. A student learns new things if the other student has more knowledge than him or her. Considering a population size of 'ps', in learner phase the values of design variables available from teachers phase are updated as per equation 7 and 8.

$$X''j,ps,i = X'j,ps,i + ri*(X'j,k,i - X'j,ps,i) \quad \ldots(14)$$

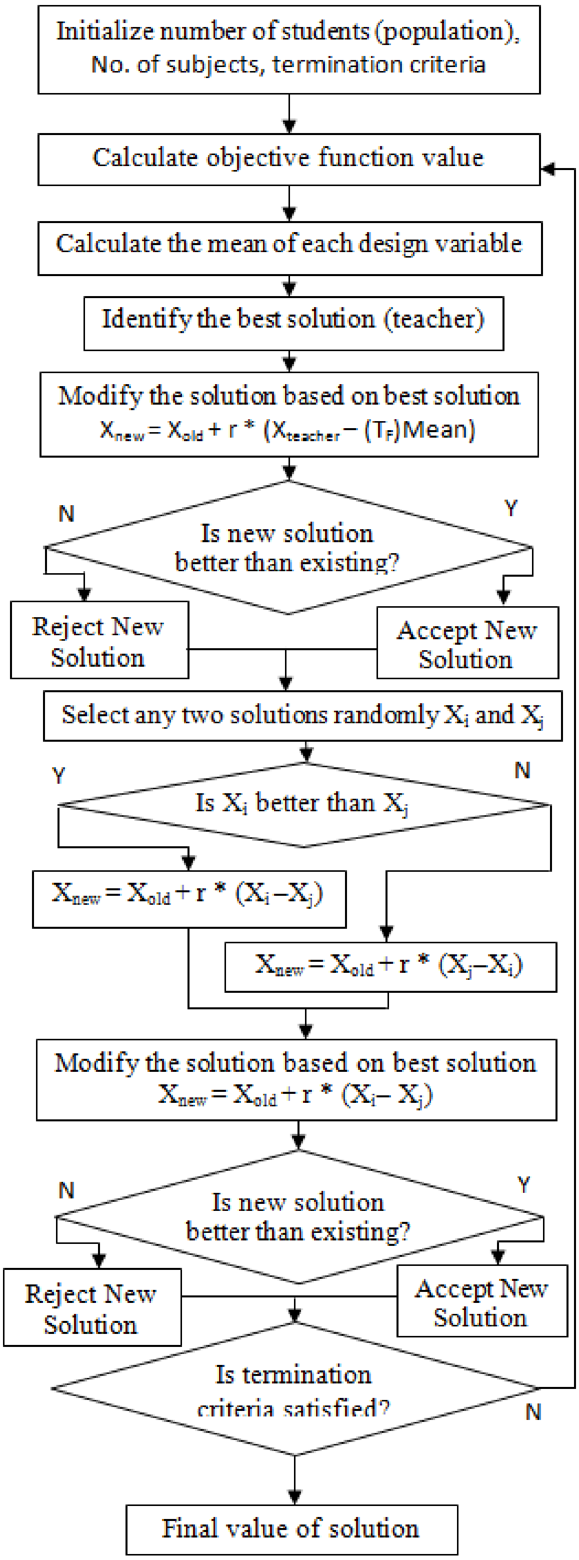

Fig.1 Flow chart of TLBO algorithm

$$X''j,ps_{i+1} = X'j,ps_{i+1} + ri(X'j,k_{i+1} - X'j,ps_{i+1}) \quad \ldots(15)$$

The updated values are compared with each other andX''j,P,iis accepted if it gives a better function value than X''j,ps$_{i+1}$ otherwise X''j,ps$_{i+1}$ will be accepted. Comparing with all other updated values of design variables the optimum value of design variable will get. This value is treated as best student. The optimum solution for objective function will be obtained from the values of best student [18]

2. RESULTS AND DISCUSSION

To validate TLBO algorithm, a test model with six thermal units is considered. The upper and lower limits of generator units with a, b and c constants are presented in Table – 1.

Table 1. Six Unit System Data

Unit	PG^{max} (MW)	PG^{min} (MW)	a ($)	b ($/MWh)	c ($/MWh^2)
1	455	150	1000	16.19	0.00048
2	455	150	970	17.26	0.00031
3	130	20	700	17.26	0.00200
4	130	20	680	16.60	0.00211
5	162	25	450	16.50	0.00398
6	80	20	370	19.70	0.00712

Initially, the optimization problem is formulated to minimize the total generation cost considering only thermal units. TLBO algorithm is applied to find optimum generation and the results are tabulated in Table – 2. In second case, the wind farm is added to supply the total load demand. As energy generated from wind generation is with negligible cost, the optimization problem is formulated to minimize the total generation cost for thermal units. The wind power available is presented in Table – 3. And optimum generation of Thermal units with wind farm is tabulated in Table – 4.

As wind power is intermittent in nature, to store the energy a pumped hydro storage (PHS) unit is considered. The operation of PHS unit is carried out to save the peak demand. The PHS unit is having a generation capacity of 125 MW, whereas it takes 140 MW while pumping. PHS unit is operated for five hours to generate the energy. To fulfill the reservoir requirement, it is required to operate PHS unit for six hours for pumping. The optimum generation considering wind farm and PHS unit is obtained using TLBO algorithm and Tabulated in Table – 5. The obtained results show that the PHS unit can be used satisfactory to store the bulk amount of electrical energy considering economic environment.

Table 2. Power Generation Considering Only Thermal Units

Time	Thermal Unit Power output (MW)						Demand
(hr)	G1	G2	G3	G4	G5	G6	(MW)
1	400	0	0	0	0	0	400
2	450	0	0	0	0	0	450
3	455	45	0	0	0	0	500
4	455	95	0	0	0	0	550
5	455	130	0	0	15	0	600
6	455	130	65	0	0	0	650
7	455	130	115	0	0	0	700
8	455	130	161	0	0	0	746
9	455	130	162	0	53	0	800
10	455	130	162	71	0	32	850
11	455	130	162	76	33	45	900
12	455	130	162	69	43	41	900
13	455	130	162	0	0	53	800
14	455	130	115	0	0	0	700
15	452	129	161	0	0	0	743
16	455	130	115	0	0	0	700
17	451	129	139	0	27	0	745
18	455	130	162	53	0	0	800
19	455	130	162	59	45	0	850
20	455	130	162	76	0	27	850
21	455	130	162	84	0	44	875
22	455	130	162	73	0	30	850
23	455	130	162	53	0	0	800
24	453	129	159	0	0	0	741
Total Generation Cost 372750 $							

Table 3. Available Wind Power

Unit	Wind Power	Unit	Wind Power	Unit	Wind Power	Unit	Wind Power
1	200	7	100	13	0	19	0
2	200	8	0	14	0	20	0
3	200	9	0	15	0	21	100
4	250	10	0	16	0	22	100
5	200	11	0	17	0	23	100
6	150	12	0	18	0	24	100

Table 4. Power Generation Considering Thermal Units and Wind Farm

Time	Thermal Unit Power output (MW)						Demand
(hr)	G1	G2	G3	G4	G5	G6	(MW)
1	0	0	162	0	38	0	200
2	250	0	0	0	0	0	250
3	0	130	162	0	0	0	291
4	300	0	0	0	0	0	300
5	400	0	0	0	0	0	400
6	455	0	0	0	45	0	500
7	455	130	0	15	0	0	600
8	451	130	162	0	0	0	742

9	455	130	162	53	0	0	800
10	455	130	162	60	43	0	850
11	455	130	162	60	50	43	900
12	455	130	162	83	32	38	900
13	455	129	162	54	0	0	800
14	455	130	115	0	0	0	700
15	455	130	161	0	0	0	746
16	455	130	115	0	0	0	700
17	455	130	162	0	0	0	747
18	455	130	162	53	0	0	800
19	444	122	162	77	39	0	843
20	455	130	162	69	34	0	850
21	451	129	157	0	0	31	768
22	455	130	160	0	0	0	745
23	455	130	115	0	0	0	700
24	455	130	65	0	0	0	650
Total Generation Cost 336230 $							

3. CONCLUSIONS

In this paper comparative analysis of economic viability with wind plant and PHS on unit commitment has considered. The basic unit commitment (UC) objective function is solved incorporating the cost model of uncertain wind power and cost of PHS unit. TLBO algorithm is executed to achieve the near optimum solution. The obtained results show that PHS is a good option to store the electrical energy which reduces the generation requirement during the peak hours leading to minimization of total cost of the system. It is observed that the implementation of PHS unit saves 3920 $ per day and also reduces the peak requirement.

Table 5. Power Generation Considering Thermal Units and Wind Farm and PHS Unit

Time	Thermal Unit Power output (MW)						Demand
(hr)	G1	G2	(hr)	G1	G2	(hr)	MW
1	455	0	0	25	0	0	480
2	455	75	0	0	0	0	530
3	455	0	125	0	0	0	580
4	455	0	125	0	0	0	580
5	455	130	95	0	0	0	680
6	455	130	162	0	33	0	780
7	455	130	15	0	0	0	600
8	453	129	162	0	0	0	743
9	455	130	162	0	47	0	793
10	455	130	15	0	0	0	600
11	455	130	65	0	0	0	650
12	446	127	0	69	0	0	642
13	451	130	161	0	0	54	796
14	455	130	115	0	0	0	700
15	455	129	161	0	0	0	745
16	455	130	115	0	0	0	700
17	451	130	162	0	0	0	743
18	451	129	162	0	51	0	793
19	455	130	15	0	0	0	600
20	455	130	15	0	0	0	600
21	455	130	162	28	0	0	775
22	453	130	162	0	0	0	744
23	455	130	115	0	0	0	700
24	455	130	0	65	0	0	650
Total Generation Cost 332310 $							

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