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Optimal coordination of thermal unit in smart grid using firefly algorithm

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*Abstract***—** ***In operational planning of power system, unit commitment problem (UCP) is an important optimizing task. The UCP means to determine the optimal schedule of start-up or shutdown of generating units for scheduled period to meet the load demand. Unit commitment problem is a two decision process of determining the commit/decommit of generating units providing the satisfaction of all operating constraints i.e. power equality and inequality constraints and all other operating constraints so that operating cost be minimized. The unit commitment problem is a multimodal, multiobjective, non-convex problem. Various search technique has been applied to find optimal solution. Pertaining to this work, Binary Particle Swarm Optimization is applied to solve the UCP Problem. Another aim of the dissertation is to optimize the performance of load and battery energy storage systems using Firefly Algorithm. Generalized Optimization Problem is discussed and implemented with Firefly Algorithm optimization technique. Renewable energy sources are included in the optimization problem by estimating wind and solar power generation considering the average and severe wind and solar conditions. In this problem it is assumed that the renewable sources and the thermal units are located near the load, hence transmission losses can be neglected. The problem is implemented on a specific test case which consists of Twelve (12) Thermal units, Three (3) Solar and Wind Power Units, Four (4) Battery Storage Units with feasible amount of Load at each nodes and the results are validated through experimental verifications.***

*Index Terms***— Average and Severe Wind Farm Conditions, Battery, Binary Particle Swarm Optimization Controllable loads, Firefly Algorithm, Thermal unit commitment.**

I. INTRODUCTION

In the operation of power system, more emphasis are put on enough generation of power is respect to meet the load demand. Several operating strategies are possible to meet the required power demand, which varies from hour to hour over the day. It is preferable to use an optimum or sub-optimum operating strategy based on economic criteria. In other words, an important criterion in power system operation is to meet the power demand at minimum fuel cost using an optimal mix of different power plants. Moreover, in order to supply high quality electric power to customers in a secured and economic manner, thermal unit commitment problem [TUCP] is considered to be one of the best available options. It is thus recognized that the optimal unit commitment of thermal systems results in a great saving for electric utilities. Unit Commitment [UC] is the problem of determining the schedule of generating units within a power system subject to device and operating constraints. Unit commitment plays an important role in the economic operation of a power system. It is very significant optimization tasks, which determine the on/off status of the generating units over a scheduling period. Unit commitment problem divided into two parts, first part is the unit scheduled problem that determines on/off status of generating units in each time period of planning horizon and second is the economic load dispatch problem [1]**.** So in TUCP, objective is the Minimize the operating cost which includes the starting cost and production cost satisfying all the constraints. Thermal unit commitment problem is subjected to several constraints that include minimum up-time and down-time, crew constraints, ramp rate limits, generation constraints, load balances, must-run units and spinning reserve constraints**.**

II. THERMAL UNIT COMMITMENT

The unit commitment problem determines the combination of available generating units and scheduling their respective outputs to satisfy the forecasted demand with the minimum total production cost under the operating constraints enforced by the system for a specified period that usually varies from 24 hours to one week. The constraints to be satisfied are usually the status restriction of individual generating units, minimum up time, minimum down time, capacity limits, generation limit for the first and last hour, limited ramp rate, group constraint, power balance constraint, spinning reserve constraint, hydro constraint, etc.[3]. The high dimensionality and combinatorial nature of the unit commitment problem curtail attempts to develop any rigorous mathematical optimization method capable of solving the whole problem for any real-size system. Nevertheless, in the literature, many methods using some sort of approximation and simplification have been proposed [4] [5]**.**

III. CONSTRAINTS

Depending on the nature of power system under study, the UCP is subjected to many constraints; the main constraints pertaining to UCP are power balance constraints and spinning reserve constraints. The other constraints include the thermal constraints, fuel constraints, security constraints etc. [11].

IV. FORMULATION OF THERMAL UNIT COMMITMENT PROBLEM

The objective of the UC problem is to minimize the total operating costs subjected to a set of system and unit constraints over the scheduling horizon. It is assumed that the production cost is a quadratic function of the generator power output. The total operating costs is the sum of the production costs and the start-up costs. The generator start-up cost depends on the time the unit has been switched-off prior to the

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start up. The start-up cost at any given time is assumed to be an exponential cost curve [14]. Cost function is minimizing the total operating cost, subject to a number of systems and unit constraints which is given by, *min F=*

$$\sum_{t\in T} FC_i(P_i(t)).u_i(t) + cost_i.u_i(t).(1-u_i(t-1))\}$$

Where,

Fc_i (P_i (t)) = Fuel cost [$] of unit i at hour t

P_i (t) = Output of unit i at hour t

u_i (t) = on/off status of unit i at hour t

$cost_i$ = startup cost [$] of unit i at hour t

Fuel cost is formulated by quadratic power output of thermal units as follows,

$$FC_i(P_i(t)) = a_i + b_iP_i(t) + c_iP_i^2(t)$$

Where a_i, b_i, c_i are the fuel coefficients for unit i.

V. BINARY PARTICLE SWARM OPTIMIZATION

Kennedy and Eberhart first introduced the particle swarm optimization (PSO) method, which is an evolutionary computation technique. Similar to genetic algorithms (GA), PSO is a population based optimization tool. The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation [6]. In PSO, the potential solutions, called particles, are "flown" through the problem space by following the current optimum particles. If x_i= (x_{i1}, x_{i2}, $x_{i3}\ldots x_{iD}$) represent the i^{th} particle in the D-dimensional space, the binary version of PSO can be formulated as follows.[9]

$$v_{id}^{k+1} = w.v_{id}^k + c_1.rand().(pbest_{id} - x_{id}^k) + c_2.rand().(gbest_{id} - x_{id}^k)$$

$$x_{id}^{k+1} = \begin{Bmatrix} 1 & rand() < S(v_{id}^{k+1}) \\ 0 & otherwise \end{Bmatrix}$$

Where

v_i^k = velocity of individual *i* at iteration *k*;

$$v^{min} \le v_i^k \le v^{max}$$

w=inertia weight factor,

often decrease linearly from about 0.9 to 0.4

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter$$

c_1 c_2=acceleration constant, often set to be 2;

rand () =uniform random number between 0 and 1;

x_{id}^k=current position of individual *i* at iteration *k*;

pbest$_i$= *pbest* of individual *i*;

gbesti =*gbest* of the group;

S (*v*) = a sigmoid limiting transformation function,

$$S(v) = \frac{1}{1+e^{-v}}$$

VI. ALGORITHM FOR BPSO

Step-1: Generate *L* initial individuals with dimension of *N**T*. The statuses at each scheduling time are determined by the given initial status and equation.

Step-2: Calculate the evaluation value of each initialized individual x_i using the evaluation function *f* as given by equation (11).

Step-3: Compare each initialized individual's evaluation value with the individual's *pbest*. The individual who owns the best evaluation value among *pbests* is set to be *gbest*.

Step-4: Modify the velocity v_i of each individual x_i according to equation (7).

Step-5: If the modified load demand (V_{id}^{k+1}) is greater than the maximum load (V_{max}), fix $V_{id}^{k+1} = V_{max}$, else if it is lesser than the minimum value of load then fix $V_{id}^{k+1} = V_{min}$

Step-6: Modify the position of individual x_i according to equation (9) and (8). Equation (9) is prior to equation (8) to satisfy the minimum up and down time constraints.

Step -7: Calculate the evaluation value of the new individual. If is better than *pbest*, then the current individual *k* 1*i x* + is set to be *pbest*. Subsequently, if the best *i pbest* is better than *gbest*, then *pbesti* is set to be *gbest*.

Step-8: If the maximum iteration number is reached, then go to step 9. Otherwise, go to step 4.

Step-9: The individual that generated the latest *gbest* indicates the optimal units-scheduled combination during the scheduling period.

VII. OPTIMIZATION OF LOAD AND BATTERY USING FIREFLY ALGORITHM

A. *Introduction*

Recently, the deregulation and liberalization in power market increase the competition in retail and power sector and many electrical sources that are possessed by independent power producer. This background leads to the competition in retail and power sector. Therefore electricity producer should use thermal units as higher efficiency as possible and reduce the operational cost and maximizes the profit. Also, the reductions of emission of CO2 and energy consumption are required due to the fossil fuel exhaustive and global warming. Therefore, renewable energy plant such as photovoltaic facilities and wind turbine generators are introduced to power system. The storage system is introduced to suppress the voltage and frequency deviation due to the introduction of renewable energy. It is possible to reduce the total cost of thermal unit by controlling the storage system and thermal units with higher efficiency. Actually, researches have been proposed, which operates the storage system and thermal units in optimally. Many literatures focus on the storage system for the load leveling to build the system to introduce electricity.

B. *Proposed Methodology*

This paper proposes the optimal algorithm considering the transmission constraint in the system introducing the renewable energy, controllable load, battery and thermal unit. Also, optimal operation of controllable load, battery and thermal units is determined by using the proposed algorithm. The system configuration is represented in Section 5.3. The proposed method is described in Section 5.4. Simulation results are shown in chapter 6, which is using the proposed

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method. This paper shows the effectiveness of proposed method by numerical simulation and verifies the capability and effect of optimization algorithm for controllable load and battery [18].

C. Formulation of Proposed Method

The purpose of this method is to determine the unit schedule that reduces the total cost in power system by introducing renewable energy plants, controllable loads, batteries and thermal units. The problem in this paper is formulated by the total problem shown by following objective function and constraint. t is the each scheduling period [hour].

D. Optimal Operation in Smart Grid

For demand response system in smart grid system, the controllable load information determined in demand side is sent to the power supply side by using the communication system such as smart meter. The power supply side get the information of controllable loads from the demand side, and schedules the next day operation include the demand side system operation. The determined schedule of next day is sent to the demand side. The thermal units operating cost is reduced by using the demand side system and the demand side get the ancillary service. The power supply side and demand side get the advantage by applying the smart grid system to thermal unit commitment program. Smart grid system is accomplished by using the above operation.

E. Optimization Method

The optimization method is Firefly Algorithm. It is assumed that load demand and heat load except the controllable loads in demand side are forecast able; therefore, the operating time should be estimated by the solar radiation. Firefly algorithm determines the operating time of the EV output and the heat pump output in hourly.

VIII. RESULTS &DISCUSSIONS

The different techniques of unit commitment and optimization discussed in the previous chapters will now be applied to the problems using renewable energy sources. In this chapter we are going to discuss problem described in the previous chapter on prescribed test system cases, with inclusion of the renewable sources of power in consideration. Moreover we will discuss the results and compare them with respect to fuel cost, generation and load, smart grid operation. Results are divided into two parts namely,

- Unit Commitment using Binary Particle Swarm Optimization
- Optimization of Controllable Load and Battery using Firefly Algorithm

The system prescribed consists of 12 thermal units, 3 solar generations and 3 wind farm generations along with 3 batteries as shown in the figure.

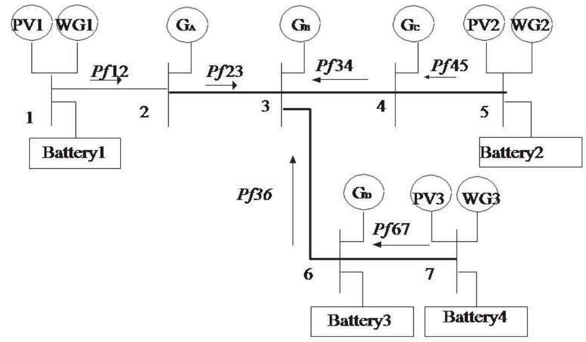

Fig 1: Test system considered for Optimization

Table 1: Generator Data for Unit Commitment

Parameter	Unit 1-6	Unit 7-9	Unit 10-12
Pimax(MW)	162	130	85
Pimin(MW)	25	20	25
a_i ($/MW)	450	700	450
b_i ($/MW)	19.70	16.60	27.74
c_i ($/MW)	0.00398	0.002	0.00079
T_{ion} (h)	6	5	3
T_{ioff}(h)	6	5	3
$cost_i$	1800	1100	520

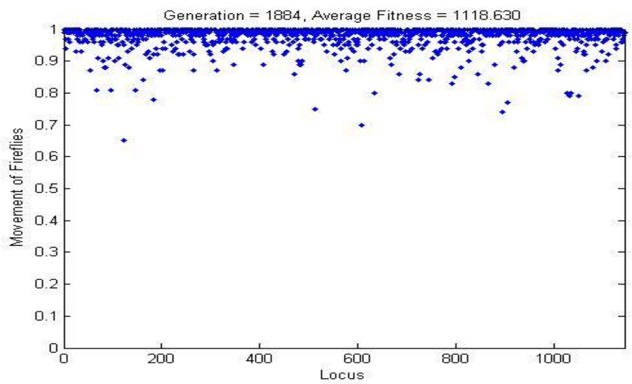

Fig 2: Movement of Fireflies

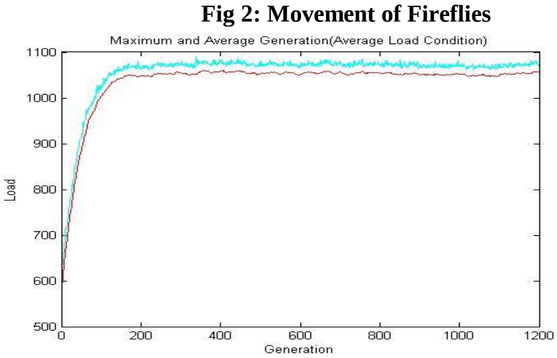

Fig 3: Maximum and Average Generation during Normal Load Condition

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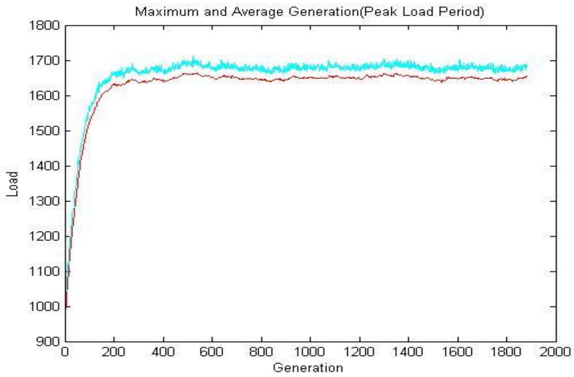

Fig 4 Maximum and Average Generation during Peak Load Period

Table 2. Total Cost for Wind Farm under Severe Condition

	Total Energy(MWh)	Total Cost($)	Cost Rate($/MWh)
Conventional	29,028	716,370	24.7
Proposed	29,028	704,930	24.3

Table 3. Total Cost for Wind Farm under Average Condition

	Total Energy(MWh)	Total Cost($)	Cost Rate($/MWh)
Conventional	29,028	713,880	24.6
Proposed	29,028	698,690	24.1

IX. CONCLUSION

Proposed method presents the optimal operation schedule algorithm for battery, thermal units and renewable power energy that reduce the operational cost of thermal units. Smart Grid approach is achieved by feeding the load data for two load scenario such as Average Load and Peak Load Periods. During average load condition, the algorithm identifies to include only a minimal number of thermal units based on generation schedule in order to satisfy the load. During the peak load period, the algorithm optimizes the operation of Battery and Renewable energy sources with the controllable load, thereby utilizing the entire capacity of the system. Unit commitment results presents a way of inclusion of thermal units based on the priority and generation schedule. In this way, Optimal Operation of thermal units is achieved for various Load dynamics.

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