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. 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].

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
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, 
\[ \min F = \sum_{id} FC_i (P_i(t)), u_i(t), \text{cost}_i, u_i(t), (1 - u_i(t - 1)) \]
Where,
\[ FC_i (P_i(t)) = \text{Fuel cost} [\$] \text{of} \text{unit} \text{i at hour} \text{t} \]
\[ P_i(t) = \text{Output of unit i at hour t} \]
\[ u_i(t) = \text{on/off status of unit i at hour t} \]
\[ \text{cost}_i = \text{startup cost} [\$] \text{of} \text{unit i at hour t} \]
Fuel cost is formulated by quadratic power output of thermal units as follows,
\[ FC_i (P_i(t)) = a_i + b_i P_i(t) + c_i P_i^2(t) \]
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 \(x_i = (x_{i1}, x_{i2}, x_{i3}, \ldots, x_{ip})\) represent the \(i^{th}\) particle in the \(D\)-dimensional space, the binary version of PSO can be formulated as follows,[9]
\[ x_{iD}^{k+1} = \begin{cases} 1 & \text{random() < } S(v_i^{k+1}) \\ 0 & \text{otherwise} \end{cases} \]
Where
\[ v_i^k = \text{velocity of individual i at iteration k;} \]
\[ w = \text{inertia weight factor, often decrease linearly from about 0.9 to 0.4} \]
\[ w = w_{\text{max}} - \frac{w_{\text{max}} - w_{\text{min}}}{\text{iter}_{\text{max}}} \times \text{iter} \]
\[ c_1, c_2 = \text{acceleration constant, often set to be 2;} \]
\[ \text{rand()} = \text{uniform random number between 0 and 1;} \]
\[ x_{iD}^k = \text{current position of individual i at iteration k;} \]
\[ \text{pbest}_i = \text{pbest of individual i;} \]
\[ \text{gbest} = \text{gbest of the group;} \]
\[ S(v) = \left(\frac{1}{1 + e^{-v}}\right) \]

VI. ALGORITHM FOR BPSO
Step-1: Generate \(L\) initial individuals with dimension of \(N \times T\). 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 \(p\text{best}\). The individual who owns the best evaluation value among \(p\text{ests}\) is set to be \(g\text{best}\).

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 \((V_{\text{max}})\), fix \(V_{id}^{k+1} = V_{\text{max}}\) else if it is lesser than the minimum value of load then fix \(V_{id}^{k+1} = V_{\text{min}}\).

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 \(x_i\) is better than \(p\text{best}\), then the current individual \(k i x + i\) is set to be \(p\text{best}\). Subsequently, if the best \(i p\text{best}\) is better than \(g\text{best}\), then \(p\text{best}\) is set to be \(g\text{best}\).

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 \(g\text{best}\) 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
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 forecastable; 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.
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