Unit Commitment with Electric Vehicle to Grid using Shuffled Frog Leaping Algorithm

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ABSTRACT

Electric vehicle to grid act as a small portable power plant to improve and enhance the grid efficiency and security. Electric vehicle provides bidirectional electric flow between the electric's battery and electric power grid. The electric vehicle discharge power to the grid during peak shaving and charge the battery during valley filling. The proposed paper represent the unit commitment with electric vehicle to grid by Shuffled Frog Leaping Algorithm (SFLA) in order to meet the power demand in peak period and maintain adequate spinning reserve. The objective for optimization of electric vehicle unit commitment using SFLA is to minimize the operational cost.

Keywords: Electric Vehicle, Unit commitment, vehicle to grid, Shuffled Frog Leaping Algorithm, operational cost.

1. INTRODUCTION

The conventional power plant is a large expensive unit to generate the electricity and satisfy the load demand including losses. The negative impacts of thermal power plant are the retardation of fuel and pollution. The nuclear power plant has a hazardous effect on the environment through radioactive emission which is hazard to human life and ecosystems. The hydro power plant is a remote station leads to the transmission and distribution cost is increases. The renewable source power plant such as wind and solar are intermittent power supply due to the reason of inconsistent of weather and climatic conditions. The diesel and gas power plant are costlier as compared to the other power plant. The capital cost of non-renewable power plant in order to satisfy incremental load demand is aggravated and emission of green house gases. Today the shortage of energy, environmental pollution and degradation of non-renewable energy sources are the major challenges effects to the power plant industry. The governments and industries encourages the public to utilize the environmentally friendly technologies.

The transportation is responsible for emission of green house gases which is the major cause of global climatic changes. In order to reduce the emission, incentives are provided to encourage the public to adopt the electric vehicle. The important application of smart grid technology is the vehicle to grid technology.

The Gridable vehicles can be considered as a new generation of electric transportation and are capable to change the electric load profile and decrease the dependency on small expensive generating units by means of battery storage technology. The electric vehicle has the advantage of no pollution, aid the energy shortage, with low noise. Based upon the energy storage and conversion, electric drive vehicle are classified as battery, hybrid and fuel cell electric vehicles. Among the pollution free electric vehicles, battery & fuel cell electric vehicle are the best choice because they are zero emission vehicle.

The electric vehicle to grid is the innovative technology for the peak shaving in the power system. The electric vehicle is used as energy storage which allows the bidirectional electrical flow between vehicle's battery and electric power grid. The electric vehicle battery pack charging and discharging during low and high demand periods to flatten the load profile, reduce the operational cost and green house gas emission.

The unit commitment problem is an efficient scheduling of least cost dispatch of existing generating unit to satisfy the load demands. The unit commitment with vehicle to grid is scheduling of existing unit and large number of electric vehicles in restricted parking lot. Meta-heuristic is an iterative technique to search both local and global optimal solution depend on problem domain and execution time limit.

The Shuffled Frog Leaping Algorithm (SFLA) involves the local and global searching abilities to reduce the cost and optimal scheduling of units and gridable vehicles. SFLA involves the local searching or memetic evolution step independently and shuffling process. Compared with other optimization technique SFLA had a faster convergence speed. The scheduling of thermal units and gridable vehicles using SFLA which combines the merits of particle swarm optimization and memetic evolvement algorithm.

The rest of paper follows as Section II introduces the nomenclature used in this paper. Section III describes the formulation of electric vehicle unit commitment. Section IV determine the solution of proposed problem by the implementation of SFLA. The simulation studies of proposed paper is shown in Section V. Finally conclude the paper in section VI.

2. PROBLEM FORMULATION

2.1. Objective function

The objective of unit commitment with Electric vehicle to grid is to optimize the operational cost and to satisfy the load demand and spinning reserve. The operational cost involves fuel cost and start-up cost.

2.1.1. Fuel Cost

The Fuel cost of each thermal unit is expressed as a quadratic functions as follows.

$$F(P_i(t)) = a_i + b_i P_i(t) + c_i P_i^2(t) \quad (1)$$

Where a_i, b_i and c_i are fuel cost coefficients.

2.1.2. Start-up Cost

The start-up cost is expressed as follows

$$suc_i = \begin{cases} suc_i^{hot} : MDNT_i \le h_i^{off}(t) \le MDNT_i + cshour_i \\ suc_i^{cold} : h_i^{off}(t) > MDNT_i + cshour_i \end{cases}$$

(2)

The objective function of UC-V2G is expressed as

Min TC=fuel cost + start-up cost

$$\text{Min } TC = \sum_{i=1}^{n}\sum_{t=1}^{H} F(P_i(t))U_i(t) + suc_i(1 - U_i(t-1))U_i(t) \quad (3)$$

2.2. Constraints

The constraints of UC-V2G must be satisfied during the optimization process. They are describes as follows:

2.2.1. Generation Constraint

The generation limits for the online unit is

$$P_i^{min} \le P_i(t) \le P_i^{max} \quad (4)$$

2.2.2. Power Balance Constraint

The UC-V2G balance the generation and load demand

$$\sum_{i=1}^{n} P_i(t)U_i(t) + P_{veh}V_{V2G}(t) - LD(t) = 0 \quad (5)$$

2.2.3. Minimum up and down time constraint

Before the unit shut down or started up, the unit is online or offline for certain period of time

$$\begin{aligned} &1 - U_i(t+1) \times MUPT_i \le h_i^{on}(t), \quad \text{if } U_i(t) = 1 \\ &U_i(t+1) \times MDNT_i \le h_i^{off}(t), \quad \text{if } U_i(t) = 0 \end{aligned} \quad (6)$$

2.2.4. Ramp Rate Constraint

A unit cannot change its power output too rapidly. The range is constrained by the ramp rate limits

$$P_i(t) - P_i(t-1) \leq UR_i$$
$$P_i(t-1) - P_i(t) \leq DR_i \tag{7}$$

2.2.5. Gridable Vehicle Balance in UC with V2G

Different patterns could be taken into account based on the constraints contributed to the system and behavior of the vehicle users, two basic assumptions are considered,

(i) The registered vehicles which charge from renewable sources and discharge to the grid are predefined in number during 24 hours period.
(ii) The charging / discharging manner of vehicles are flexible throughout the predefined scheduling period.

$$\sum_{t=1}^{H} abs\left[V_{V2G}(t)\right] = Freq \times V_{V2G}^{max} \tag{8}$$

2.2.6. Vehicle Parking Lot Limit

Each parking lot has space limit for parking vehicles

$$V_{V2G}(t) \leq V_{V2G}^{max}(t) \tag{9}$$

2.2.7. Capacity Limit

The total amount of electricity stored in EV is limited by the capacity of EV batteries

$$\sum_{v=1}^{V} EV_v^{cap} - \sum_{v=1}^{V} EV_v^{t} \geq 0 \tag{10}$$

2.2.8. Charging Frequency Limit

To save the battery life, charging frequency of EVs is limited. So maximum amount of electricity charged to EVs is limited

$$\sum_{t \in T_{charge}} P_{veh} V_{V2G}(t) \times \Delta t \leq \sum_{v=1}^{V} EV_v^{cap} \times Freq_v \tag{11}$$

2.2.9. Battery Electricity Balance

The total electricity stored in the batteries of EV remain same after a complete scheduling period. In this process, the energy consumed by EVs themselves are also considered. Assume that total number of EVs is constant during scheduling period

$$\sum_{t=1}^{H} P_{veh} V_{V2G}(t) \times \Delta t + \sum_{v=1}^{V} EV_v^{con} = 0 \tag{12}$$

3. PROPOSED SOLUTION APPROACH

3.1. Shuffled Frog Leaping Algorithm

Shuffled Frog Leaping Algorithm is an evolutionary based algorithm which mimics the social behavior of species. It is a combinational features of genetic based memetic algorithm and social behavior based PSO algorithm. In SFLA, population of frogs is divided into memplexes which consists of group of frogs. A memeplexes undergone local search independently, each frog in a memplexes influenced by its own idea and by others. In global exploration, ideas are shuffled between the memplexes to achieve the optimal solution. The local exploration and shuffling process are continued until the predefined convergence criteria.

The steps of SFL algorithm are given below

1. Initialization. Initialize the randomly generated population 'p' of frogs. For N-dimensional problems (N variables), a frog is defined as $X_i=(X_{i1}, X_{i2}, X_{i3}....., X_{iN})$.
2. Evaluation. Evaluate the fitness function of each frog.
3. Sorting. According to the fitness values, sorting the frogs in a descending order.
4. Partition. The entire population 'p' is divided into 'm' memeplexes each 'm' containing 'n' frogs, then p=m*n.
5. Allocation. The strategy of allocation is: 1st frog goes to 1st memeplex, 2nd frog goes to 2nd memeplex, mth frog goes to mth memeplex and frog m+1 goes back to first memplex and so on.
6. Local Exploration. The position of the frog with best and worst fitness is represented as X_b and X_w within each memplex. The worst frog position leap towards the best frog position by

   $$D_i = rand(\ ) * (X_b - X_w) \quad (13)$$

   $$X_{w,new} = X_{w,current} + D_i \quad (14)$$

   Where $D_{imin} < D_i < D_{imax}$,
   D_{imin}, D_{imax} = minimum and maximum allowed step in frog's position.
   ran( ) = random number between 0 and 1.
   If $X_{w,new}$ is better than $X_{w,current}$, replace current position $X_{w,current}$ by new postion $X_{w,new}$, else go to step 7.
7. Global Exploration. The frog position with global best fitness is identified as X_g . The worst frog position within memplex leap towards the global best frog position by

   $$D_i = rand(\ ) * (X_g - X_w) \quad (15)$$

   $$X_{w,new} = X_{w,current} + D_i \quad (16)$$

If $X_{w,new}$ is better than $X_{w,current}$, replace current position $X_{w,current}$ by new postion $X_{w,new}$, else go to step 8.

8. Regeneration. Regenerate new frog position randomly to replace the worst frog.

$$X_{w,new} = X_{min} + rand(\ ) * (X_{max} - X_{min}) \quad (17)$$

Where X_{min}=(X_{min1}, X_{min2}, X_{min3}....., X_{minN}) and X_{max}=(X_{max1}, X_{max2}, X_{max3}....., X_{maxN}).

9. Termination the calculation is continued until the termination criterion is reached. The termination criterion could be number of iterations or when a frog of maximal fitness is found.

3.2. Implementation of SFLA in EVUC

The algorithm for implementation of SFLA in EVUC is as follows

1. Initialize the generators, electric vehicles parameters and load demand for 24hrs.
2. Calculation of Electric vehicles
   (i) Initialize the common statistics data describing the travel data of EV such as EV battery capacity, mileage, average drive distance and time.
   (ii) Include the EV fleet data files; EV fleet travel data; Number of EV fleets in the entire power system; state of charge (SOC) of battery and assume energy consumed is equal in each trip.
   (iii) Calculate locational marginal price for 24hrs in all buses.
   (iv) Power dispatch from Grid to vehicles: Find the parking bus after the travel; Sorting in ascending order of the locational marginal price for parking bus between old arrival time to bus to new departure time; assume 100% SOC before the travel; calculate number of hours of park bus utilization; find the hour and power dispatch from grid at low locational marginal price and update EV-SOC.
   (v) Power dispatch from vehicle to grid: Sorting in descending order of the locational marginal price for parking bus between old arrival time to new departure time; Calculate energy available for discharge and power dispatch from vehicle to grid at high locational marginal price in order to reduce the load demand in peak hours.
3. Generate all combinations of generator states; find the minimum and maximum power of the combination, initial state of generator before the first time step, feasible state combination.
4. Select the state from all feasible states one by one; compare it with each feasible state at previous hour; check if the transition from previous state to the current state is possible regarding minimum up and down times.
5. Calculate the generation power (MW) and production cost for each unit; Save the updated generator works, times when moved from previous state to the current state.

6. Find out the best solution (least expensive state) at the last hour of the optimization horizon.
7. Evaluate the solution and print the results.

Shuffled Frog Leaping Algorithm

Step 1: Initialization of dimension of search space(p), number of frog population pairs(N), number of memeplexes (memNo), evolution coefficient/ leap length(B) and number of iteration/generation(G) and initial position of best known frog.
Step 2: Generating random population of 2N frogs.
Step 3: Evaluate the fitness of frogs
Step 4: Sorting the frogs according to their fitness
Step 5: Partition frog population into memeplexes
Step 6: Memetic Evolution: Frog leap process within memeplexes and regrouping the population.
Step 7: Displaying the results.

3.3. Constraints Management

Frog populations are generated randomly does not satisfy all the constraints. The constraint of UC with V2G is validated by the direct repair is given below.

1. If total number of vehicles is not satisfied, difference between left and right sides of $\sum_{t=1}^{H} V_{V2G}(t) = V_{V2G}^{max}$ is randomly distributed among 24 h.
2. Satisfy the system power balance, generation limit and ramp rate constraints in ED of UC with V2G.
3. For inequality constraints nearest upper or lower valid limit is assigned.

The penalty is added to discourage the invalid solutions even though it repair.

3.4. Economic Dispatch Calculation

Economic dispatch calculation satisfy load demand by scheduled generating units and selected number of gridable vehicles. The schedule is $[U_1(t), U_2(t), \ldots, U_N(t), V_{V2G}(t)]^T$ at hour t, then power from vehicles is

$$\xi \times V_{V2G}(t) \times P_{veh} \times (1 - \Psi) \tag{18}$$

the remaining demand is

$$LD(t) - \xi \times V_{V2G}(t) \times P_{veh} \times (1 - \Psi) \tag{19}$$

is fulfilled by running units of schedule $[U_1(t), U_2(t), \ldots, U_N(t)]^T$. Lambda iteration is used to calculate economic dispatch (ED). Lagrange multiplier is calculated as

$$\lambda_t = \frac{2LD(t) + \sum_{i=1}^{n} \frac{b_i}{a_i}}{\sum_{i=1}^{n} \frac{1}{a_i}} \tag{20}$$

The output power of unit i at time t is

$$P_i(t) = \frac{\lambda_t - b_i}{2a_i} \tag{21}$$

The solution of Eqn.21 may violate inequality power constraint. If so, the maximum or minimum output power of unit it will be selected to be the actual output depend on which limit does the solution violate.

4. NUMERICAL STUDIES

Base 4 generating unit with gridable vehicles are simulated. Table.1 gives the capacity and cost coefficient of thermal units. Table.2 represent the time dependent parameters of thermal units. The load demand for 24 hours in Table.3. Assume that the cold start-up cost is twice of hot start-up cost and total scheduling period is 24 hours.

Table.1
Capacity and Cost Coefficients of Thermal Units

Unit	P_i^{max} (MW)	P_i^{min} (MW)	a_i ($/h)	b_i ($/h)	c_i ($/h)
1	80	350	211.4	6.589	0.099
2	250	60	205.9	5.85	0.0819
3	300	75	209.5	4.85	0.090
4	60	20	192.5	6.25	0.085

Table.2
Time Dependent Parameters of Thermal Units

Unit	MUT_i	MDT_i	$h_i^{on}(t)(h)$	SC_i^{hot} ($)	SC_i^{cold} ($)	$T_i^{cold}(h)$
1	4	2	4	150	350	-5
2	5	3	5	170	400	+8
3	5	4	5	500	1100	+8
4	1	1	5	0	0.02	-6

Parameters values are number of frog population pairs =24; Number of Memplexes =2; Evolution Co-efficient/leap length=0.5; number of generations/iteration=4; EV Battery Capacity=19kWh;EV Mileage=3.65 miles/kWh; EV average energy=9kWh/day;EV average drive distance=33 miles/day; EV average drive time=4 hours/day charging-discharging frequency=1 per day; state of charge, Ψ=50%;efficiency , ξ=85%;average EV energy consumption over 24 hours EV^{con}=17kWh. The electric vehicle fleet data are shown in Table.4.

The dispatch schedule of UC with V2G are shown in Table.5 Running cost is $97,431 considering V2G. However other constraints are the same during the schedule 24 hours. The charging and discharging of V2G depends upon the locational marginal price of the generating units. During the high locational marginal price of the generating units, the power supplies / discharge from the vehicle to grid.

Table.3
System Load Demand (MW)

Hour	Demand	Hour	Demand
1	560	13	442
2	571	14	338
3	578	15	439
4	569	16	604
5	400	17	552
6	351	18	580
7	290	19	343
8	476	20	397

9	427	21	417
10	491	22	410
11	326	23	380
12	450	24	500

Table.4
Electric Vehicle Fleet Data

Fleet No.	Min Capacity (kWh)	Max Capacity (kWh)	Min Charge (kW)	Min Discharge (kW)	Max Charge (kW)	Max Discharge (kW)
1	13.152	65.76	7.3	6.2	24.8	21.08
2	10.96	54.8	7.3	6.2	14.58	12.4
3	5.48	27.4	7.3	6.2	7.29	6.29
4	8.768	43.84	7.3	6.2	11.67	9.92
5	10.96	54.8	7.3	6.2	14.58	13.4
6	15.2	62.76	7.3	6.2	22.8	21.08
7	14.76	57.8	7.3	6.2	15.58	8.4
8	17.28	33.4	7.3	6.2	8.12	7.89
9	13.88	45.84	7.3	6.2	8.67	7.92
10	15.96	42.8	7.3	6.2	16.78	13.8

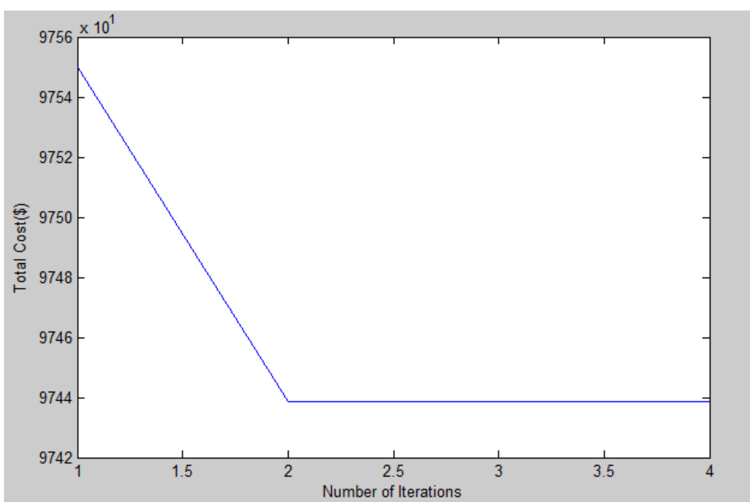

Fig.1 Convergence of the proposed SFLA for UC with V2G

Fig. 1 shows the convergence of the proposed SFLA for UC with V2G. In the beginning, it converges faster, then converges slowly at the middle of generation and then very slowly or steady from the near final iterations. Therefore, the proposed SFLA holds the above fine-tuning characteristic of a good optimization method.

Table.5
Dispatch Schedule of UC with Gridable Vehicles for 4 Generating Units

Time (H)	U-1 (MW)	U-2 (MW)	U-3 (MW)	U-4 (MW)	V2G (MW)	Total Gen (MW)	Demand (MW)
1	80	221	199	60	-8	561	560
2	114	169	234	54	-5	578	571
3	91	235	181	76	-2	589	578
4	80	225	207	60	-4	570	569
5	81	110	143	72	0	404	400
6	70	105	120	60	0	351	351
7	55	90	105	50	0	300	290
8	80	161	176	60	0	477	476
9	90	145	130	69	0	435	427
10	98	158	183	52	0	497	491
11	65	100	115	60	0	340	326
12	80	150	165	60	0	455	450
13	80	145	160	60	-2	444	442
14	65	100	115	60	-4	340	338
15	90	149	145	66	-5	445	439
16	80	225	240	60	0	605	604
17	86	218	189	64	0	558	552
18	80	215	230	60	-5	593	580
19	70	105	120	60	-5	355	343
20	80	118	143	60	0	405	397
21	80	135	150	60	-8	425	417
22	85	137	137	54	-5	415	410
23	80	115	130	60	-2	385	380
24	82	192	168	60	-4	505	500
Total Running Cost= $97,431							

5. CONCLUSION

The paper has a new optimization problem, namely, joint scheduling of EVs and UC, called EVUC. The main idea of the problem is to employ EVs as power sources and storages at different times, instead of only using them as loads. The major improvement of our formulation with previous formulations is that we consider the special characteristics of EVs while optimizing the total system running cost. This improvement makes our model more realistic and also more effective at reducing the total system running cost. In order to assess the efficiency of our formulation, we employ SFLA to solve the optimization problem. The Simulation results shows that the proposed scheduling algorithm can reduce the running cost and maintain spinning reserve to handle emergency situations.

6. NOMENCLATURE

H Scheduling Hours.
t Index of a time interval.
n Total number of thermal units.
i Index of thermal units.
V Total number of electric vehicles.
v Index of Electric vehicles.
cs $hour_i$ Cold start hour of ith unit.
$P_i(t)$ Power output at unit i at time t.
suc_i Start-up cost of unit i.
suc_i^{hot} Hot start-up cost of ith unit.
suc_i^{cold} Cold start-up cost of ith unit
$U_i(t)$ State of unit i at time t. 1 is online and 0 is offline
$F_i(P)$ Fuel cost of unit i when generating P power output.
P_i^{max} Maximum power output of unit i.
P_i^{min} Minimum power output of unit i.
LD(t) Load demand at time t.
P_{veh} Capacity of each vehicle.
$V_{V2G}(t)$ Number of vehicles connected to the grid.
$V_{V2G}^{max}(t)$ Maximum number of charging / discharging vehicles at hour t.
V_{V2G}^{max} Total vehicles in the system
$MUPT_i$ Minimum up time of unit i.
$MDNT_i$ Minimum down time of unit i.
$h_i^{on}(t)$ Duration of continuously on state of unit i at time t. $h_i^{off}(t)$ Duration of continuously off state of unit i at time t.
DR_i Ramp down rate of unit i.
UR_i Ramp up rate of unit i.

Freq Maximum charging / discharging frequency.

EV_v^{cap} Battery capacity of Electric vehicle v.

EV_v^t Amount of electricity hold by EV v at time t.

$Freq_v$ Charging frequency of EV v.

Δt Length of a time interval.

EV_m^{con} Total energy consumed by EV v in a complete scheduling period.

T_{charge} The set of time intervals when EVs are charging from the power grid.

ξ Efficiency.

Ψ State of charge.

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