A New Solution to Profit Based Unit Commitment Problem Considering PEVs/BEVs and Renewable Energy Sources

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Abstract. Daily load demand for industrial, residential and commercial sectors are changing day by day. Also, inclusion of e-mobility has totally effected the operations of realistic power sector. Hence, to meet this time varying load demand with minimum production cost is very challenging. The proposed research work focuses on the mathematical formulation of profit based unit commitment problem of realistic power system considering the impact of battery electric vehicles, hybrid electric vehicles and plug in electric vehicles and its solution using Intensify Harris Hawks Optimizer (IHHO). The coordination of plants with each other is named as Unit commitment of plants in which the most economical patterns of the generating station is taken so as to gain low production cost with higher reliability. But with the increase in industrialization has affected the environment badly so to maintain the balance between the generation and environment a new thinking of generating low cost power with high reliability by causing less harm to environment i.e. less emission of flue gases is adopted by considering renewable energy sources.

Keywords: BEVs, HEVs, Profit Based Unit Commitment Problem.

1. Introduction:

In the modern power sector it is important to gain optimal scheduling to solve profit based unit commitment problem as the actual objective is associated with minimization of cost due to increase in fuel prices as well as maximize with profit. Also, the complication of conventional profit based unit commitment problem has increased due to discharging and charging behaviour of PEV. To minimize the environmental pollution and economic cost, the execution of smart grid need more tools for computation with faster improvement of generation of renewable energy sources, PEVs and further modified electricity storages in power system. The ever-rising interest for vitality has driven experts to pay special mind to inexhaustible wellsprings of vitality and with its developing impact. An unnatural weather change, corruption of the environment and nature of air requires genuine game plan [12]. More work should be done right now. Motivated by these research challenges, intend of the suggested research is to develop a hybrid meta-heuristics research algorithm for the solution of PBUCP of electrical power sector considering power demand of renewable energy source and plug-in charging vehicles [15] [16].

2 Review of Literature

Profit based unit commitment and economic dispatch effort pair in power generation industry to empower grid management and power generation [13] [14], along these lines adding to a system's general unwavering quality. Be that as it may, the expanding utilization of renewable power generation sources, (for example, solar based and wind based power) is adding uncommon measures of vulnerability to a system operator's power generation scheduling and grid management. The clog of transmission halls because of wind power is getting less surprising since locales with the best wind power potential are regularly situated a long way from load focuses [19] [20]. The stochastic idea of wind modifies the unit responsibility and dispatch issue [21]. By and large, diminish anticipated expenses. One of the errands of the unit commitment problem is to envision this circumstance and execute preventive and remedial control activities by submitting suitable reserve margins or by planning wind power shortening [22] [23] .

Table 1. Literature survey of Profit Based Unit Commitment considering Solar and Wind Power Uncertainty with impact of BEVs/PEVs

Reference	Year of Publication	Main findings to proposed research work
[1]	2019	The effectiveness of Binary Differential Evolution algorithm had been verified on PBUCP

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		system with 10 gen unit, 40 gen unit and 100 gen unit over the time schedule.
[2]	2019	Hybrid GWO and Random Exploratory Search (RES) technique had been useful for PBUCP.
[3]	2018	Another philosophy was developed to solve PBUCP using optimization method dependent on whale (binary) to acquire the outcomes as parallel in environment of PBUC Problem.
[4]	2018	Right now output including arrangement quality and consistency were contrasted and other approached utilizing constrained optimization and environment roused optimization.
[5]	2018	The arrangement superiority from the research was taken thought for choose the position of commitment scheduling and cause profit to develop by GENCOs.
[6]	2015	This methodology was intended to discover the greatest benefit in power advertise about how much power must be taken in available to be purchased and save
[7]	2015	This method was actualized an IBM PC through which in a sensible timespan an enormous sorts of framework can be continue
[8]	2015	This paper fundamentally examined about rapidly begin and moderate unit utilizing some essential limitations which helps in Power Scheduling and represent to the progression for plan for vitality to leads unreachable conveyance of electrical framework
[9]	2018	Optimum scheduling for unit commitment problem considering photovoltaic insecurity and suitable power of EVs and output showed the reduction of production cost and improved load flow.
[10]	2018	Priority-based method was designed to solve stochastic UCP considering parking lot cooperation and renewable energy sources
[11]	2018	Dynamic programming technique was used to discover realistic conditions of power generating units, while consecutive quadratic programming algorithm was applied for ELD of committed gen. units

Now a days, in power sector, there are different kinds of electric power generating stations like nuclear, thermal and hydro power plants etc [17] [18]. During a day, the demand of electric power is changing continuously and achieves various peak values.

3 Equations and mathematics

The generating power is distributed along with utilities of generator scheduling which will meet the time varying load demand for a specific time period is known as Unit Commitment Problem (UCP). The actual objectives of UCP is minimization of overall cost for production considering different system constraints. The overall cost of production including sum of shutdown cost & start-up cost, cost of fuel are given below:

$$\min(TFC) = \sum_{h=1}^{H}\sum_{i=1}^{NG}\left\{F_{\cosh i}(P_{hi}) + SUC_{hi} + SDC_{hi}\right\} \quad (1)$$

The total cost of fuel over the scheduled time span 'h',

$$TFC = \sum_{h=1}^{H}\sum_{i=1}^{NG}[F_{\cosh i}\times U_{hi} + SUC_{hi}(1-U_{i,(h-1)})\times \mathrm{U}_{hi}] \quad (2a)$$

$$TFC = \sum_{h=1}^{H}\sum_{i=1}^{NG}[(A_iP_i^2 + B_iP_i + C_i)\times U_{i,h} + SUC_{i,h}(1-U_{i,(h-1)})\times \mathrm{U}_{i,h}] \quad (2b)$$

Here, cost for fuel $F_{\cos ih}(P_{ih})$ is stated as quadratic design that mostly working by researchers, also named as equation of convex function.
For the cost of fuel of (n) unit at (t) hour can be mathematically represented as such an equation which is given below:

$$F_{\cos ih}\left(P_i\right) = A_iP_i^2 + B_iP_i + C_i \quad (3)$$

Where A_i B_i and C_i are represented as coefficients of cost that may expressed as $\$/h$, $\$/MWh$, and. $\$/MWh^2$ correspondingly.
Start-up cost can mathematically represented by step function which is given below:

$$SUC_{ih} = \begin{cases} HSU_i; & for \quad T_i^{DW} \le T_i^{UP} \le (T_i^{DW} + T_i^{COLD}) \\ CSU_i; & for \quad T_i^{UP} > (T_i^{DW} + T_i^{COLD}) \end{cases}$$

$$(i \in NU \quad ; \quad h = 1,2,3,...,H) \quad (4)$$

In usual value of the Shutdown cost for standard system is denoted as zero and this can be established as fixed cost folowed by the equation number (5).

$$\mathrm{SDC}_{ih} = \mathrm{KP}_{ih} \quad (5)$$

Where K is represented as incremental cost for shut-down.
Which is subjected through some constraints followed by: (1) System constraints and (2) Unit constraints

$F_{\cosh i}(P_{hi})$ = Cost of Fuel for a particular generating unit i[th] at that particular time'h' hour

SUC_{ih} = Cost of Start-up for i[th] unit within'h' hours

SDC_{ih} = Cost of Shutdown for i[th] unit within'h' hours

SR_h = Spinning reserve necessity

P_{hi}^{MAX} = Maximum electrical power generation by unit i

P_i^{MIN} = Minimum electrical power which generation by unit i

$P_{i,h}$ = Electrical power generation of unit i[th] at the time span'h'

PD_h = Load Demand at'h' hours

INSi = Initial status of unit n at time'h'

$T_{i,h}^{OFF}$ = Initial OFF status for nth unit at time'h'

$T_{i,h}^{ON}$ = Initial ON status for nth unit at time'h'

T_i^{UP} = UP condition for i no. of power generating unit

T_i^{DW} = DOWN condition for i no. of power generating unit

T_i^{COLD} = Time span for COLD start of i no. of generating unit

Np= Population Number

h= No. of hours

NU = No. of generators

$P_h^{Renewable}$ = Power generation considering renewable energy source at time 'h'

$D_h^{EVs/BEVs}$ = Power demand considering the impact of BEVs/EVs at time 'h'

Constraints for System

System constrains are interrelated with all generating unit existing in the systems. The systems constrains are characterised into two types like:

Power Balance or Load Balance Constraints

In power system the constraint including power balance or load balance is more important parameter consist of summation of whole committed generating unit at t[th] time span must be larger than or equivalent to the power demand for the particular time span 't'

$$\sum_{i=1}^{NU} P_{i,h} \times U_{i,h} = PD_i \quad (6)$$

Spinning Reserve (SR) Constraints

Reliability of the system can be considered as facility of extra capability of power generation that is more important to deed instantly when failure is occurred due to sudden change in load demand for such power generating unit which is already running. The extra capability of power generation is recognized as Spinning Reserve which is exactly represented as:

$$\sum_{i=1}^{NU} P_{i,h}^{MAX} \times U_{i,h} \geq PD_h + SR_h. \quad (7)$$

Step1: Sort the generators in descending order of maximum generating capacity.

Step2: *for* g = 1 to G

if $u_{g,h} = 0$

then $u_{g,h} = 1$

else if $T_{g,h}^{OFF} > MDT_g$

then $T_{g,h}^{ON} = T_{g,h-1}^{ON} + 1$

and $T_{g,h}^{OFF} = 0$

Step-3: Verify new generating power of units.

Step-4: if $\sum_{j=1}^{NG} P_{j,\max} u_{j,h} \geq D_h + R_h$ then stop the algorithm, else go to step-2.

Step-5: if $T_{OFF}^{g,h} < MDT_g$ then do $l = h - T_{g,h}^{OFF} + 1$ and set $u_{g,h} = 1$

Step-6: Calculate $T_g^l = T_{g,l-1}^{ON} + 1$ and $T_{g,t}^{OFF} = 0$

Step-7: if l>h, Verify generator output power for $\sum_{j=1}^{N} P_{j,\max} u_{j,h} \geq PD_i + SR_i$, else increment l by 1 and go to step-5

Fig. 1. PSEUDO code of SR repairing

Constraints for Power Generating Unit

The specific constraints related with particular power generating unit exist in the systems are called generating unit constraint which are given as:

Thermal unit constraints

Thermal power units are controlled manually. This types of unit need to undertake the change of temperature gradually. So it take certain time span to take the generating unit accessible. So some crew members are essential to execute the maintenance and procedure of some thermal power generating units.

Minimum up Time

This constraint is defined as here will be minimum period of time previously the unit can be start over when the unit have already been shut down which is mathematically defined as:

$$T_{i,h}^{ON} \geq T_i^{UP} \quad (8)$$

Where, $T_{i,h}^{ON}$ is defined as interval through which the generating unit i is constantly ON (in hours) and T_i^{UP} is defined as minimum up time (in hours) for the generating unit n.

Minimum down Time

When the power generating units will be DE-committed, there is required least period of time for recommitted of the unit which is mathematically given as:

$$T_{i,h}^{OFF} \geq T_i^{DW} \quad (9)$$

Where, $T_{i,h}^{OFF}$ is time period for which generating unit n is constantly OFF (in hrs) and T_i^{DW} is denoted as minimum down time (in hours) for the unit.

To adequate minimum downtime and up time repair by heuristic mechanism is accepted those stages are stated as below in Fig. 2.

for h=1 to H
  if h==1
    Compute $T_h^{ON} = T_{h_0}^{ON} U_{hi} + U_{hi}'$
    Compute $T_h^{OFF} = (T_{h_0}^{OFF})' \bar{T}_h^{ON} + \bar{T}_h^{ON}$
    else
      Compute $T_h^{ON} = T_{h-1}^{ON} U_{hi}' + U_{hi}'$
      Compute $T_h^{OFF} = T_{h-1}^{OFF} \bar{T}_h^{ON} + \bar{T}_h^{ON}$
  end
end

Fig. 2. PSEUDO code for MUD/MUT constraints

Max and Min Electric Power Generating Limits

All electricity generating unit have its individual max/ min electric power generating limit, below and outside which will cannot produce and this is known as maximum and minimum power limits, which is mathematically written as:

$$P_i^{MIN} \leq P_{i,h} \leq P_i^{MAX} \quad (10)$$

Initial Status for operation of electrical units

For every units have initial operating position that must proceeds as the day's earlier generation scheduled are taken into consideration, thus each and all generating units can fulfils its lowest down/up time.

Crew Constraint

When any power plant consist of added one units and they couldn't turn on at the same time period. So here need more than one crew members to attend such units in a same time while starting up.

Unit Accessibility Constraint

For the constraint shows accessibility of power generating unit surrounded by any of the resulting various circumstances:

A) Accessible or Non Accessible

B) Must Outage or Out

C) Must running condition

Initial Status of Electricity Generation Unit

It signifies value of initial grade of power generating unit. Its favorable rate signifies the position of current generating unit which already in up condition, which mean about numeral time periods of the generating units are previously up, and for its negative value which is an index of the integer of hour then power generating unit has been previously in down condition. For the position of generating unit +/- earlier the 1st hour through the schedule which is an essential feature to define where its newest situation interrupts the constraint of T_i^{UP} & T_i^{DW} .

By joining the photovoltaic energy of solar power generation with the charging of PEV , it is conceivable to amplify the advantages and limit the expenses, through high entrances of the two penetrations in the power part, what decreases outflows from the EV charging at peak time. The first one gives power during top noontime in summer, diminishing the requirement for extra generation limit. The second one retains vitality from photovoltaic plants that would be wasted because of low power demand in the spring time. Numerical construction for unit commitment problem considering the impact of EVs/BEVS/PEVs/HEVs are given below;

Maximum and Minimum Operating Limits of Generators:

All generating units have its individual minimum/maximum electric power generation limit, below and outside which will cannot produce and this is known as maximum and minimum power limits, which is mathematically written as:

$$P_{i(\min)} \leq P_{hi} \leq P_{i(\max)} \qquad (i = 1,2,\ldots,NG; \quad h = 1,2,\ldots,H) \quad (11)$$

In power system the constraint including power balance or load balance is more important parameter consist of summation of whole committed generating unit at hth time span must be larger than or equivalent to the power demand for the particular time span 'h'

Power Balance Constraints: $\sum_{i=1}^{NG} P_{hi} U_{hi} = D_h$ (12)

In recent years, renewable energy sources have been one of the quickly developing vitality change frameworks. Renewable energy sources assumes significant job in satisfying the electricity demand and environmental protection. The deep penetration of wind and sun based force is a basic part of things to future power grid. In any case, the irregularity and stochasticity of these renewable resources carry significant difficulties to the dependable and financial activity of intensity frameworks. Considering Renewable Energy Sources (RES), the power through RES are taken into consideration.

$$\sum_{i=1}^{NG} P_{hi} U_{hi} - P_h^{\mathrm{Re}\,newable} = D_h \quad (13)$$

To achieve the unit commitment generation scheduling, power losses must be taken into account,

$$\sum_{i=1}^{NG} P_{hi} U_{hi} = D_h + P_{hL} \quad (14)$$

Electric power generation in power stations go through huge and complex systems like transformers, overhead lines, links and other gear and reaches toward the end users. Transmission and Distribution losses are the amounts that are not paid for by clients. Considering Power Losses considering Renewable Energy Sources, the equation is given below,

$$\sum_{i=1}^{NG} P_{hi}U_{hi} - P_h^{\mathrm{Re}newable} = D_h + P_{hL} \tag{15}$$

By using power balance equation, the power output for Rth reference unit can be written as:

$$P_{hR} = D_h + P_{hL} - \sum_{\substack{i=1\\ i\neq R}}^{NG} P_{hi} \tag{16}$$

By using power balance equation and considering Renewable Energy Sources, the power output for R[th] reference unit can be written as:

$$P_{hR} = D_h + P_{hL} - (\sum_{\substack{i=1\\ i\neq R}}^{NG} P_{hi} + P_h^{\mathrm{Re}newable}) \tag{17}$$

The extra capability of power generation is recognized as Spinning Reserve which is exactly represented as:
Spinning Reserve Constraints:

$$\sum_{i=1}^{NG} P_{i(\max)}U_{hi} \geq D_h + R_h \tag{18}$$

Case-1: During Charging of EVs/BEVs:

The vehicle electrification will significantly affect the power grid because of the expansion in power utilization. It is essential to perform intelligent planning for charging and discharging of electric vehicles (EVs). In any case, there are two significant difficulties in the scheduling issue. To start with, it is trying to discover the all-around ideal scheduling arrangement which can limit the complete expense. It is hard to locate an appropriated scheduling plan which can deal with an enormous population and the arbitrary appearances of the EVs. In power system the constraint including power balance or load balance is more important parameter consist of summation of whole committed generating unit at hth time span must be larger than or equivalent to the power demand for the particular time span 'h'. The power balance constraints during charging of EVs and considering renewable energy sources is given below.
Power Balance Constraints:

$$\sum_{i=1}^{NG} P_{hi}U_{hi} = D_h + D_h^{EVs/BEVs} \tag{19}$$

Considering Renewable Energy Sources, the power balance equation is given below,

$$\sum_{i=1}^{NG} P_{hi}U_{hi} - P_h^{\mathrm{Re}newable} = D_h + D_h^{EVs/BEVs} \tag{20}$$

While charging or discharging electric vehicles, power loss happen. Another utilization case for electric vehicles, grid services has as of recently started business activity. Considering Power Losses during Charging of EVs/BEVs including renewable energy sources, the equation is given below.

$$\sum_{i=1}^{NG} P_{hi}U_{hi} = D_h + P_{hL} + D_h^{EVs/BEVs} \tag{21}$$

Considering Renewable Energy Sources during Charging of EVs/BEVs:

$$\sum_{i=1}^{NG} P_{hi}U_{hi} - P_h^{\mathrm{Re}newable} = D_h + P_{hL} + D_h^{EVs/BEVs} \tag{22}$$

By using power balance equation, the power output for R[th] reference:

$$P_{hR} = D_h + P_{hL} - (\sum_{\substack{i=1\\ i\neq R}}^{NG} P_{hi} - D_h^{EVs/BEVs}) \tag{23}$$

By using power balance equation considering Renewable Energy Sources, the power output for Rth reference unit can be written as:

$$P_{hR} = D_h + P_{hL} - (\sum_{\substack{i=1\\ i\neq R}}^{NG} P_{hi} + P_h^{\mathrm{Re}newable} - D_h^{EVs/BEVs}) \tag{24}$$

Reliability of the system can be considered as facility of extra capability of power generation that is more important to deed instantly when failure is occurred due to sudden change in load demand for such power generating unit which is already running.
Spinning Reserve Constraints:

$$\sum_{i=1}^{NG} P_{i(\max)}U_{hi} \geq D_h + D_h^{EVs/BEVs} + R_h \tag{25}$$

Spinning Reserve Constraints considering Renewable Energy Sources:

$$\sum_{i=1}^{NG} P_{i(\max)}U_{hi} - P_h^{\mathrm{Re}newable} \geq D_h + D_h^{EVs/BEVs} + R_h \tag{26}$$

Case-2: During Discharging of EVs/BEVs:

The plug-in electric vehicles (PEVs) represents the alternatives of the outflow of poisons from vehicles controlled by petroleum derivatives. The plug-in electric vehicle charging is recurrent, variable and to some degree of unpredictable, as it goes about as a load to the power grid. Power Balance Constraints during discharging:

$$\sum_{i=1}^{NG} P_{hi}U_{hi} = D_h - D_h^{EVs/BEVs} \tag{27}$$

Power Balance Constraints considering Renewable Energy Sources and EVs/BEVs:

$$\sum_{i=1}^{NG} P_{hi}U_{hi} - P_h^{\mathrm{Re}newable} = D_h + P_{hL} - D_h^{EVs/BEVs} \tag{28}$$

In spite of the charging need, a PEV can likewise be utilized to offer subordinate types of assistance to the power system, pointing the grid benefit. Such vehicles are truncated as V2G, from vehicle-to-grid, and, as significant models, can give guideline, renewable sources support and distribution losses minimization. Considering Power Losses during discharging of electric vehicle is given below.

$$\sum_{i=1}^{NG} P_{hi}U_{hi} = D_h + P_{hL} - D_h^{EVs/BEVs} \tag{29}$$

Power Balance Constraint considering Transmission Losses and Renewable Energy Sources:

$$\sum_{i=1}^{NG} P_{hi} U_{hi} - P_h^{Renewable} = D_h - D_h^{EVs/BEVs} \quad (30)$$

By using power balance equation, the power output for R[th] reference:

$$P_{hR} = D_h + P_{hL} - (\sum_{\substack{i=1 \\ i \neq R}}^{NG} P_{hi} + D_h^{EVs/BEVs}) \quad (31)$$

By using power balance equation considering Renewable Energy Sources, the power output for Rth reference unit can be written as:

$$P_{hR} = D_h + P_{hL} - (\sum_{\substack{i=1 \\ i \neq R}}^{NG} P_{hi} + P_h^{Renewable} + D_h^{EVs/BEVs}) \quad (32)$$

Reliability of the system can be considered as facility of extra capability of power generation that is more important to deed instantly when failure is occurred due to sudden change in load demand for such power generating unit which is already running.

Spinning Reserve Constraints:

$$\sum_{i=1}^{NG} P_{i(\max)} U_{hi} \geq D_h - D_h^{EVs/BEVs} + R_h \quad (33)$$

Spinning Reserve Constraints considering Renewable Energy Sources and EVs/BEVs

$$\sum_{i=1}^{NG} P_{i(\max)} U_{hi} - P_h^{Renewable} \geq D_h - D_h^{EVs/BEVs} + R_h \quad (34)$$

3 Results & Discussions

The recently developed Intensify Harris Hawks Optimizer developed by corresponding author has been applied to solve the proposed research problem. The mathematical formulation and Pseudo code of IHHO algorithm can be found in [24]. Generation Schedule of Committed Units for 10-Unit Test System at 5% and 10% Spinning Reserve are shown in fig. 3 and fig. 4. This system has been verified for 24-hour electric power demand outline at various spinning reserve capability such as 5% and 10% including Charging and Discharging Behaviour of EVs and considering renewable energy sources in the season of winter and summer.

Table 2. Total overall generation cost for 10 unit test system including Charging and Discharging Behaviour of EVs

Generating Units	Generation Cost without the effect of EVs ($)	Generation Cost with the effect of EVs ($)
10-unit (5% SR)	557533.12	552325
10-unit (10% SR)	563937.6875	559256.7

Table 3. Total overall generation cost for 10 unit test system considering Renewable Energy Sources in winter and summer

Generating Units	Generation Cost in Winter	Generation Cost in Summer
10-unit (5% SR)	536200	529980
10-unit (10% SR)	539110	534050

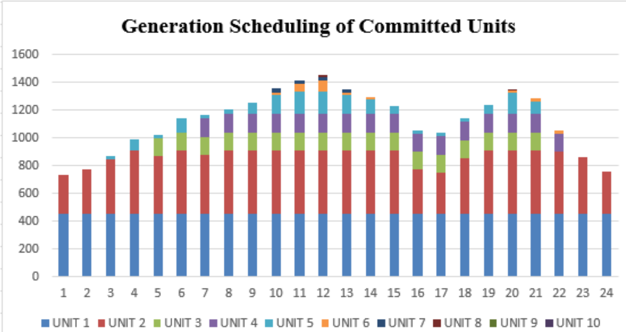

Fig. 3. Generation Schedule of Committed Units for 10-Unit Test System at 5% Spinning Reserve considering Charging and Discharging Behaviour of EVs

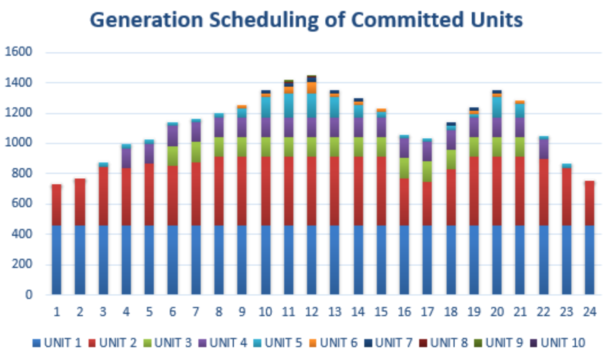

Fig. 4. Generation Schedule of Committed Units for 10-Unit Test System at 10% Spinning Reserve considering Charging and Discharging Behaviour of EVs

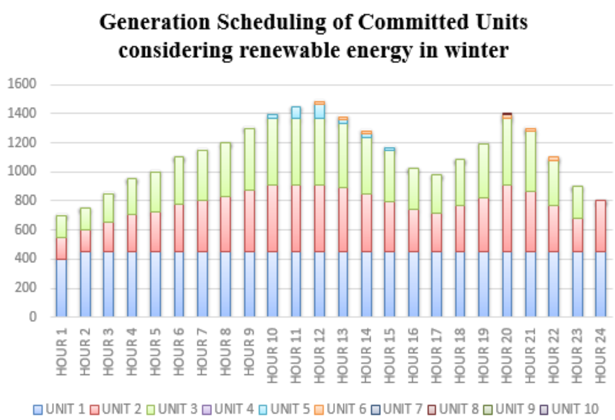

Fig. 5. Generation Schedule of Committed Units for 10-Unit Test System at 5% Spinning Reserve considering Renewable Energy Sources in winter

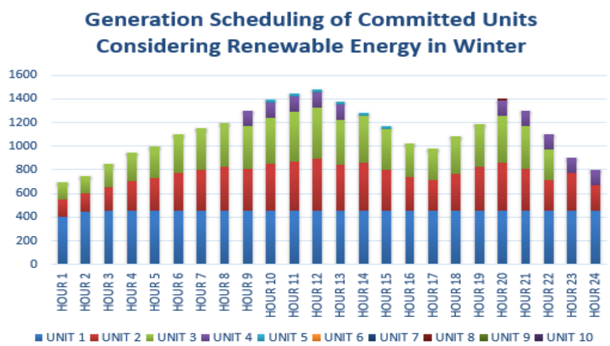

Fig. 6. Generation Schedule of Committed Units for 10-Unit Test System at 10% Spinning Reserve considering Renewable Energy Sources in winter

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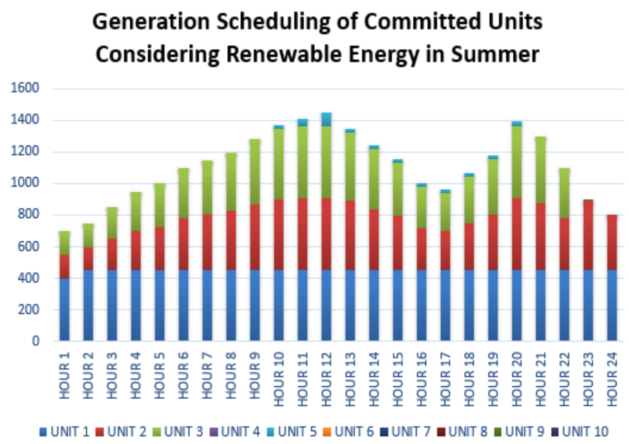

Fig. 7. Generation Schedule of Committed Units for 10-Unit Test System at 5% Spinning Reserve considering Renewable Energy Sources in summer

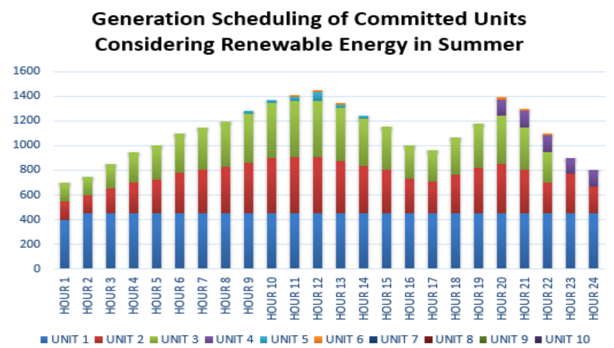

Fig. 8. Generation Schedule of Committed Units for 10-Unit Test System at 10% Spinning Reserve considering Renewable Energy Sources in summer

CONCLUSIONS

In the suggested research work, the authors has successfully presented mathematical formulation of PBUCP considering battery electric vehicles, plug-in electric vehicles and renewable energy sources (solar and wind power), which is one of the challenging problems in power system operation control and planning. PBUCP of electric power system is considered. The proposed numerical construction of PBUCP will be helpful for researchers, who are working in this kind of problems with electric vehicles (EVs) i.e. battery electric vehicles, Renewable energy sources (RES) and plug-in hybrid electric vehicle as one of the research objectives.

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