Optimal Scheduling for Plug-in-Electric Vehicles in Smart Grid

Gopinathan P ,
AP/EEE, Department of Electrics and Electronics Engineering
Paavai College of engIneering,Namakkal – 637018

Agilan S
Department of Electrics and Electronics Engineering
Paavai College of Engineering,namakkal – 637018

Arun V
Department of Electrics and Electronics Engineering
Paavai College of Engineering,Namakkal – 637018

Atchayan KA
Department of Electrics and Electronics Engineering
Paavai College of Engineering,Namakkal – 637018

Dina S
Department of Electrics and Electronics Engineering
Paavai College of Engineering,Namakkal – 637018

ABSTRACT Green transportation has become our top priority due to the depletion of the earth's natural resources and rising pollutant emission levels. Plug-in electric vehicles (PEVs) are seen as a solution to the problem because they are more cost and environment friendly. Due to rapid industrialization and government incentives for zero-emission transportation, a significant challenge is also constituted in power grids by the self-interested nature of PEVs, with the asymmetry of information between the charging power demand and supply sides. In this paper, we propose an optimal strategy in industrial energy management system, based on evolutionary computing, to characterize different charging situations. The proposed approach considers stochastic, off-peak, peak, and electric power research institute charging scenarios for attaining the vehicle- to-grid capacity in terms of optimal cost and demand. An extensive scheduling of charging cases is studied in order to avoid power outages or scenarios in which there is a significant supply-demand mismatch. Furthermore, the proposed scheme model also reduces the greenhouse gases emission from generation side to build a sustainable generation infrastructure, which maximizes the utility of fuel-based energy production in the presence of certain nonlinear constraints. The simulation analysis demonstrates that PEVs can be charged and discharged in a systematic manner. The participation of transferable load through the proposed methodology can significantly reduce the economic costs, pollutant impacts, efficiency, and security of power grid operation.

INDEX TERMS Energy emission dispatch (EED), industrial energy management system (IEMS), plug- in electric vehicle (PEV), plug-in electric vehicle charging coordination (PEVCC), vehicle-to-grid (V2G), valve-point loading effect (VLE).

I. INTRODUCTION

A. *BACKGROUND*

The world-wide industrial expansions on global scale gave birth to the continuous demand of electricity, and scientists around the globe are finding new tools for the power demand and supply adjustment to achieve the energy gap demands [1], [2], [3], [4], [5], [6], [7], [8]. The primary objective of energy emission dispatches (EEDs) is to find the best combination of thermal units to minimise air pollutants and the total cost of generation of electricity [9], [10], [11], [12], [13], [14], [15], [16]. The attainment of lowest cost of a reliable energy supply to a power system can be a really complicated task due to the increase of complex new load types such as plug-in-electric vehicles (PEVs) and green energy charging stations, which depend heavily on grid control [17]. Another important aspect of the world order is power generation utilities are affecting the earth's atmosphere dramatically, and emission regulatory authorities are forcing the power generation companies to limit their emission to an acceptable level. According to US environmental protection agency, 50% of emissions of greenhouse gases is caused by the electricity production and transportation alone [18]. These agencies are also encouraging industries to switch the users on green energy with lower or zero emission by providing tax free rebates and other financial benefits to protect the environment [19]. In the future, it is expected that PEVs will dominate all other means of transportation industries due to zero carbon foot prints and easy maintenance as compared to combustion engines. The distribution of charging infras- tructure is unquestionably one of the most essential areas of studying the mechanics and applications of traditional EVs recharging, whether for PEVs or exchange recharging tech- niques. Some recent research focused on developing charging technologies for EVs, including rapid inductive recharging (RIR), short mileage capacity, and extended charging periods. Fathollahi et al. [20], [21] developed a statistical technique for the positioning and navigation of commercial EVs. Taking into account variables such as EVs energy potential, fuelling facility construction costs, power setbacks, and energy hubs' power dissipation, the proposed method has successfully mapped the location of IRR infrastructure and the scheduling of EVs. Majhi et al. [22] developed a combined optimization technique for identifying an economical approach for the optimal distribution of RIR infrastructure on a large transport grid while maintaining a satisfactory SOC. However, due to the nature of their use, many commercial and domestic PEVs are charged at frequent intervals. This results in an abrupt increase in the demand for electricity on the energy generating hubs. To contemplate this situation, a viable solu- tion is needed to avoid energy mismatch of energy integrated systems [23].

B. *RELATED WORK*

The primary concern of the EEDs is to improve the use of energy supplies in the power grid [7], [24], [25], [26], [27], [28], [29], [30]. In the past, several techniques have been used to reduce the overall cost of fuel-based production units and for delivering high-quality electricity to customers, while EEDs are the most cost-effective and best possible options [31]. In recent years, car manufacturers and federal financial institutions have preferred the adoption of PEVs because they have low oxides emission, better torque, energy saving and easy maintenance [32], [33], [34], [35]. However, a substan- tial percentage of PEVs will cause massive instability in the operation of power grids [36], [37]. Due to inherent autonomy of PEVs, an efficient charging model of all PEVs in a given urban area is presented in [38] and [39]. After government legislation of PEVs charging, a voltage control model has been proposed to reduce power system voltage fluctuations while ignoring the power losses in the optimization goal [40], [41]. The charging nature of PEVs as load in grid network system reflects it as the highly non-convex and non-differential task.

Electricity and transportation industries are the largest emitters of greenhouse gases on earth. Primarily, solar and wind integration in the electricity industry can reduce these harmful emissions [42]. The emission reductions may be further aided by grid-enables vehicles (GVs), which are PEVs with a V2G feature. PEVs have been used as loads, energy sources, and energy storage in a smart power system with renewable energy sources [43]. In the past decade, scientists have considered many PEVs penetrations in the conventional power grid systems [44]. Abdullah et al. [45] studied the risks and obstacles that come from charging and discharging PEVs as well as their potentials as a way to integrate renewable energy sources. Qiao et al. [46] developed an adaptive struc- ture of PEVs and wind farms that utilises the charging and discharging of PEVs to mitigate the wind energy penalty costs associated with exceeded and underrated wind energy availability. Behera et al. [47] used fuzzy decision approach, based on constriction particle swarm to solve the dynamic EEDs and attained feasible greenhouse gases emission rate by integrating renewable energy sources and PEVs. Flower pol- lination meta-heuristic optimization algorithm is used in [48] to tackle the complex dynamic EEDs subject to traditional and charging constraints of PEVs. However, the charging constraint model has considered the conventional capacity limit on power generation, and practically, the charging of PEVs is truly stochastic in nature [49], [50], [51].

Hong et al. [52] suggested the power systems concept to manage the charging behaviour of all PEVs in a single urban area due to their intrinsically autonomous properties. On the basis of V2G technology, Wei et al. [53] suggested that PEVs may be employed as a tiny transportable power plant. They initially introduced the EEDs model for unit commitment with PEVs and then utilized particle swarm optimization for power mismatch constraints. Wu et al. [54] presented an hier- archical approach for scheduling PEVs as industrial loads. The model, on the other hand, does not take into account the limits imposed by the EVs or the spinning reserves.

To elude the problem, Liu et al. [55] analyzed the pricing model and dispatching scheme for PEVs-storage participa- tion in the alternate service model and proposed an opti- mal allocation strategy for PEVs-storage with the goal of economic dispatch. The study can be found to effectively improve PEVs reaction to ancillary service market participa- tion and to increase the hub revenue. Babaei et al. [56] used data mining approach for the uncertain load management of PEVs over power network, considering a convex optimiza- tion model. In [57], the authors solved a combined EEDs problem by using a back tracking search algorithm. Li et al. [58] suggested an improved sailfish optimizer for strate- gic planning scheme to ensure flexibility in the program- ming of power systems and addressed random wind power effectively while reducing the operating costs and pollutant emission. Numerous methods have been used as effective optimiza- tion tools and have become widespread in the search for the optimal solution to the EEDs problem [59], [60]. However, the implementation of an appropriate multi-objective eco- nomic emission dispatch system is still an intensively studied topic that requires additional effort to balance the power grid network energy flow in order to support the rapid develop- ment of PEVs [61], [62], [63], commercial flying drones, and other dynamic loads of energy storage devices [64], [65], [66]. The authors in [67] presented a combined grid stability and cross emissions reduction model for the energy dispatch by considering PEVs to attain the lowest grid operational cost. The presented model can reduce the operational cost and emissions of energy hubs by relocating the transferable electrical loads, such as PEVs, to time intervals when gen- eration costs are low. In [68], the challenging dilemma of electricity grid security due to uncertain load demand was investigated. The authors have used a reinforcement learning model to meet the energy demand of PEVs with varying users in various places while concurrently boosting energy security. Nonetheless, avoiding local minima is a major challenge when solving optimization problems with strict constraints. The researchers in [69] came up with a hybrid optimiza- tion scheme, namely GSA-PSO, in order to improve the global search performance. Additionally, some recent works have presented the state-of-the-art ways to solve the hard optimal energy dispatch problem while taking PEVs into consideration [70], [71], [72], [73].

C. *RESEARCH OBJECTIVE AND CONTRIBUTION*

This work proposes a new paradigm to address the economic emission model, contemplating unsteady load management of PEVs. The developed framework provides the optimum solution of cost and emission while delivering a unified strat- egy for achieving a more precise and stable dispatch with the addition of PEVs as additional loads. One of the most difficult problems in power system control is to schedule the active powers from all engaged thermal power stations in such a manner that the generation costs and emissions are minimized to the maximum possible extent while satisfying all associated constraints. In addition, the EEDs for a sin- gle connected load for a fixed time while meeting restric- tion such as capacity generation limitations is referred to as static EEDs. The EEDs for a loading condition of 24 hours while taking ramp constraints into account is referred to as dynamic EEDs, which is a more appropriate and pragmatic dispatch requirement. An astute soft computing paradigm is proposed and applied to solve the dynamic EEDs with traditional convex and nonlinear constraints such as valve-point effect, prohibited operating regions, internal network losses. A new constrained model of PEVs with energy stor- age and multi-charging mechanism is also incorporated as an unsteady load. CEED with consideration for PEVs is an important power system optimization task. This research assists energy operators and policymakers

PEVs POWER DEMAND AND CHARGING SCENARIO

PEVs are recognised as the unconventional electric loads due to their manufacturing hardware circuit complexities, as compared to the traditional domestic and industrial loads. The use of synchronous charging for household purposes with a capacity of 0.02 MW and fast charging for industrial purposes with a capacity of 0.2 MW (turbochargers) can be accounted, which are primarily used by PEVs. This will cause substantial rising spikes in the daily system demand load curve. By appropriate scheduling of thermal power stations and PEVs, these cascading effects on the daily demand curve are preventable. Four different charging cases are examined and taken from [79] and [88]. The detailed charging mecha- nisms for PEVs are as follow.

A. *PEAK CHARGING CHARACTERISTICS FOR PEVs*

This profile is continuous recharging of lithium-ion powered automobiles, having 3 loading rates for the power sources of electric vehicles during peak hours. Table 3 presents the probabilistic distribution at peak hour. It is a serious case comparison to prior situations, since electric vehicles require energy between 13^{th} and 20^{th} peak hours. The rate of charge and times for this case are in-line with [91].

B. *STOCHASTIC CHARGING CHARACTERISTICS FOR PEVs*

The stochastic charging profile of PEVs is used by enabling charging uncertainties. We consider quick or instant charging of an immediate vehicle at an irregular time frame of all TABLE 3. Peak charging scenarios of EVs.

Time	Probabilities					
01:00-06:00	0	0	0	0	0	0
07:00-12:00	0	0	0	0	0	0
13:00-18:00	0.185	0.185	0.185	0.185	0.09	0.09
19:00-24:00	0.04	0.04	0	0	0	0

day long in the stochastic charging scenario of PEVs. By a margin of 5%, the random probability distribution shows the normal distribution exactly. There are probabilities for the stochastic charge scenario, presented in Table 4 for every hour of the schedule. In all periods, the probability distribu- tion ranges from 1.1 to 9.7 percent for the stochastic charg- ing profile, where state-of-charge (SOC) changes randomly. This research proposes a stochastic charging characteristic to account for PEVs owner behaviour uncertainties. The profiles are adopted from [79] to demonstrate the performance of proposed method under uncertain charging scenarios. More explicit results on uncertain behaviour of drivers can be seen in the work [92]. It is pertinent to mention here that the selected stochastic profile is assumed to be Gaussian as compared to [92].

Figure 1 shows the rates of load demands for each of the four situations. These models take into account the identical proportion of demand in balance for load power $P_{EV,\tau}$. The research problem becomes more complicated and multidi- mensional by considering the presented scenarios [79].

TABLE 4. Stochastic charging scenarios of EVs.

Time	Probabilities					
01:00-06:00	0.057	0.049	0.048	0.024	0.026	0.097
07:00-12:00	0.087	0.048	0.011	0.032	0.021	0.057
13:00-18:00	3.8	2.2	0.021	0.061	0.032	0.022
19:00-24:00	0.028	0.022	0.055	0.025	0.035	0.082

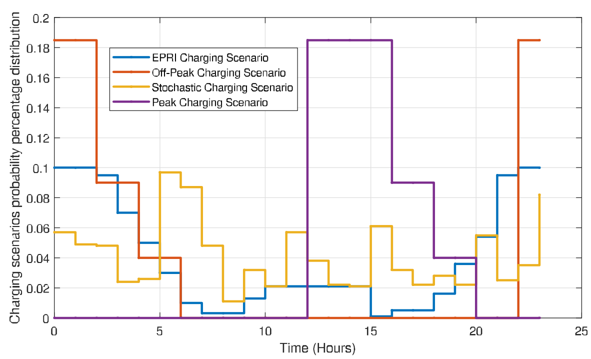

FIGURE 1. Distribution curves for various charging scenarios.

II. METHODOLOGY FOR OPTIMAL SCHEDULING OF PEVCC

The presented methodology resolves the PEVCC problem by defining an optimal schedule for energy exchange between the batteries of PEVs and the energy grids. Additionally, an economically viable operation for the EEDs is attained, and operational limitations are satisfied. The optimal charg- ing scheduling must minimize the energy costs by avoiding battery discharge on PEVs and by minimizing power loss in EDDs. V. Hayyolalam and A. Pourhaji Kazem [93] proposed a new evolutionary optimization algorithm based on the mat- ing rituals of black widow spiders, which has been applied in many different advanced industrial research problems due to its convenience of use, adaptivity and speed. The efficient black widow optimization (EBWO) is influenced by the black widow spider's unusual sexual dimorphism. This methodol- ogy includes a unique stage known as cannibalism. As a result of this phase, the circle excludes species with poor fitness which further leads to early convergence. For the purpose of determining the effectiveness of the proposed method in finding optimal solutions, the EBWO algorithm is evaluated on five different test systems. The EBWO algorithm performs admirably during the exploitation and exploration processes because it ensures rapid convergence and avoids local opti- mum issues. Furthermore, it should be noted that EBWO has the ability to strike a fine line among exploitation and exploration. In other words, it has the capability of scanning a large area in search of the best optimal solutions. As a result, EBWO is an excellent choice for solving a variety of optimization problems involving a multiple local optima [93].

A. LIFESTYLE STAGES OF BLACK WIDOW

Black widows are atrocious arachnids known for their hourglass-shaped logo on their abdomens, which can be found all over the world in places that are moderate in tem- perature. The brief life cycle of balck widow is as follow.

1) BLACK WIDOW SPIDER MATTING PROCESS

Black widow spiders are most dangerous to insects and male black widows. After mating, females will sometimes devour their mates. This behaviour is referred to as ‘‘black mating’’ and gives the insect its name. In contrast to other species, black widows have a generally solitary lifestyle throughout the year except for this violent mating behavior. By reducing the attractiveness of females’ webs to rivals, the first male enters the web. Females devour males during or immediately after mating and then transfer eggs to their egg blister. Sib- ling cannibalism is committed by the offspring immediately after hatching. They do, however, spend some time on their mother’s webs, where they can eat her. Fit and strong [94] are guaranteed to live through this cycle. The optimal solution is the one that achieves the global optimum of the targeted function.

2) REPRODUCTION AND CANNIBALISM

Sex cannibalism is known to occur among invertebrates, such as tarantulas, arachnids, and praying mantises. It is an enthralling natural phenomenon to observe. By adjust- ing their approach in response to these factors, males are able to reduce their risk of being killed. It is one of very few significant species where the male actively participates in sexual cannibalism with the female. During mating, the female usually eats the male in two-thirds of the cases. Non- consumed males die shortly after mating from their injuries.

3) SELF-DEVOURING IN SIBLINGS

As soon as their eggs are laid, spider lings can begin to hatch. They can then emerge from the egg blister after about 11 days, though cooler weather can probably slow their development and delaying emergence for months. In the egg sac, they feed on the yolk and moult once after hatching. During the first few days or weeks of life on the prenatal web, sibling cannibalism is most common. They are then carried away by the wind. Cannibalistic behavior is caused by several fac- tors, the most obvious being contest among predation related species and the potential for alternative food sources during periods of low prey availability. Un-selective sibling canni- balism’s precise effect on parental fitness may have an influ- ence on the development of parenting practices procreative strategies. Cannibalism lowers the amount of survivor spider expressed as follow.

$$Fitness = f(Widow) = f(Q_1, Q_2, \ldots, Q_{Wvar}). \qquad (10)$$

The optimization process begins with a starting population of spiders in order to generate a feasible widow matrix of size $Wpop \times Wvar$ that can be used to solve the optimization problem. Next, sets of family members are chosen at random to perform the procreative step of mating, during which the
female black widow consumes the male black widow, and the process is repeated.

2) PROCREATIVE

Mating occurs in parallel amongst the pairs, just as nature dictates, with each pair breeding within its own web and without the interference of the others. In the real world, each mating produces approximately thousand eggs, but some of the stronger spider babies survive. For breeding purposes, an array termed alpha must be formed as long as the widow array consists random numbers. After that, descendants are created by employing σ and the following equation, in which m_1 and m_2 are parents and Q_1 and Q_2 are offspring.
lings; however, if survivors have improved body condition, it may also increase parental fitness. It would be expected that cannibalism rates would rise in proportion to family size

$$m_1 = \sigma \times Q_1 + (1 - \sigma) \times Q_2, \; m_2 = \sigma \times Q_2 + (1 - \sigma) \times Q_1. \qquad (11)$$

if cannibalism follows the same patterns as other forms of cannibalism, especially if the potential cannibal is in poor health. Additionally, in some instances, unfertilized spider lings consume their mother slowly. In a matter of weeks, she deteriorates to the point where she can no longer move and is completely devoured.

B. LOGICAL STEPS FOR EBWO

A re-adjustment of the variables in the traditional EDP opti- mization problem with PEVs acting as an additional unsteady load is required in order to solve the optimization prob- lem successfully. The main structured variable is referred as widow in EBWO, chromosome in genetic algorithms, and particle position in swarm optimization. Each problem vari- able depicts as widow and fitness of each variable depends on predefined fitness function. EBWO proceeds in the following sequence of logical steps.

1) INITIAL POPULATION

A widow of $1 \times W_{var}$ dimensional array represents the solution to a multi-dimensional EEDs optimization problem considering PEVs as additional load with all associated con-
straints. Furthermore, the following describes the definition of this array:
$Widow = [Q_1, Q_2, \ldots, Q_{Wvar}]$. (9)

A floating-point number is used to represent each value asso- ciated with the variable (Q_1, Q_2, Q_{Wvar}). A widow's
fitness level is determined by applying the fitness function f at (Q_1, Q_2, Q_{Wvar}). The expression for fitness can be Following this, the babies and their mothers are incorporated
into an array and classified according to fitness value. Now, depending on the canabolism rate, the best participants are incorporated into the newly produced population, and all pairs should adhere to the procedure.

3) CANNIBALISM

Cannibalism is a mechanism for population control or for ensuring a participant's genetic contribution. In the life cycle of Black Widow spider, we have three types of cannibalism as follow.

i) First case of sexual cannibalism is when the lady spider widow consumes her companion male.
ii) Sibling cannibalism in which stronger spider lings con- sume their weaker siblings.
iii) Spider lings consume their materfamilias.

4) MUTATION

Individuals from the population are randomly selected which are mutepop individuals. Each of the selected solutions swaps two variables as depicted in Figure 2, and mutation rate is used to calculate mutepop. The shared solutions are further evaluated in accordance with the specified value in Table 1 to generate the new improved mutated optimal population.

5) EBWO CONVERGENCE

Similar to other meta-heuristic approaches, three stopping conditions are considered as follow.

i) A pre-configured iteration count.
ii) Maintaining a constant fitness value for the best widow over a number of iterations.
iii) Attaining the prescribed level of precision.

6) PARAMETER CONFIGURATION

The parameters must be adjusted appropriately to enhance the algorithm's success in finding gain advantages. Efficient parameter tuning provides the ability to jump out of any local optimum with greater chances of success while making a comparison between exploitation and exploration. It includes the rate of reproduction (RP), the rate of cannibalism (RC), and the rate of mutation (RM). The norms for these character- istics that were chosen for this article are tabulated in Table 5. RP is the procreating percentage, which indicates the number

TABLE 5. Controlling parameter setting.

Parameter	Value
Rate of reproduction (RP)	0.61
Rate of cannibalism (RC)	0.42
Rate of mutation (RM)	0.44

of individuals participating in reproduction. RC eliminates the inadequate individuals from the available population. Setting the appropriate value for this parameter ensures that the exploitation stage performs well by transferring search agents. RM decides the proportion of individuals who par- ticipate in mutation. Maintaining a more delicate balance

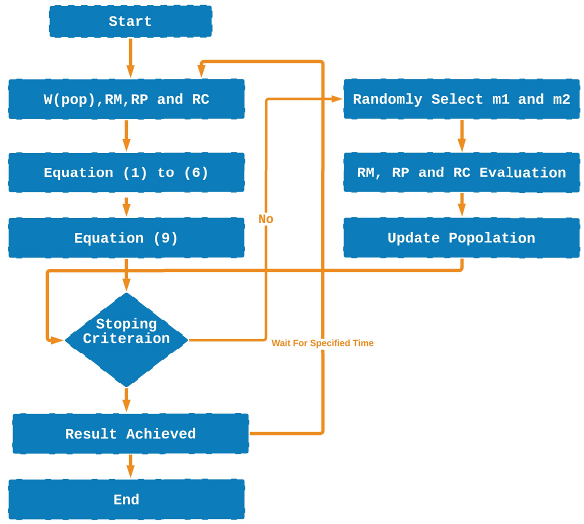

FIGURE 3. Flowchart for dynamic optimal scheduling of PEVCC.

between exploitation and exploration with the precise value for this parameter is beneficial. This factor can be used to handle the transition of search agents from the global to the local level, as well as to direct them toward the most optimal solution possible. The diagrammatic representation in the form of flowchart for PEVCC is depicted in Figure 3 which shows the step-by-step working of EBWO to solve the optimal scheduling of PEVCC. As a starting point for the proposed EBWO, a population of spiders, each of which demonstrates an optimal solution, is leveraged in-line with the parameter values as indicated in Table 1. As a first phase, these spiders hook up and attempt to produce a new genera- tion that will update the population and randomly select two genes according to the specified procedure of cannibalism and mutation. Again, the population is updated in line with the parameter values, and the process continues until the stopping requirement is fulfilled (that is, all constraints are satisfied and the global optimal point is found). In this work, an evolutionary computing-based approach is presented to solve the complex, nonlinear practical problem in indus- trial operation of utilities. Compared to [74], the EBWO approach's versatility in dealing with wide range of con- straints has also been demonstrated. Furthermore, the CEED model is re-designed by induction of two more practical real- world constraints, namely SRs and FOR. The performance and reliability of presented approach has been evaluated using several charging scenarios for PEVs on economic dispatch, and the results are compared with [74], [79], [80], and [95], and the references therein.

III. TEST AND RESULTS

In this section, we apply EBWO to the benchmark test systems of PEVCC by taking PEVs into account. As the optimal solutions for test systems are known in literature, achieving a specified level of accuracy demonstrates the proposed technique's superiority over other state-of-the-art heuristic techniques. The benchmark test systems of PEVCC that consider PEVs charging under various scenarios make the model high-dimensional and complicated. The constraints causing the complexity of the problem have a direct impact on energy grid stability, daily operational costs, and environ- mental implications. The reason for choosing EBWO for this complex optimization problem with contiguous constrained restrictions is that it has a very superior efficiency in intelli- gently identifying the global optimal cost with a high degree of precision and rapid convergence.

Five case studies have been performed to showcase the effectiveness and feasibility of designed scheme for real-world power system applications. The EBWO was sim- ulated for the dynamic CEED responses and the optimised cost of fuel for charging fleet of plug-in electric vehicles under various scenarios was compared to advanced heuristic approaches. The required time analysis was carried out on a Lenovo notebook equipped with an Intel celeron (R) N2940 CPU running at 1.83GHz and 4.0 GB of RAM, with MAT- LAB version R2017b. The experimental layout of case stud- ies is depicted in Figure 4 which consists of three linked blocks. The first block is problem formulation block where two highly conflicted objective functions along with the system constraints are modeled into single objective function with the help of scaling weights. The second block represents the working strategy of EBWO along with algorithm para- metric values, and it will generate the best optimal values of given problem by satisfying the all constraints and fed it to energized load line represented in block three. All dynamic loads are considered for attaining optimal fuel cost price and emission under system constraints such as valve-point loading effect, transmission losses with additional dynamic load of PEVs charging. The brief system description of case studies is as follow.

EEDs system, constrained by equations (3)-(6), for demand presented in Appendix B taking into account PEV charging scenarios. The results of these case studies are compared to other advanced methods, including PSO, SA, TLBO, EP, and other hybrid schemes. EBWO outperformed in terms of achieving the best global optimal with stable convergence, as demonstrated by the results. In addition, the effective- ness of the proposed EBWO is not restricted to smaller test systems, as demonstrated by Case Study V. This case study focuses on a 15-unit system with rigid system constraints. The numerical simulations demonstrate that the proposed EBWO achieves a global optimum solution regardless of a large search space in a shorter amount of time than other advanced hybrid methods reported in the literature, including SL-TLBO, w-PSO, PSO-CF, DE, e-TLBO, m-TLBO, and MAFRL.

A. *CASE STUDY-I*

The cost coefficient data for dynamic economic dispatch of five units is taken from [96]. The EBWO approach is capable of generating powers of all committed units optimally for 24 hours, as illustrated in Figure 5. The result is compared to the previously used approaches and is shown in Table 6 and Figure 6. The statics obtained through EBWO has a lower fuel dispatch cost than several other techniques such as SA, PS, EP, PSO, SL-TLBO, and MAFRL [74] reported in the literature.

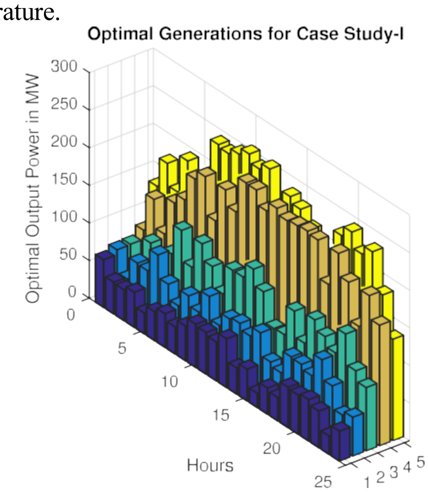

FIGURE 4. Experimental layout of the formulated problem, algorithm, and charging load of PEVs with other loads.

i) Case Study-I: Five units test system with VLEs and transmission losses without considering charging sce- nario of PEVs.

ii) Case Study-II: Five units test system with VLEs and transmission losses by considering four charging sce- nario of PEVs.

iii) Case Study-III: Five units test system of dynamic emis- sion dispatch, VLEs and transmission losses by consid- ering charging scenario of PEVs.

iv) Case Study-IV: CEED model with VLEs and transmis- sion losses by considering charging scenario of PEVs.

v) Case Study-V: Large-scale system with 15 units of dynamic economic dispatch by VLEs and transmission losses.

CONCLUSION AND FUTURE WORK

In this paper, an evolutionary computation-based method, namely EBWO, has been considered to solve the optimal charging coordination of PEVs in energy hubs for various charging strategies, such as EPRI, peak, stochastic, and off- peak, of PEVs by considering a dynamic load. Each scenario is confined by complex energy dispatch system limitations such as generation capacity, load demand, valve-point load- ing effects, ramp-rate limitations and forbidden operating regions. Additionally, a more complex multi-objective model has also been investigated to examine the environmental effects and emission costs of power plants. Furthermore, four complex charging scenarios for PEVs by taking into account the driver behavior and energy grid peak and off-peak hours are investigated. The proposed scheme determines the optimal charging schedules, optimal cost and optimal emissions in order to avoid operational concerns associated with uncontrolled PEVs charging in IEMS such as grid security and stability. There was no PEVs energy curtail- ment in any of the scenarios studied herein with regard to system load imbalance, and the charging schedules were able to meet the operational constraints.

REFERENCES

[1] S. Fayyaz, M. K. Sattar, M. Waseem, M. U. Ashraf, A. Ahmad, H. A. Hussain, and K. Alsubhi, ''Solution of combined economic emission dispatch problem using improved and chaotic population-based polar bear optimization algorithm,'' IEEE Access, vol. 9, pp. 56152–56167, 2021.

[2] I. Ahmed, A. R. Rao, A. Shah, E. Alamzeb, and J. A. Khan, ''Performance of various metaheuristic techniques for economic dispatch problem with valve point loading effects and multiple fueling options,'' Adv. Electr. Eng., vol. 2014, Nov. 2014, Art. no. 765053, doi: 10.1155/2014/765053.

[3] M. H. Hassan, S. Kamel, S. Q. Salih, T. Khurshaid, and M. Ebeed, ''Developing chaotic artificial ecosystem-based optimization algorithm for combined economic emission dispatch,'' IEEE Access, vol. 9, pp. 51146–51165, 2021.

[4] U.-E. Alvi, ''A novel incremental cost consensus approach for distributed economic dispatch over directed communication topologies in a smart grid,'' Soft Comput., vol. 26, pp. 6685–6700, Jul. 2022.

[5] I. Ahmed, U.-E.-H. Alvi, A. Basit, M. Rehan, and K.-S. Hong, ''Multi- objective whale optimization approach for cost and emissions scheduling of thermal plants in energy hubs,'' Energy Rep., vol. 8, pp. 9158–9174, Nov. 2022.

[6] M. Rehan, N. Iqbal, and K.-S. Hong, ''Delay-range-dependent control of nonlinear time-delay systems under input saturation,'' Int. J. Robust Nonlinear Control, vol. 26, no. 8, pp. 1647–1666, 2016.

[7] I. Ahmed, M. Rehan, A. Basit, S. H. Malik, U.-E.-H. Alvi, and K.-S. Hong, ''Multi-area economic emission dispatch for large-scale multi-fueled power plants contemplating inter-connected grid tie-lines power flow lim- itations,'' Energy, vol. 261, Dec. 2022, Art.