IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received November 10, 2020, accepted November 23, 2020, date of publication November 30, 2020, date of current version December 11, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.3041309

Stochastic Economic Dispatch Incorporating Commercial Electric Vehicles and Fluctuating Energy Sources

VELAMURI SURESH[1], (Member, IEEE), S. SREEJITH[2], (Member, IEEE), SURESH KUMAR SUDABATTULA[3], (Member, IEEE), S. HARI CHARAN CHERUKURI[4], (Student Member, IEEE), NATARAJAN PRABAHARAN[1], (Member, IEEE), PIERLUIGI SIANO[5], (Senior Member, IEEE), AND HASSAN HAES ALHELOU[6], (Senior Member, IEEE)

[1]School of Electrical and Electronics Engineering, SASTRA Deemed University, Thanjavur 613401, India
[2]Department of Electrical Engineering, National Institute of Technology Silchar, Assam, Silchar 788010, India
[3]School of Electronics and Electrical Engineering, Lovely Professional University, Phagwara 144411, India
[4]Department of Electrical Engineering, IIT Gandhinagar, Palaj 382355, India
[5]Department of Management and Innovation Systems, University of Salerno, 84084 Salerno, Italy
[6]Department of Electrical Power Engineering, Faculty of Mechanical and Electrical Engineering, Tishreen University, Lattakia 2230, Syria

Corresponding author: Hassan Haes Alhelou (alhelou@tishreen.edu.sy)

ABSTRACT Increase in utilization of electric vehicles and penetration of Renewable Energy Sources (RES) creates a greater impact on traditional power systems. Intermittent output from renewable energy resources and uneven usage pattern of electric vehicles creates a greater impact on the economic operation of power system. In this article, a stochastic Dynamic Economic Dispatch (DED) problem incorporating Commercial Electric Vehicles (CEVs) and intermittent renewable energy resources is addressed. The charging pattern of CEVs as well as intermittency of solar and wind resources creates a significant impact on power system peak demand. The behaviour of these CEVs and RES in various seasons is considered and the same is tested on a real time south Indian practical test system. An attempt is made to improve the swarm-based Moth Flame Optimization (MFO), named as IMFO is developed and utilized for solving the considered problem. The efficacy of the said method is tested and necessary validations are carried out in this article.

INDEX TERMS Economic dispatch, electric vehicles, improved moth flame optimization, renewable energy sources, solar, wind.

NOMENCLATURE

$P_{i,t}, P_{sj,t}, P_{wk,t}, P_{evl,t}$	Power produced by thermal, solar, wind generation and CEVs at t^{th} time interval respectively.
$F_{i,t}, F_{j,t}, F_{k,t}$	Fuel cost of thermal, solar and wind generation at t^{th} time interval respectively.
a_i, b_i, c_i	Thermal generator cost coefficients.
e_i, f_i	Valve point loading coefficients.
$d_{j,t}, d_{k,t}, d_{l,t}$	Direct cost of solar, wind and CEVs at t^{th} time interval.
P_d, P_L	System demand and power loss in MW.
τ	Penetration level constraint.
$P^{\min}, P^{\max}$	Minimum and Maximum generation limits.
$UR(i), DR(i)$	Up-rate and Down-rate of i^{th} generator.
B_{ij}, B_{0i}, B_{00}	Transmission loss coefficients.
V_{MPPT}, I_{MPPT}	Voltage and Current at maximum power point.
V_{OC}, I_{SC}	Open circuit voltage and Short circuit current of the PV panel.
$SOC_{\min}, SOC_{\max}$	Minimum and Maximum limits of State of Charge.

The associate editor coordinating the review of this manuscript and approving it for publication was Zhehan Yi.

P_{ch}, P_{disch}	Charging and Discharging limits of the CEVs.
PD_{cev}	Additional demand due to CEVs.
P_T, P_S, P_W	Thermal, Solar and Wind power generated respectively.
P_G, P_D, P_L	Total Power generated, Power demand and Power Loss respectively.
F_T, F_S, F_W, T_C	Fuel cost of Thermal, Solar, Wind and Total generation respectively.

I. INTRODUCTION

Economic Dispatch (ED) is a primary issue in the operation and planning of modern power systems. In ED, the best combination of generators is exploited for minimization of fuel cost. Furthermore, ED helps in improvement of power system security and reliability. To bridge the demand generation gap ED has become an essential tool which involves quite a few constraints. Besides this, addition of large-scale intermittent energy sources (Solar and Wind) adds a lot more constraints to the ED problem. With the increased number of constraints, the problem of ED has become highly nonlinear, constrained and complex.

For solving nonlinear problems heuristic optimization techniques are widely used. Optimization techniques are classified into classical, analytical and Meta heuristic methods. Various power system problems are solved using these methods. Classical methods like Lambda Iteration Method (LIM) [1], Linear Programming (LP) [2], Quadratic Programming (QP) [3] and Gradient Method (GM) [4] are applied to solve the ED problem. High computational time, large number of iterations and poor constraint handling are the drawbacks of these methods.

Whilst Meta heuristic methods do not ensure an optimized global solution, they are widely implemented for solving ED problem with a reasonable computational time. Traditional ED problem has been solved using various optimization techniques such as [5]–[22]. In [23], optimal economic dispatch is solved using linear programming for a large test system. This method considers a piecewise linear model of the network for handling the various parameters of the network. In [24], Chemical Reaction Optimization (CRO) is used for solving various types of dispatch problems. Constraints like valve point effect, Prohibited Operating Zone (POZ) and emission are considered in the above-mentioned method and the effectiveness of CRO is explained.

Recently researchers considered incorporation of RESs in the existing ED problem. In [25], the problem of ED is solved in the presence of high wind power and storage using MBFA. Additionally, composite operating costs of wind power are also introduced. Combined economic emission dispatch (CEED) incorporating PEVs and RESs is employed using PSO in [26]. It is inferred that the PEVs alone cannot reduce the emission of greenhouse gases (GHGs); rather the combination of PEVs and RESs can help in minimizing the GHGs emission. Renewable energy based ED has been implemented in [27]–[30], whereas emission parameter has been additionally taken into account in [28], [31] and reserve constraint is included in [32]. The wait and see approach to estimate the wind speed is used and the estimations are incorporated with existing ED problem which makes it an entirely different problem and the same is solved in [33]. Market clearing mechanism-based ED considering wind and thermal systems is presented in [34]. In [35], the ED incorporating wind energy conversion system by considering the estimates of wind power using weibull distribution model is projected. ED considering spinning reserve of a system in the presence of wind and thermal units is solved using CMA-ES technique in [36].

To reduce the environmental pollution and promote clean energy, accelerated usage of Electric Vehicles (EVs) over Internal Combustion Engines (ICEs) is being promoted by many countries. Government of India is promoting EVs and provides incentives for effective usage of electric mobility systems. Despite of increased penetration of EVs, their charging patterns will create a significant impact on peak electricity demand. Consequently, it is very essential to study the scheduling of EVs along with the generation units. A few works reported in literature in this direction are studied and the same are as follows. In [37]–[41], charging of EVs is addressed in terms of valley filling. The works presented so far do not try to handle the peak demand. In [42]–[44], DED including PEVs is studied by considering various charging and discharging profiles. The method presented in [44] solved the problem of DED in presence of EVs. However, the authors did not consider the charging rate. By looking at the literature on static/dynamic economic dispatch referred in [1]–[36], it can be understood that the focus of all those works is only to find out a better operating solution of the generation units in the absence of electric vehicles in the system. Further, by having a glance at the articles [37]–[44], it can be understood that the penetration of the EVs into the system has been taken into account by the researchers, but the impact of CEVs on the optimal ED considering RES is less attempted in the literature.

Taking into account the presented literature, it can be established that the problem of static and dynamic economic load dispatch in the presence of fixed and intermittent energy sources has not been addressed adequately. On the other hand, various works reported in the literature also focused only on developing the optimal charging/discharging profile for EVs considering their running patterns. By considering the aforementioned statements, it can be understood that the problem of EV and generation scheduling is being solved individually. Therefore, in this work an attempt is being made to bring in a comprehensive solution to the problem of static and dynamic economic dispatch in the presence of large fleet of commercial electric vehicles and renewable energy resources.

A. CONTRIBUTIONS OF THE ARTICLE

- A new method namely smart charging method is proposed for scheduling Commercial EVs.

- An effective solution to DED incorporating RES and CEVs is developed which reduces the cost and power loss minimization.
- An improved version of MFO (IMFO) algorithm is proposed, which is better than the existing MFO method.

The rest of this article is organized as follows. In section 2 mathematical formulation of DED including RES and CEVs is presented. Later in section 3 Modelling of RES and CEVs is discussed. In section 4 the results obtained using the developed method are presented.

II. MATHEMATICAL FORMULATION OF DED PROBLEM INCLUDING RES AND CEVs

The goal of ED problem is to minimize the generation cost of all the units participating in dispatch while satisfying the constraints posed on the generating units. Three different kinds of ED problems are considered for the study. Firstly, Static ED considering thermal generators is represented in Eq 1. Second, Static ED considering thermal generators with valve point effect represented in Eq 2. Finally, stochastic DED considering CEVs and RES are represented in Eq 3 and 4.

The quadratic cost function for minimizing thermal generation cost is [45]

$$\min \sum_{i=1}^{N} F_i\left(P_i\right) = \min \sum_{i=1}^{N} \left(a_i P_i^2 + b_i P_i + c_i\right) \tag{1}$$

The quadratic cost function considering valve point effect is given by [46]

$$\min \sum_{i=1}^{N} F_i\left(P_i\right) = \min \sum_{i=1}^{N} \begin{matrix}(a_i P_i^2 + b_i P_i + c_i \\ + \left|e_i \times \sin\left(f_i \times \left(P_i^{\min} - P_i\right)\right)\right|)\end{matrix} \tag{2}$$

The quadratic cost function for 24 hours time horizon considering solar and wind energy as well as CEVs is

$$\min \left\{ \sum_{t=1}^{T} \left\{ \begin{matrix} \sum_{i=1}^{N} F_{i,t}\left(P_{i,t}\right) + \sum_{j=1}^{m} F_{j,t}(P_{sj,t}) \\ + \sum_{k=1}^{n} F_{k,t}(P_{wk,t}) + \sum_{l=1}^{p} d_{l,t} P_{evl,t} \end{matrix} \right\} \right\} \tag{3}$$

which can be rewritten in expanded form as

$$\min \left\{ \sum_{t=1}^{T} \left\{ \begin{matrix} \sum_{i=1}^{N} (a_i P_{i,t}^2 + b_i P_{i,t} + c_i) + \sum_{j=1}^{m} d_{j,t} P_{sj,t} \\ + \sum_{k=1}^{n} d_{k,t} P_{wk,t} + \sum_{l=1}^{p} d_{l,t} P_{evl,t} \end{matrix} \right\} \right\} \tag{4}$$

Following constraints must be satisfied while solving the problem

Power balance Constraint

$$\sum_{i=1}^{N} P_i + \sum_{j=1}^{n} P_{sj} + \sum_{k=1}^{n} P_{wk} = P_d + P_L + P_{ch} \tag{5}$$

where power loss

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i \in j} B_{0i} + B_{00} \tag{6}$$

Generating Capacity Constraint

$$P_i^{\min} \le P_i \le P_i^{\max} \tag{7}$$

Prohibited Operating zones POZ

$$P_i \in \left\{ \begin{matrix} P_i^{\min} \le P_i \le P_{i,1}^{lb} \\ P_{i,k-1}^{ub} \le P_{gi} \le P_{i,k}^{lb} \\ P_{i,z_i}^{ub} \le P_i \le P_i^{\max} \end{matrix} \right\}, \quad k = 2, 3, \ldots Z_i \tag{8}$$

Ramp Constraints

$$\begin{aligned} P_{(i,t)} - P_{(i,t-1)} &\le UR(i) \\ P_{(i,t-1)} - P_{(i,t)} &\le DR(i) \end{aligned} \tag{9}$$

Renewable Penetration Constraint

$$\left(\sum_{j=1}^{n} P_{sj} + \sum_{k=1}^{n} P_{wk} \right) \le \tau \times P_d \tag{10}$$

The constraints of CEVs are represented by following equations [47]

CEV(Battery) state of charge constraint

$$SOC_{\min} \le SOC_{i,t} \le SOC_{\max} \tag{11}$$

CEV(Battery) Power limits

$$\begin{aligned} p_{ch,i,t} &\le p_{ch,i}^{\max} \\ p_{disch,i,t} &\le p_{disch,i}^{\max} \end{aligned} \tag{12}$$

III. MODELLING OF RES AND SCHEDULING OF CEVs

The mathematical modelling of solar & wind energy resources, and smart scheduling model for CEVs is discussed in this section.

A. SOLAR ENERGY SYSTEM MODELING

Solar energy is the radiation from sun harnessed using modern techniques such as photovoltaic, solar heating and many other methods. The obtained solar energy is variable due to the stochastic nature of irradiance. For estimating the future output of solar energy, stochastic nature is characterized using probability distribution function. The preliminaries for estimating the solar output are the historical data of chosen location and rating of the PV panel.

Probability of Solar irradiance distribution is given by

$$f_p(s,t) = \frac{\Gamma(\alpha_t + \beta_t)}{\Gamma(\alpha_t)\Gamma(\beta_t)} s^{(\alpha_t - 1)} (1-s)^{(\beta_t - 1)} \ \forall \begin{cases} 0 \le s \le 1 \\ \alpha_t, \beta_t \ge 0 \end{cases} \tag{13}$$

where

$$\beta_t = (1-\mu_t)\left(\frac{\mu_t(1+\mu_t)}{\sigma_t^2} - 1\right) \quad and \quad \alpha_t = \frac{\mu_t \beta_t}{1-\mu_t}$$

s is a random variable of solar irradiance (kW/m^2). μ_t, σ_t are the mean and standard deviation.

TABLE 1. Specifications of 220W Solar Panel.

Parameter	Value
Maximum Power point Voltage, V_{MPPT}	28.36 V
Maximum Power point Current, I_{MPPT}	7.76 A
Open circuit Voltage, V_{OC}	36.96 V
Short Circuit current, I_{SC}	8.38 A
Nominal Operating Temperature, N_{OT}	43°C
Ambient Temperature, T_A	30.76°C
Voltage Temperature Coefficient, K_v	0.1278 V/°C
Current Temperature Coefficient, K_i	0.00545 A/°C

The output power expected from the solar panel is given by

$$P(s) = P_o(s) * f_p(s) \tag{14}$$

where, $P_o(s), f_p(s)$ are power output and probability distribution of solar irradiance.

The total power output from a solar panel for a specified time is

$$TP = \int_0^1 P_o(s) * f_p(s) ds \tag{15}$$

while

$$P_o(s) = N * FF * V_y * I_y \tag{16}$$

The PV module characteristics can be obtained by

$$FF = \frac{V_{MPPT} * I_{MPPT}}{V_{OC} * I_{SC}} \tag{17}$$

$$V_y = V_{oc} - K_v * T_{cy} \tag{18}$$

$$I_y = s\,[I_{sc} + K_i(T_{cy} - 25)] \tag{19}$$

$$T_{cy} = T_A + s\left(\frac{N_{OT} - 20}{0.8}\right) \tag{20}$$

where FF is the Fill Factor. The specifications of the solar panel are given in Table 1.

B. WIND ENERGY SYSTEM MODELING

Wind energy is a process of generating electricity from wind turbines. The wind energy is intermittent due to the probabilistic nature of wind. For estimating the future output of wind energy, stochastic nature is characterized using weibull distribution function. The preliminaries for estimating the wind output are the historical data of chosen location and rating of the wind turbine.

Probability of wind speed distribution is given by

$$f_v(v,t) = \frac{k_t}{c_t}\left(\frac{v_t}{c_t}\right)^{k_t - 1} . \exp\left(-\left(\frac{v_t}{c_t}\right)^{k_t}\right) \quad \forall \begin{cases} c_t > 1 \\ k_t > 0 \end{cases} \tag{21}$$

where

$$k_t = \left(\frac{\sigma_{vt}}{\mu_{vt}}\right)^{-1.086} \tag{22}$$

TABLE 2. Specifications of Wind Turbine.

Parameter	Value
Cut in Speed	3.5 m/s
Cut out Speed	25 m/s
Rated Speed	15 m/s
Hub Height	90 m
Power Rating	3 MW

$$c_t = \frac{\mu_{vt}}{\Gamma\left(1 + {}^1/_{k_t}\right)} \tag{23}$$

For a designed wind turbine, the power output corresponding to wind speed is given by

$$P_{wk,t} = \int_{v=1}^{N_v} P_{wr} * f_v(v,t)\, dv \tag{24}$$

where

$$P_{wr} = \begin{cases} 0 & v < v_{in} \text{ or } v > v_{out} \\ (a * v^3 + b * P_r) & v_{in} \le v \le v_r \\ P_r & v_r \le v \le v_{out} \end{cases} \tag{25}$$

where

$$a = \frac{P_r}{v_r^3 - v_{in}^3} \text{ and } b = \frac{v_{in}^3}{v_r^3 - v_{in}^3}$$

Here $v, v_r, v_{in}, v_{out}, P_r, N_v$ represents the wind speed, rated, cut-in, cut-out speeds, rated power of wind turbine and Number of states in wind speed respectively. The specifications of considered wind turbine are given in 2.

C. PROPOSED SMART STRATEGY FOR CHARGING THE CEVs

Generally, the EV users tend to charge their vehicles immediately after they return home. But this method may not be beneficial. This method can lead to high power loss, dip in voltage profile and may also lead to mal-operation in the network due to congestion. This method is named as Dumb charging method. It is always beneficial to charge the EVs (V2G) during off-peak hours and supply power to the grid (G2V) during peak hours. So, the EVs scheduling strategy is formulated in such a way to ensure the priority-based demand sensitive charging and discharging of EVs. This method is called as Smart Charging Method. This model ensures effective load management in such a way that stable voltage profile and minimal power loss are achieved. In this method, the utility and EV users will have a mutual interaction about the system demand and further strategy on improving the system performance is implemented. The methodology for scheduling considers Peak to Average Ratio (PAR) of system load demand. Generally, the PAR is defined as the ratio of peak demand to average demand of the system. If the PAR of the system is high, then it is required to operate the generators with high fuel cost. Thereby, the overall cost for generation scheduling will be increased.

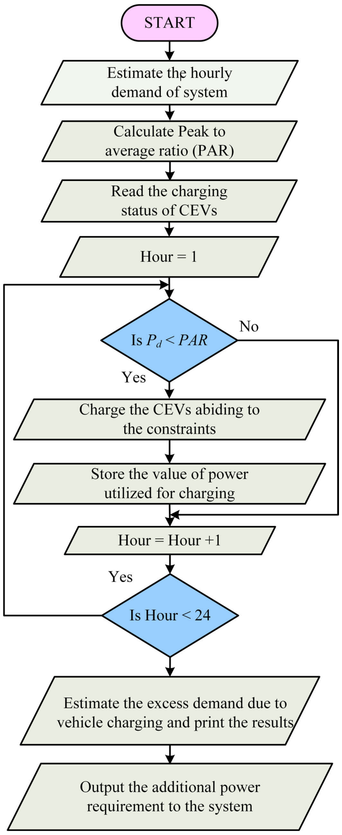

FIGURE 1. Smart charging strategy for charging the CEVs.

The main objective of scheduling EVs is minimizing PAR, which is represented as follows

$$PAR = \frac{P_{d,peak}}{P_{d,mean}} \tag{26}$$

It is very important to consider two constraints here. The EVs scheduled can never be negative and also number of EVs to be allotted at new time step cannot be greater than number of EVs at initial step.

$$\sum_{t=1}^{N} EV_{pit} \leq EV_T \tag{27}$$

where, EV_{pit} is the number of EVs of type P to be shifted from i^{th} hour to t^{th} hour and EV_T is the total number of EVs available for scheduling. The flowchart of EVs scheduling is shown in Fig 1.

D. IMPROVED MOTH-FLAME OPTIMIZATION

Moth-Flame is a new optimization technique, proposed by Seyedali Mirjalili [48] in 2015 for solving higher order multi objective problems. An improved moth flame algorithm for solving optimal power flow problem is presented in [49]. Moths basically belong to butterfly's family. These insects have a special navigation method named as transverse orientation. Moths take off in a straight line for longer distances by maintaining a certain angle with moon [48]. The

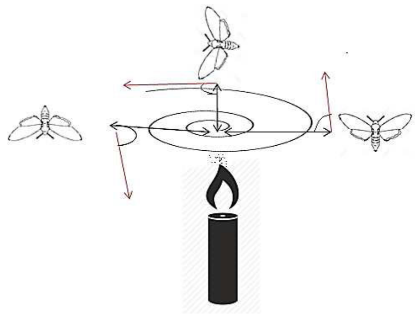

FIGURE 2. Spiral Flying Path of Moths towards artificial light.

transverse orientation is helpful only when the distance is very large. Generally, these Moths travel around the artificial lights to converge towards light. The convergence towards artificial light is as shown in Fig 2. The considered behavior is mathematically formulated as an optimization technique for problem solving. In this optimization, moths correspond to candidate solutions and their position in free space corresponds to problem variables. The movement of moths is multi-dimensional, since it is a population-based optimization methodology. Both moths and flames correspond to individual solutions in the space. The actual search agents are moths whereas the flames are the finest positions obtained by moths. The implemented mechanism helps in saving all the better solutions without missing them in between. Although moths and flames are individual solutions the way of treating them differs in each iteration. A logarithmic spiral is used for updating the positions around the flame which helps in a guaranteed exploration and exploitation.

The steps involved for implementation of IMFO are as follows.

Step 1: Initialize the number of moths $X = (X_1, X_2, \ldots X_N)^T$, where each moth represents i^{th} unit power generation. Update flames, dimension, lower bound and upper bound of all variables.

Step 2: Create two matrices with a size of p x v, for positions of moths (M) and Positions of flames (F) respectively. They are represented in equations 28 and 29.

$$M = \begin{bmatrix} m_{1,1} & m_{1,2} & \cdots & \cdots & m_{1,v} \\ m_{2,1} & m_{2,2} & \cdots & \cdots & m_{2,v} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ m_{p,1} & m_{p,2} & \cdots & \cdots & m_{p,v} \end{bmatrix} \tag{28}$$

$$F = \begin{bmatrix} F_{1,1} & F_{1,2} & \cdots & \cdots & F_{1,v} \\ F_{2,1} & F_{2,2} & \cdots & \cdots & F_{2,v} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ F_{p,1} & F_{p,2} & \cdots & \cdots & F_{p,v} \end{bmatrix} \tag{29}$$

Step 3: Assume two arrays for storing corresponding fitness values for the moths (FM), as well as flames (FF). They are represented in equations 30 and 31.

$$FM = \begin{bmatrix} FM_1 \\ FM_2 \\ \vdots \\ FM_n \end{bmatrix} \quad (30)$$

$$FF = \begin{bmatrix} FF_1 \\ FF_2 \\ \vdots \\ FF_n \end{bmatrix} \quad (31)$$

Step 4: A spiral flying path for the moths is created around the light, is modeled using a logarithmic spiral and is given by

$$M_i = S(M_i, F_j) = D_i.e^{bt}.\cos(2\pi t) + F_j \quad (32)$$

whereas $D_i = |F_j - M_i|$ is the distance between the i^{th} moth and j^{th} flame and t is rand [-1, 1].

Step 5: Using adaptive mechanism, the number of flames is reduced with increase in the number of iterations. The equation for updating flame number is given by

$$FN = round\left(N - l * \frac{N-1}{T}\right) \quad (33)$$

whereas l, N and T are the iteration number, maximum flames and total number of iterations respectively.

Step 6: Update the Moth Positions using equation 32.

1) IMPROVED MOTH FLAME OPTIMIZATION

Now, random walk-based probability distribution is implemented to bring the positions out of local optimum. The random walk distribution equation is given by

$$X_{t+1} = X_t + rnd(d) \times X_t \quad (34)$$

where

$$rnd(d) = 0.01 \times \frac{r1 \times \sigma}{|r_2|^{\frac{1}{\beta}}} \quad (35)$$

$r1$ and $r2$ are the random numbers in [0, 1] and β is a constant and σ is given by

$$\sigma = \left(\frac{\Gamma(1+\beta) \times \sin(\frac{\pi\beta}{2})}{\Gamma(\frac{1+\beta}{2}) \times \beta \times 2^{\left(\frac{\beta-1}{2}\right)}} \right)^{\frac{1}{\beta}} \quad (36)$$

After the termination of iterations, the best moth is given back as the finest estimate.

2) IMPLEMENTATION OF IMPROVED MOTH FLAME ALGORITHM FOR GENERATION SCHEDULING PROBLEM

The generation scheduling problem requires to solve the quadratic cost function in association with various set of constraints. The methodology for this problem is implemented using IMFO method. The flow chart of IMFO method for generation scheduling in the presence of CEVs and RES is shown in Fig. 3. The state of charge of CEVs is obtained from the smart charging method for each interval considering the overall system demand and PAR of the system. The output of solar and wind resources is estimated using beta and Weibull probability density function considering the historic data of the site. So, the inputs for IMFO algorithm are the state of charge of CEVs participating in generation scheduling and the output from the solar & wind resources during the same hour. In addition to this, it also requires the constraints of thermal generators, capacity limits of solar & wind sources and power limits of CEVs. Considering all the inputs and constraints, it is required to initialize the population, control variable limits and maximum iterations.

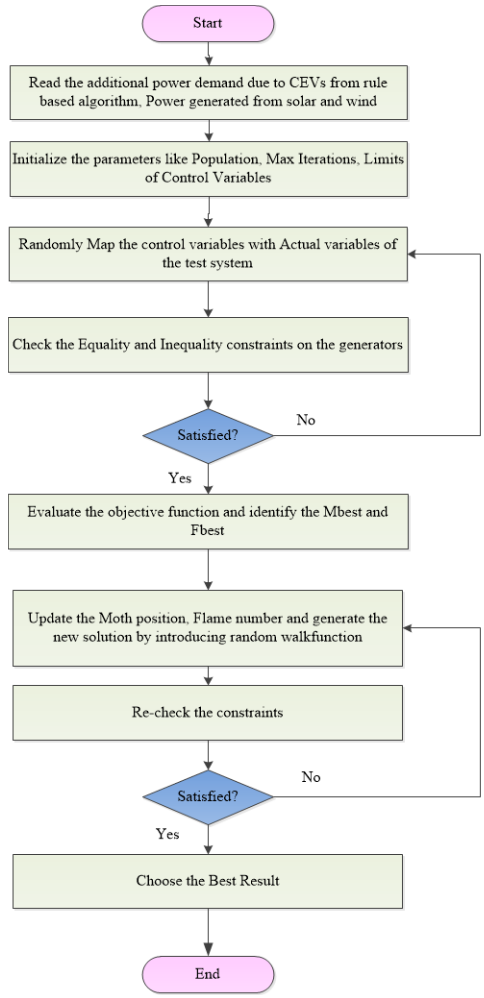

FIGURE 3. Flow chart of Improved Moth Flame optimization.

IV. RESULTS AND DISCUSSION

First, SED is implemented on 4 different test systems without considering renewable energy resources and electric vehicles to prove the superiority of IMFO algorithm. Next SED and DED are implemented on a real time south Indian test system considering the seasonal variation in RES. Further, a smart scheduling strategy for charging the CEVs is proposed and analyzed their impact on DED.The entire analyses were

TABLE 3. Dispatch of 6 generator system considering Transmission loss.

Gen	Dispatch (MW)	Pmin (MW)	Pmax (MW)
P1	434.5764	100	500
P2	175.8422	50	200
P3	276.1471	80	300
P4	113.6267	50	150
P5	160.7526	50	200
P6	113.2089	50	120
PL	11.1539 MW		

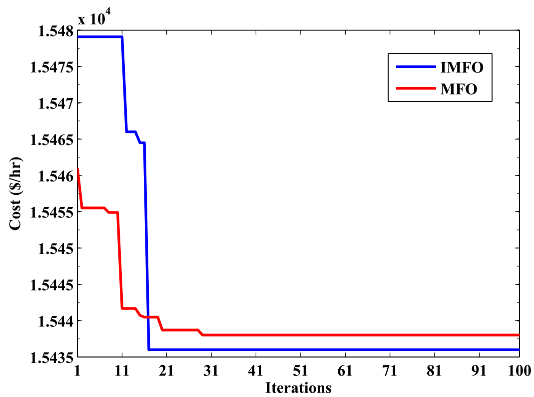

FIGURE 4. Convergence curve for 6 generator system.

performed in MATLAB 2018b on a PC with 8gb RAM, i5 processor.

A. SED WITHOUT CONSIDERING RES

SED is implemented on 4 different test systems using proposed IMFO method without violating the operating constraints. The obtained results are compared with existing MFO and other recent methods available in literature.

1) SIX GENERATOR SYSTEM

In this case, six generator system (IEEE 30 bus system) is considered. Data for this system is obtained from [50]. The objective function shown in equation 1 is solved using IMFO with constraints stated in Equations 5,6,7,8. The results obtained for this case are given in Table 3 and 4. SED of 6 generators is given Table 3 and is observed that the generation is within the bounds and the power loss is minimal. While incorporating valve point loading into the system, there is a chance that the solution falls into local minima. So, various metrics like minimum, maximum and mean cost, standard deviation are compared with other methods and are given in Table 4. This method delivers the optimal solution in less time compared to many methods. The method requires 2000 evaluations which indicate least computational effort than other methods. The power loss computed using this method is 12.932 MW, which is the least compared to all other methods reported in Table 4. The convergence curves of proposed IMFO and MFO is plotted for cost minimization objective and is shown in Fig 4. A smooth convergence curve

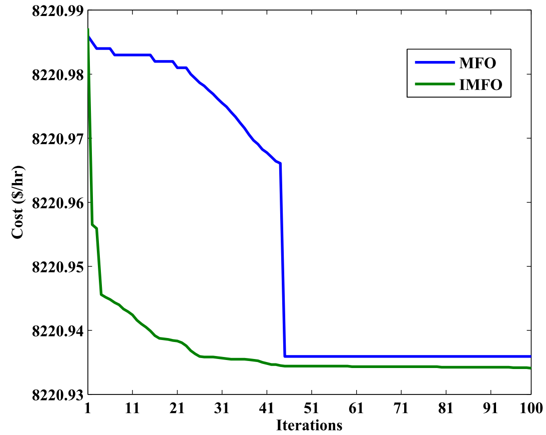

FIGURE 5. Convergence curve obtained for 3 generator system.

is observed in this case which shows the efficiency of the method in delivering optimal solution.

2) THREE GENERATOR SYSTEM

Here, the case study is carried out in a 3-generator test system with valve point effect for a demand of 850 MW. The objective function represented in equation 2 is solved using IMFO with constraints stated in equations 5, 7 and 8. The cost coefficients for this system is available in [14]. The dispatch schedule obtained for the case is P1=349.4662 MW, P2=400 MW, P3=100.5338 MW, which indicates that the generators are scheduled between the prescribed minimum and maximum limits. The cost obtained for the dispatch is 8220.93 $\$/hr$ which is less compared to other methods. Comparison of various metrics obtained by different optimization methods for 50 trails is given in Table 5.

IMFO gives an approximately same cost for all the trails and hence the standard deviation is very low. The time for converging is 0.06 sec for 100 iterations which is reasonable. Though f-CPSO [60] has a short run time, the cost prevailed is considerably high compared to other methods. IMFO offers the solution with 1500 evaluations. From the above compared metrics, it can be said that IMFO gives enhanced results in short computational time. Fig. 5 represents the convergence curve obtained for three generator test system using existing MFO and proposed IMFO methods. The MFO method converges only after 45 iterations to achieve the minimal cost whereas the IMFO method converges to nearly an optimal value by 21^{st} iterations itself. Also, the cost obtained using IMFO method is better than the MFO method.

3) THIRTEEN GENERATOR SYSTEM

A case study is carried out on 13 generator system for which the demand is 1800 MW. The data for this system is obtained from [14]. The objective function represented in Eqn 2 is solved using IMFO with constraints stated in equations 5 - 8 and the results are given in Tables 6 and 7. It is observed that the generators dispatch is within the operating limits as well as the POZ constraint is also satisfied. The

TABLE 4. Validation of various metrics for 6 generator test system.

Method	Min Cost	Mean Cost	Max Cost	Std Dev	Time (sec)	Eval
IMFO	15436.00	15442.88	15459.39	0.3632	0.942	2000
MFO	15449.99	15450.48	15453.45	0.47	1.05	3000
DHS [51]	15449.9	15449.93	15449.99	14.86	-	3000
PSO [50]	15450	15454	15492	-	-	20000
MTS [52]	15450.06	15450.06	15451.17	0.9287	1.29	20000
GA [50]	15459	15469	15469	0.2528	7.58	20000
NPSO-LRS [53]	15450	15452	15454	-	-	100000
CBA [54]	15450.24	15454.76	15518.66	2.965	0.704	-
MABC [55]	15449.9	15449.9	15449.9	6.04	0.62	-
GA [56]	15451.66	15469.21	15519.87	-	-	-
TS [52]	15454.89	15472.56	15454.56	13.7195	20.55	-
SA [52]	15461.1	15488.98	15545.5	28.3678	50.36	-

TABLE 5. Validation of various metrics obtained by IMFO optimization.

Method	Min Cost	Mean Cost	Max Cost	Std Dev	Time (sec)	Eval
IMFO	8220.93	8220.97	8220.97	0.0084	0.06	1500
IAEDP [14]	8220.93	8224.51	8245.18	5.0812	0.18	1500
CE-SQP [57]	8234.07	8234.07	-	-	-	-
CTLBO [58]	8234.07	8234.08	8234.18	0.025	-	-
GA-API [56]	8234.07	-	-	-	-	-
SDE [59]	8234.07	-	-	-	-	-
f-CPSO [60]	8234.07	-	-	-	0.02	6000

TABLE 6. Real power dispatch for 13 generator system.

Gen	Dispatch (MW)	Pmin (MW)	Pmax (MW)
P1	605.61	0	680
P2	209.89	0	360
P3	271.89	0	360
P4	60	60	180
P5	103.43	60	180
P6	133.15	60	180
P7	61.79	60	180
P8	60	60	180
P9	104.28	60	180
P10	40.00	40	120
P11	40.00	40	120
P12	55.00	55	120
P13	55.00	55	120

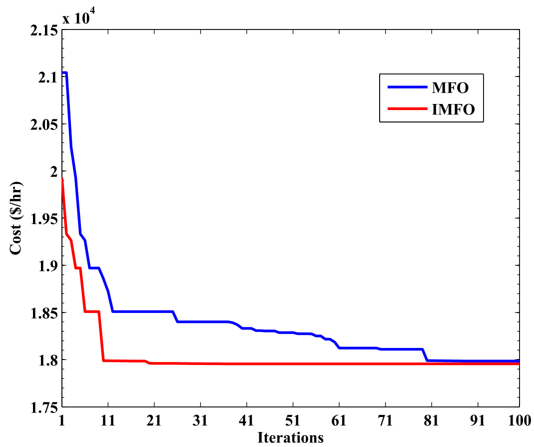

FIGURE 6. Convergence curve obtained for 13 generator system.

minimum cost achieved for this case is 17955.41 $\$/hr$ which is less compared with other recent methods.

Further SED is repeated for 50 times and the comparison of obtained generation cost is made with other recent methods in Table 7, which indicates that IMFO gives the better cost in very short computational time. It requires a smaller number of evaluations for solving this problem which indirectly aids in faster convergence. The convergence curves of IMFO and MFO optimization techniques obtained for 13 generator test system is given in Fig 6. This method converges to optimal solution in less iteration. It is observed that the minimal cost is obtained at 15^{th} iteration and is settled at this point without a prominent deviation.

4) SEVENTEEN GENERATOR TEST SYSTEM (REAL TIME SOUTH INDIAN 86 BUS TEST SYSTEM)

The fourth test system considered for the study is a practical network in southern part of India, which consists of 17 generators, 86 buses and 131 transmission lines which signifies the complexity of the network. The data for the test system is obtained from [64]. The demand for the system is 1796.3 MW for the particular hour of study. Constraints such as up reserve, down reserve and transmission loss are considered while solving the problem. From the obtained generation schedule given in Table 8, it can be inferred that generators operate in specified limits for satisfying the demand and power loss. Minimum cost and power loss acquired in satisfying the demand are 355439 $\$/hr$ and 48.12 MW.

5) SUMMARY

From the 4 case studies performed in the above sub-sections, it is clearly evident that IMFO method is efficient in handling various constraints such as POZ, valve point and other

TABLE 7. Validation of various metrics by IMFO for 13 generator system.

Method	Min Cost	Mean Cost	Max Cost	Std Dev	Time (sec)	Eval
IMFO	17955.41	17970.45	17985.95	11.612	0.166	3000
IAEDP [14]	17961.43	17980.19	18052.32	21.666	0.876	25000
CE-SQP [57]	17963.73	17967.94	-	-	-	-
HAAA [61]	17963.83	17967.84	17963.93	0.018	-	-
CTLBO [58]	17972.81	18013.38	18159.34	43.2	-	-
SDE [59]	17963.82	17963.97	17964.09	-	-	-
CBA [54]	17963.83	17965.49	17995.22	6.847	0.97	-
SSA [62]	17963.77	17963.88	-	0.0185	-	-
MABC [55]	17963.83	17962.83	17963.83	0.00026	-	-
HCRO-DE [63]	17960.38	17960.59	17961.04	0.069	4.1	-
DPO [9]	17963.82	17963.83	17963.83	-	-	-

TABLE 8. SED on Real Time South Indian 86 bus test system.

Gen	IMFO	MFO	Pmin	Pmax
P1 (MW)	104.69	106.00	20	210
P2 (MW)	103.22	103.97	20	210
P3 (MW)	75.03	74.51	20	210
P4 (MW)	87.77	87.92	20	210
P5 (MW)	158.00	158.43	20	210
P6 (MW)	159.18	159.98	20	210
P7 (MW)	157.59	154.12	20	210
P8 (MW)	60.00	60.00	10	60
P9 (MW)	60.00	60.00	10	60
P10 (MW)	100.59	98.94	10	110
P11 (MW)	99.07	99.75	10	110
P12 (MW)	86.16	85.46	10	110
P13 (MW)	119.99	118.01	20	210
P14 (MW)	116.50	117.04	20	210
P15 (MW)	117.17	118.02	20	210
P16 (MW)	119.92	120.88	20	210
P17 (MW)	119.59	121.47	20	210
PL (MW)	48.12	48.19	-	-
FC ($\$/hr$)	355439.99	355447.94	-	-

constraints for various sized complex test systems. Therefore, all the further studies performed in this work are carried-out using IMFO method.

B. SED IN SOUTH INDIAN 86 BUS SYSTEM INCORPORATING RES

In this section, SED incorporating solar and wind resources acting independently as well as jointly are performed on a real time south Indian 86 bus test system.

1) SED IN SOUTH INDIAN 86 BUS SYSTEM INCORPORATING SOLAR ENERGY

Vellore area ($12.9165°N$, $79.1325°E$), Tamilnadu, India has abundant solar irradiance throughout the year. The irradiance data of a year for this region is considered for modeling of solar farm [65]. Due to distinct variations of weather conditions, the available data in the study period is segregated into 4 seasons namely summer (May-July), autumn (August-October), winter (November-January) and spring (February-April). These seasons are again divided in to 24 segments which correspond to hours of the day. Beta distribution function [66] is used for developing the probabilistic model of

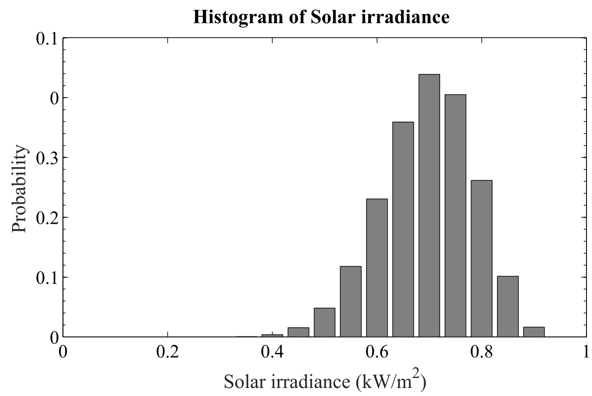

FIGURE 7. Beta PDF for solar irradiance for a typical day in winter season.

solar farm. The specifications of the PV panel are taken from [67].

In this study, modified South Indian 86 bus test system incorporated with solar farm is considered for the analysis. To control the penetration level of solar power in a system, a parameter called penetration level constraint is introduced in the problem. This parameter is assumed as 30% of the system demand. A 540 MW Solar farm which corresponds to 30 percent of the system demand is incorporated at bus number 8 of the test system.

The output from solar panel is determined during the middle of the day in each season i.e (12^{th} hour). The histogram and expected power output for the same during winter season are given in Fig's 7 and 8. The solar power output during the said interval is 314.736 MW.

For a uniform load demand of 1796.3MW, SED incorporating solar farm is implemented considering seasonal changes in solar power output and a feed in tariff of 40 $/MW. SED with and without considering solar farm has been analyzed and the results are presented in Table 9. From the table 9, it is evident that the operating cost and power loss will be reduced with high penetration of solar energy.

2) SED IN SOUTH INDIAN 86 BUS SYSTEM INCORPORATING WIND ENERGY

Kayathar area ($8.9470°N$, $77.7738°E$), Tamilnadu, India has abundant wind throughout the year. The wind speed data of

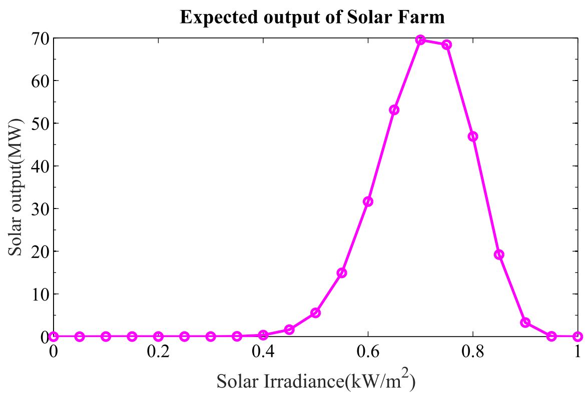

FIGURE 8. Solar farm output at middle of the day.

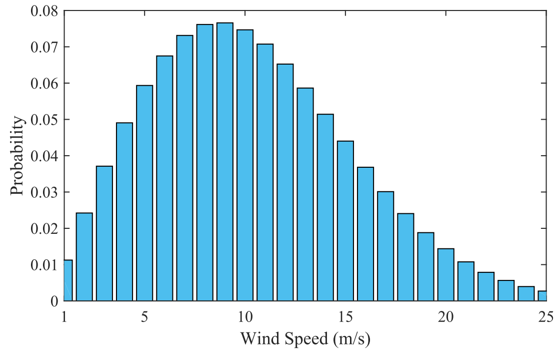

FIGURE 9. Weibull PDF for wind speed at 12^{th} hour of the day in summer season.

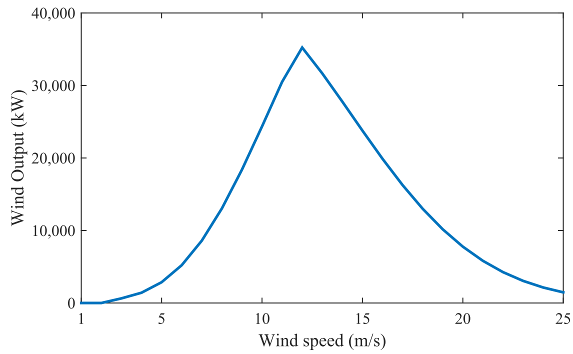

FIGURE 10. Wind farm output at middle of the day.

TABLE 9. SED considering solar farm on real time 86 bus system.

Dispatch	No Solar	Summer	Autumn	Winter	Spring
P1 (MW)	105.93	80.63	82.13	84.63	82.48
P2 (MW)	104.58	78.29	80.63	83.02	80.18
P3 (MW)	74.24	60.81	61.93	62.79	61.44
P4 (MW)	88.32	69.47	70.81	72.74	70.16
P5 (MW)	155.13	119.85	122.80	126.57	122.08
P6 (MW)	159.16	119.98	122.71	125.82	122.67
P7 (MW)	156.63	120.11	122.95	126.40	122.45
P8 (MW)	60.00	60.00	60.00	60.00	60.00
P9 (MW)	60.00	60.00	60.00	60.00	60.00
P10 (MW)	99.63	74.56	76.69	78.92	76.42
P11 (MW)	99.54	74.65	76.41	78.79	76.16
P12 (MW)	85.75	65.56	67.41	69.44	67.55
P13 (MW)	119.40	92.31	94.39	97.38	94.19
P14 (MW)	118.43	91.28	92.95	96.07	93.94
P15 (MW)	118.07	91.61	93.51	96.05	93.38
P16 (MW)	119.84	93.09	95.38	97.42	95.31
P17 (MW)	119.90	93.45	95.61	97.99	94.74
PT (MW)	1844.54	1445.65	1476.29	1514.04	1473.16
PS (MW)	0.00	380.25	350.90	314.74	353.87
PG (MW)	1844.54	1825.26	1827.19	1828.76	1827.03
PL (MW)	48.24	29.61	30.88	32.47	30.72
TC ($/hr)	355439.99	230144	238767	249630	237888

TABLE 10. Profit analysis integrating wind generation in south Indian 86 bus system.

Dispatch	No Wind	Summer	Autumn	Winter	Spring
P1 (MW)	105.93	84.95	91.18	103.12	102.77
P2 (MW)	104.58	82.38	88.62	100.96	100.01
P3 (MW)	74.24	63.24	66.53	73.02	72.68
P4 (MW)	88.32	72.09	76.39	86.44	85.58
P5 (MW)	155.13	125.81	135.64	153.60	152.83
P6 (MW)	159.16	126.09	135.20	154.68	151.44
P7 (MW)	156.63	124.23	135.49	153.55	152.38
P8 (MW)	60.00	60.00	60.00	60.00	60.00
P9 (MW)	60.00	60.00	60.00	60.00	60.00
P10 (MW)	99.63	78.61	84.77	97.11	95.62
P11 (MW)	99.54	78.10	84.28	97.19	96.07
P12 (MW)	85.75	68.96	73.97	83.62	82.88
P13 (MW)	119.40	95.61	103.33	115.51	115.23
P14 (MW)	118.43	95.75	101.86	114.51	113.54
P15 (MW)	118.07	94.69	102.16	114.19	113.19
P16 (MW)	119.84	97.52	104.52	116.83	116.84
P17 (MW)	119.90	97.65	104.53	116.86	116.37
PT (MW)	1844.54	1505.69	1608.48	1801.19	1787.41
PW (MW)	0.00	322.74	224.46	40.86	54.11
PG (MW)	1844.54	1828.43	1832.94	1842.05	1841.52
PL (MW)	48.24	32.13	36.64	45.75	45.22
TC ($/hr)	355440	247207	277901	340535	335786

a year for this region is considered for modeling of wind farm [65]. The study period is divided into 4 seasons and Weibull distribution function [45] is used for developing the probabilistic model of wind farm.

In this study, modified South Indian 86 bus test system incorporated with Wind farm is considered for the analysis. A 540 MW Wind farm which corresponds to 30 percent of the system demand is incorporated at bus number 10 of the test system.

The output from wind farm is determined during the middle of the day in each season i.e (12^{th} hour). The histogram and expected power output for the same during summer season are given in Fig's 9 and 10. The wind power output during the said interval is 322.74 MW.

SED incorporating wind farm is performed on real time 86 bus system with a load demand of 1796.3 MW. The seasonal changes in wind power output are included and a uniform feed in tariff of 40 $/MW is considered for the analysis. The results for cases with and without incorporation of wind farm are presented in Table 10. It can be noticed that the wind power output is highly variable. So, the thermal generation also gets continuously varied from season to season noticeably. This seasonal change in wind power output heads to significant change in operating cost of

TABLE 11. Analysis on South Indian 86 bus system with solar and wind farms.

Dispatch	No Ren	Summer	Autumn	Winter	Spring
P1 (MW)	105.93	81.90	85.48	91.05	88.39
P2 (MW)	104.58	79.86	83.27	89.34	87.40
P3 (MW)	74.24	61.09	62.97	66.45	65.25
P4 (MW)	88.32	69.97	72.79	77.36	75.61
P5 (MW)	155.13	122.13	127.27	136.37	132.28
P6 (MW)	159.16	121.62	126.49	135.04	132.70
P7 (MW)	156.63	122.13	126.72	134.92	131.67
P8 (MW)	60.00	60.00	60.00	60.00	60.00
P9 (MW)	60.00	60.00	60.00	60.00	60.00
P10 (MW)	99.63	76.05	79.67	84.38	82.57
P11 (MW)	99.54	75.57	79.09	84.73	83.02
P12 (MW)	85.75	67.02	69.54	73.53	72.48
P13 (MW)	119.40	93.61	98.25	104.86	100.89
P14 (MW)	118.43	92.54	96.93	101.31	100.40
P15 (MW)	118.07	93.08	96.07	101.27	100.70
P16 (MW)	119.84	94.68	97.49	103.61	102.18
P17 (MW)	119.90	94.29	98.50	105.28	102.13
PS (MW)	0.00	253.51	233.64	209.84	235.91
PW (MW)	0.00	107.58	74.82	13.62	18.04
PG (MW)	1844.54	1465.53	1520.54	1609.50	1577.67
PL (MW)	48.24	30.32	32.70	36.67	35.32
TC ($/hr)	355440	235753	251543	278229	268487

thermal generating units. The cost of generation is reduced by 30.45% in summer season which is remarkably high. The operating cost is reduced in other seasons also. The power loss is decreased to a maximum of 32.13 MW in summer season from a base value of 48.24 MW. It is also observed that integration of wind power at bus number 10 helps in simultaneous reduction of thermal generation, power loss and operating cost of the system.

3) SED IN SOUTH INDIAN 86 BUS SYSTEM INCORPORATING BOTH SOLAR AND WIND FARMS

In this study, South Indian 86 bus system incorporating solar and wind farms all together is considered for the study. The solar farm is located at bus number 85 and wind farm at bus number 10 respectively. The installed capacities of the plants are chosen in such a way that the output from both the farms will not exceed 30 percent of the base demand of the test system. The installed capacities of solar and wind farms are 360 MW and 180 MW respectively. The analysis is performed at 12^{th} hour of the day. It is observed that the output from the solar farm is high compared to wind output for the considered interval. Here a feed on tariff of 40 $/MW is considered for purchasing power from renewable power producers.

SED incorporating solar and wind farms is performed on real time south Indian 86 bus system having a demand of 1796.3 MW. Considering the seasonal variations from solar and wind energy resources, the analysis is carried out and obtained results are furnished in Table 9. For instance, in winter season the expected output from the solar and wind energy resources are 65.53% and 10.02% respectively. It can be inferred that the output from the wind energy resource is very low for the considered interval. Simultaneous allocation of solar and wind resources in the system helps in reducing

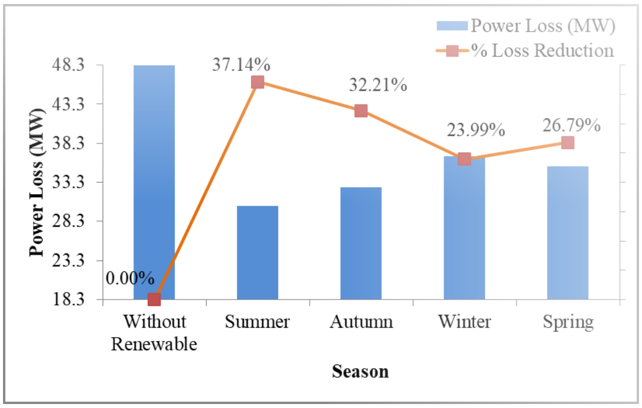

FIGURE 11. Comparison of power loss in South Indian 86 bus system.

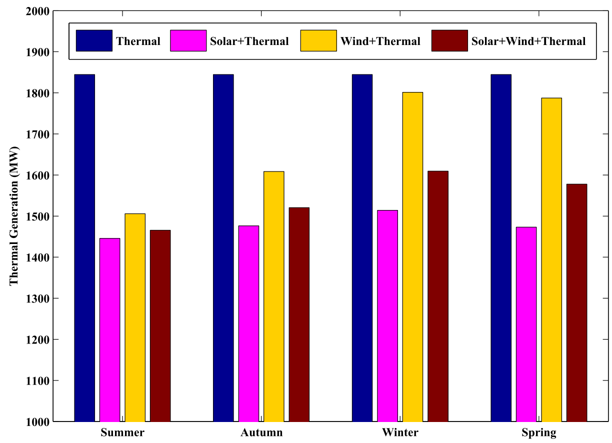

FIGURE 12. Comparison of reduction in thermal generation in various seasons.

TABLE 12. Comparison of on power loss and operating cost in real time 86 bus system.

Method	P_L (MW)	FC ($/hr)
IMFO	1139.98	8438048.00
MFO	1154.41	8438914.34
ADFA [45]	1145.50	8,438,737.34
ABC [64]	1160.653	8,584,198.00

the power loss as well as operating cost of the system. The thermal power generation depends on output obtained from the renewable energy sources. If the output from these sources is high, dependency on thermal power generation is reduced. The comparison of power loss reduction for various seasons is shown in Fig 11. It is observed that the power loss has been significantly reduced to a minimum of 23.99% compared to base case. The maximum power loss reduction is observed in summer season for the considered time interval.

4) COMPARISON OF SED RESULTS WITH AND WITHOUT CONSIDERING RES IN REAL TIME 86 BUS SYSTEM

In this section, a comparison between optimal choices of two sources solar and wind is presented. The output power from solar and wind resources are not uniform throughout the

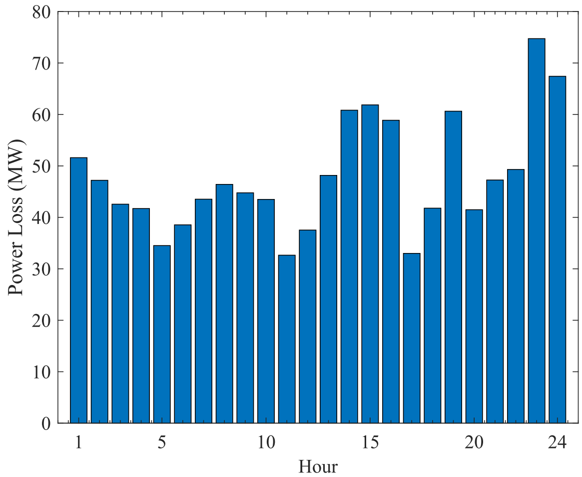

FIGURE 13. Power for each hour in real time South Indian 86 bus system.

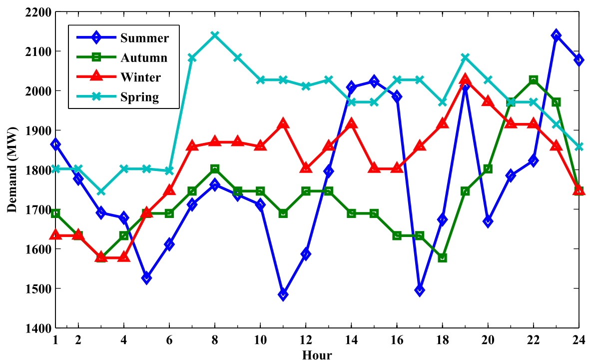

FIGURE 14. Typical Load curve of real time South Indian 86 bus system for various seasons.

year. For instance, consider the thermal generation utilization without and with renewable sources are shown in Fig 12. From the figure, it can be understood that usage of thermal generation is significantly reduced with incorporation of renewable energy sources. Whereas if we consider the case of renewable energy sources, for a given time interval the output from solar farm is high compared to wind farm. Further, if both the sources are simultaneously considered in a suitable proportion, the deficit from the wind farm can be overcome in the considered interval of time. It may be noted that in some other interval of time output from solar farm may be low compared with wind farm. In this regard, a suitable proportion of renewable energy sources in the system is very important and also it is more effective to use both solar and wind resources jointly rather than independently.

C. DED WITHOUT CONSIDERING RES AND CEVs

DED is implemented on real time South Indian 86 bus test system [64] using IMFO method. The power loss obtained for a typical day is shown in Fig 13. The simulated results are compared with other methods available in literature and shown in Table 12. From the results it can be understood that the proposed method is superior to existing methods.

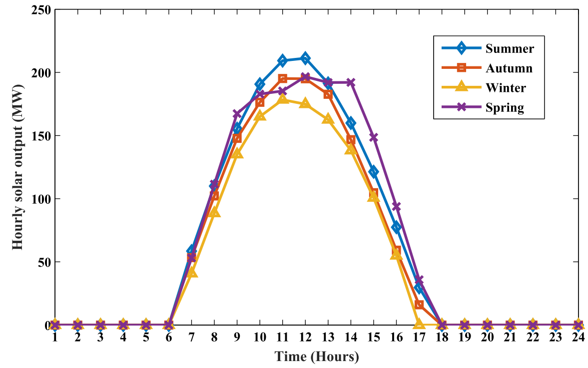

FIGURE 15. Hourly solar output estimated using beta distribution function.

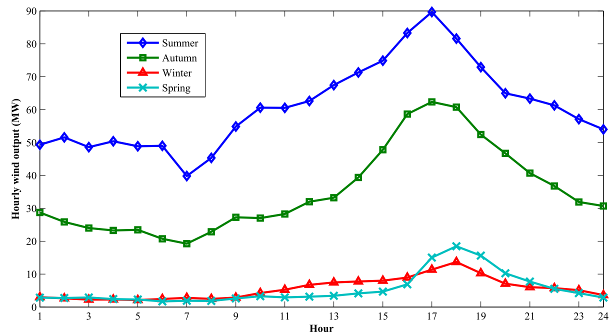

FIGURE 16. Hourly Wind output estimated using weibull distribution function.

TABLE 13. DED incorporating Solar and Wind resources in various seasons.

Dispatch	Summer	Autumn	Winter	Spring
PT (MW)	40641.24	40267.93	43290.72	46265.91
PS (MW)	1515.044	1379.236	1239.053	1559.038
PW (MW)	1463.187	844.1615	134.2796	129.5258
PG (MW)	43619.47	42491.33	44664.05	47954.47
PL (MW)	994.3682	965.6137	1110.145	1265.447
FT ($/day)	7407903	7239347	8228339	9272804
FS ($/day)	60601.76	55169.45	49562.12	62361.53
FW ($/day)	58527.48	33766.46	5371.182	5181.034
TC ($/day)	7527032.24	7328282.91	8283272.30	9340346.56

D. DED ON SOUTH INDIAN 86 BUS UTILITY CONSIDERING RES

DED is performed on real time South Indian 86 bus test system, without and with renewable power generation for a typical day in various seasons. The load curve representing seasonal variations is shown in Fig 14. Solar and wind resources are connected at bus 10 and bus 85 respectively. The expected hourly output from solar and wind resources is shown in Fig's 15 and 16 respectively.

DED is performed on south Indian 86 bus system considering the thermal and renewable power generation. The generation scheduling, fuel costs and power loss for a typical day in various seasons are given in Table 13. A comparison of percentage reduction in fuel cost and power loss after incorporating RES are given in Table 14. There is a significant

TABLE 14. Comparative analysis of Cost and power loss without and with renewable sources.

Season	Cost ($/day)			Loss (MW)		
	Without	With Ren	% reduction	Without	With Ren	% reduction
Summer	8439879.57	7527032.24	12.13	1150.37	994.368	15.69
Autumn	8023094.58	7328282.91	9.48	1082.72	965.614	12.13
Winter	8751582.42	8283272.30	5.65	1188.38	1110.15	7.05
Spring	10029891	9340346.56	7.38	1396.6	1265.45	10.36

reduction in operating cost as well as power loss, if RES is scheduled in conjunction with thermal generation. Further it is to be kept in mind that the output from these sources is subjective to weather conditions and there is a possibility of either increase or decrease in output compared to the expected values.

E. DED ON SOUTH INDIAN 86 BUS UTILITY CONSIDERING CEVs AND RES

In this section, the impact of CEVs on DED in presence of RES is studied in detail. The considered South Indian 86 bus test system is a heavily loaded network, which has a peak demand near to the thermal limits of transmission lines. The primary objective of this work is to allocate the additional demand due to CEVs at off peak hours so that the peak hour congestion is reduced.

The following assumptions are made to analyze the performance of the study.

- The CEVs considered in the study are primarily public transport vehicles which are used to ferry passengers from one location to the other. Therefore, it is assumed that the CEVs operate from 06.00 AM, 07.00 AM and 08.00 AM respectively in 3 groups.
- BYD k9 model e-buses (CEVs) are assumed to be operated in the study and each CEV will cover an average driving distance of 120 km (3 trips x 40 km) by the end of scheduled trip per day.
- Charging Station (CS) infrastructure available for charging these CEVs allows a maximum of 500 EVs to be charged in couple of hours. So, it requires a total of 6 hours per day to charge all CEVs.
- In order to facilitate charging for all the CEVs, each vehicle is allowed to charge only once per day (other than trip hours).
- It is also assumed that the system consists of a 3-way communication channel between the CEVs, CS and the power utility. This allows the CS to monitor various system parameters as well as the scheduled trip time. Further, it is also assumed that the data is transferred from one location to the other without any delay.

The specifications of considered CEV model are given in Table 15. The CEVs are charged in groups in 2 ways. An intelligent method to charge CEVs by considering the network demand. If the CEVs are charged immediately after completing their scheduled trips without considering the network demand, then the method is called as dumb charging method since it can lead to congestion during the peak hours as it will not refer to the system demand or any other parameters before scheduling. The other method is smart charging method which considers the system demand, CEVs SOC level and time left for next trip. This gives an appropriate time slot for each CEV to charge before it leaves for the trip. The allocation of CEV load with proposed smart and dumb charging method is shown in Fig 17. This method allocates the CEVs charging schedule from 2^{nd} hour to 7^{th} hour i.e. off-peak hours of the specified day. The dumb charging hours and smart charging hours of the CEVs are determined by the algorithm and the same is presented in Table 16.

TABLE 15. Specifications of BYD *k*9 model CEV (e-Bus).

Specification	Rating
Capacity of Battery	300 kWh
SOC min	0.2
SOC max	0.9
No of CEVs	1500
Avg Power consumption	1.56 kWh/km

TABLE 16. Time slots for allocating CEV load in various seasons.

Season	Dumb charging	Smart charging
Summer	19^{th} hour to 24^{th} hour	2^{nd} hour to 7^{th} hour
Autumn	19^{th} hour to 24^{th} hour	2^{nd} hour to 7^{th} hour
Winter	19^{th} hour to 24^{th} hour	1^{st} hour to 6^{th} hour
Spring	19^{th} hour to 24^{th} hour	1^{st} hour to 6^{th} hour

Further, DED is performed on South Indian 86 bus system considering the charging patterns obtained from dumb and smart charging methods. The results are presented in Tables 17 and 18. In Table 17, DED considering of RES and CEVs dumb charging pattern load is presented for 4 seasons. Later in Table 18, DED is performed with smart charging method. A comparison of both the studies indicate that smart charging method of CEVs contributes to reduction in power loss and generation cost.

Lastly, by comparing the data presented in Table 17 and 18 it can be understood that the there is a difference in the total generation cost for all the seasons as well as the power loss. The savings in operating cost per day in each season is shown in Fig 18. To make a comparison it can be said that the total cost of generation for the considered 4 seasonal days due to the adoption of dumb and smart charging methods is about 32.925 and 32.862 million $ respectively. Hence,

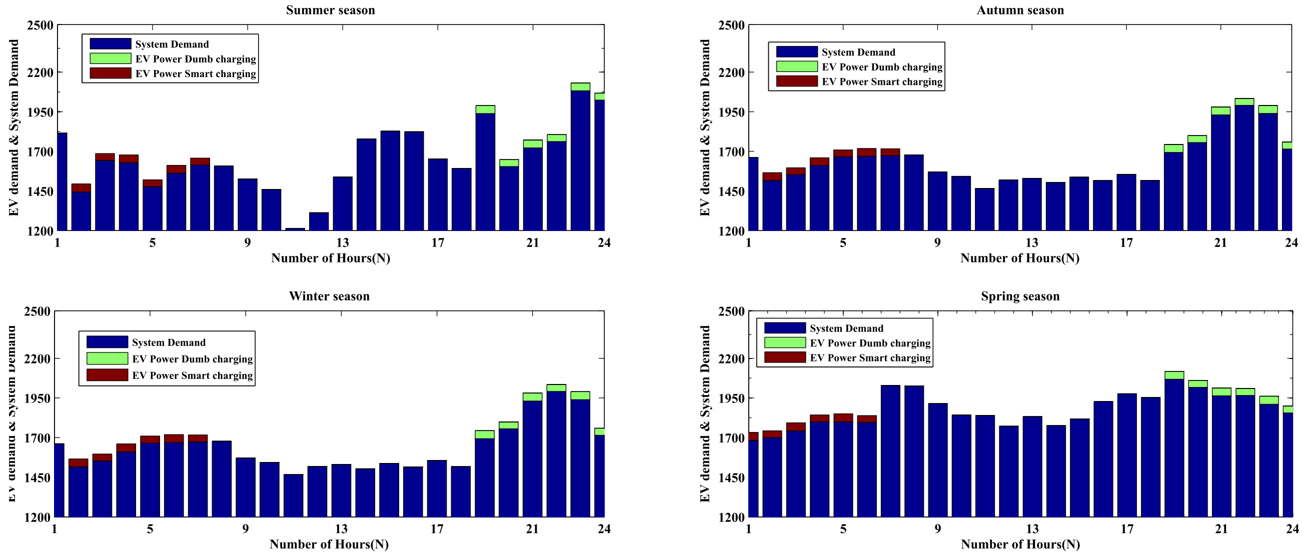

FIGURE 17. Dumb charging and Smart charging method of allocating CEVs load in various seasons.

TABLE 17. DED of south Indian 86 bus system with integration of RES and CEV by Dumb Charging.

Dispatch	Summer	Autumn	Winter	Spring
PT (MW)	40937.51	40564.62	43590.03	46569.01
PS (MW)	1515.044	1379.236	1239.053	1559.038
PW (MW)	1463.187	844.1615	134.2796	129.5258
PG (MW)	43619.47	42491.33	44664.05	47954.47
PD_{cev} (MW)	280.8	280.8	280.8	280.8
PL (MW)	1009.845	981.512	1128.649	1287.754
FT ($/day)	7518490	7346922	8339794	9389214
FS ($/day)	60601.76	55169.45	49562.12	62361.53
FW ($/day)	58527.48	33766.46	5371.182	5181.034
TC ($/day)	7637619.24	7435857.91	8394727.30	9456756.56

TABLE 18. DED of south Indian 86 bus system with integration of RES and CEV by Smart Charging.

Dispatch	Summer	Autumn	Winter	Spring
PT (MW)	40935.95	40561.59	43585.19	46561.13
PS (MW)	1515.044	1379.236	1239.053	1559.038
PW (MW)	1463.187	844.1615	134.2796	129.5258
PG (MW)	43619.47	42491.33	44664.05	47954.47
PD_{cev} (MW)	280.8	280.8	280.8	280.8
PL (MW)	1008.281	978.4756	1123.811	1279.875
FT ($/day)	7499121	7333694	8323555	9375099
FS ($/day)	60601.76	55169.45	49562.12	62361.53
FW ($/day)	58527.48	33766.46	5371.182	5181.034
TC ($/day)	7618250.24	7422629.9	8378488.3	9442641.56

it can be said that the reduction in the generation cost due to the implementation of smart charging method is about 62,951 $ for the considered 4 days, which is substantial. Also, by looking at the total power lost for 4 days it can be said that the lost power due to the implementation of dumb and smart charging methods is around 4408 MW and 4390 MW respectively. Therefore, it can be said that there is a reduction in the power loss due to the implementation of smart charging method and the same amounts to 18 MW which is once again interesting.

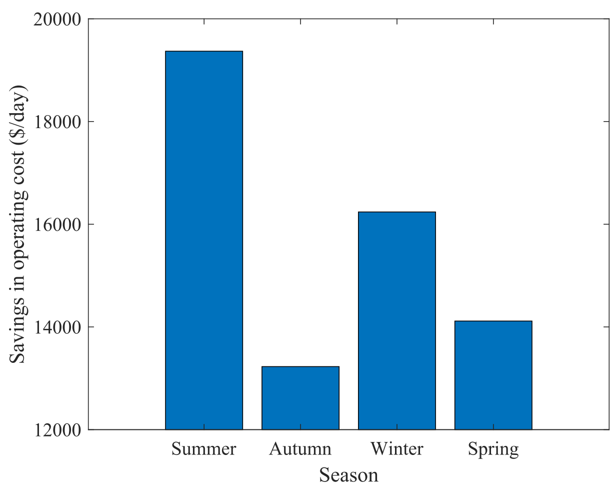

FIGURE 18. Saving in operating cost per day by Smart charging method of allocating CEVs.

V. CONCLUSION

In this article, a DED problem in presence of CEVs and RES is solved. Initially, Static ED without RES is performed on various test systems using IMFO technique and the results are compared with existing methods. Later SED and DED are performed on a real time south Indian test system considering the impact of solar and wind resources. The output from solar and wind resources is estimated for a desired location using probabilistic methods. The estimated solar and wind outputs are considered for generation scheduling along with the thermal power. Later DED is performed on a real time south Indian test system considering the dumb and smart charging pattern of CEVs as well as the RES. With the proposed coordinated charging strategy of CEVs and proper installation of RES, a significant reduction in the operating cost and power loss can be achieved. Further, the future scope of this work can be on developing suitable economic dispatch models considering the impact of different types of electric vehicles,different charging times and appropriate forecast models.

REFERENCES

[1] P. Aravindhababu and K. R. Nayar, "Economic dispatch based on optimal lambda using radial basis function network," *Int. J. Electr. Power Energy Syst.*, vol. 24, no. 7, pp. 551–556, Oct. 2002.

[2] J. Parikh and D. Chattopadhyay, "A multi-area linear programming approach for analysis of economic operation of the Indian power system," *IEEE Trans. Power Syst.*, vol. 11, no. 1, pp. 52–58, 1996.

[3] J.-Y. Fan and L. Zhang, "Real-time economic dispatch with line flow and emission constraints using quadratic programming," *IEEE Trans. Power Syst.*, vol. 13, no. 2, pp. 320–325, May 1998.

[4] J. C. Dodu, P. Martin, A. Merlin, and J. Pouget, "An optimal formulation and solution of short-range operating problems for a power system with flow constraints," *Proc. IEEE*, vol. 60, no. 1, pp. 54–63, 1972.

[5] H. Lu, P. Sriyanyong, Y. H. Song, and T. Dillon, "Experimental study of a new hybrid PSO with mutation for economic dispatch with non-smooth cost function," *Int. J. Electr. Power Energy Syst.*, vol. 32, no. 9, pp. 921–935, Nov. 2010.

[6] M. Basu and A. Chowdhury, "Cuckoo search algorithm for economic dispatch," *Energy*, vol. 60, pp. 99–108, Oct. 2013.

[7] B. Mandal, P. K. Roy, and S. Mandal, "Economic load dispatch using krill herd algorithm," *Int. J. Electr. Power Energy Syst.*, vol. 57, pp. 1–10, May 2014.

[8] S. Pothiya, I. Ngamroo, and W. Kongprawechnon, "Ant colony optimisation for economic dispatch problem with non-smooth cost functions," *Int. J. Electr. Power Energy Syst.*, vol. 32, no. 5, pp. 478–487, Jun. 2010.

[9] L. Han, C. E. Romero, and Z. Yao, "Economic dispatch optimization algorithm based on particle diffusion," *Energy Convers. Manage.*, vol. 105, pp. 1251–1260, Nov. 2015.

[10] X.-S. Yang, S. S. Sadat Hosseini, and A. H. Gandomi, "Firefly algorithm for solving non-convex economic dispatch problems with valve loading effect," *Appl. Soft Comput.*, vol. 12, no. 3, pp. 1180–1186, Mar. 2012.

[11] M. J. Morshed and A. Asgharpour, "Hybrid imperialist competitive-sequential quadratic programming (HIC-SQP) algorithm for solving economic load dispatch with incorporating stochastic wind power: A comparative study on heuristic optimization techniques," *Energy Convers. Manage.*, vol. 84, pp. 30–40, Aug. 2014.

[12] S. Khamsawang and S. Jiriwibhakorn, "DSPSO–TSA for economic dispatch problem with nonsmooth and noncontinuous cost functions," *Energy Convers. Manage.*, vol. 51, no. 2, pp. 365–375, Feb. 2010.

[13] B. Jeddi and V. Vahidinasab, "A modified harmony search method for environmental/economic load dispatch of real-world power systems," *Energy Convers. Manage.*, vol. 78, pp. 661–675, Feb. 2014.

[14] V. S. Aragón, S. C. Esquivel, and C. A. Coello Coello, "An immune algorithm with power redistribution for solving economic dispatch problems," *Inf. Sci.*, vol. 295, pp. 609–632, Feb. 2015.

[15] A. Bhattacharya and P. K. Chattopadhyay, "Biogeography-based optimization for different economic load dispatch problems," *IEEE Trans. Power Syst.*, vol. 25, no. 2, pp. 1064–1077, May 2010.

[16] J. G. Vlachogiannis and K. Y. Lee, "Economic load dispatch—A comparative study on heuristic optimization techniques with an improved coordinated aggregation-based PSO," *IEEE Trans. Power Syst.*, vol. 24, no. 2, pp. 991–1001, Apr. 2009.

[17] V. R. Pandi, B. K. Panigrahi, M. K. Mallick, A. Abraham, and S. Das, "Improved harmony search for economic power dispatch," in *Proc. 9th Int. Conf. Hybrid Intell. Syst.*, vol. 3, 2009, pp. 403–408.

[18] C.-C. Kuo, "A novel coding scheme for practical economic dispatch by modified particle swarm approach," *IEEE Trans. Power Syst.*, vol. 23, no. 4, pp. 1825–1835, Nov. 2008.

[19] B. K. Panigrahi, S. R. Yadav, S. Agrawal, and M. K. Tiwari, "A clonal algorithm to solve economic load dispatch," *Electr. Power Syst. Res.*, vol. 77, no. 10, pp. 1381–1389, Aug. 2007.

[20] N. Noman and H. Iba, "Differential evolution for economic load dispatch problems," *Electr. Power Syst. Res.*, vol. 78, no. 8, pp. 1322–1331, Aug. 2008.

[21] B. Panigrahi and V. R. Pandi, "Bacterial foraging optimisation: Nelder–Mead hybrid algorithm for economic load dispatch," *IET Gener., Transmiss. Distrib.*, vol. 2, no. 4, pp. 556–565, 2008.

[22] A. Pereira-Neto, C. Unsihuay, and O. R. Saavedra, "Efficient evolutionary strategy optimisation procedure to solve the nonconvex economic dispatch problem with generator constraints," *Gener., Transmiss. Distrib., IEE Proc.*, vol. 152, no. 5, pp. 653–660, Sep. 2005.

[23] S. Elsaiah, M. Benidris, N. Cai, and J. Mitra, "Fast economic power dispatch method for power system planning studies," *IET Gener., Transmiss. Distrib.*, vol. 9, no. 5, pp. 417–426, Apr. 2015.

[24] K. Bhattacharjee, A. Bhattacharya, and S. Halder nee Dey, "Chemical reaction optimisation for different economic dispatch problems," *IET Gener., Transmiss. Distrib.*, vol. 8, no. 3, pp. 530–541, Mar. 2014.

[25] H. Chen, R. Zhang, L. Bai, G. Li, and F. Li, "Economic dispatch of wind integrated power systems with energy storage considering composite operating costs," *IET Gener., Transmiss. Distrib.*, vol. 10, no. 5, pp. 1294–1303, Apr. 2016.

[26] A. Gholami, J. Ansari, A. Kazemi, and M. Jamei, "Environmental/economic dispatch incorporating renewable energy sources and plug-in vehicles," *IET Gener., Transmiss. Distrib.*, vol. 8, no. 12, pp. 2183–2198, Dec. 2014.

[27] S. Surender Reddy, P. R. Bijwe, and A. R. Abhyankar, "Real-time economic dispatch considering renewable power generation variability and uncertainty over scheduling period," *IEEE Syst. J.*, vol. 9, no. 4, pp. 1440–1451, Dec. 2015.

[28] N. A. Khan, A. B. Awan, A. Mahmood, S. Razzaq, A. Zafar, and G. A. S. Sidhu, "Combined emission economic dispatch of power system including solar photo voltaic generation," *Energy Convers. Manage.*, vol. 92, pp. 82–91, Mar. 2015.

[29] A. A. ElDesouky, "Security and stochastic economic dispatch of power system including wind and solar resources with environmental consideration," *Int. J. Renew. Energy Res.*, vol. 3, no. 4, pp. 951–958, 2013.

[30] K. Geetha, V. Sharmila Deve, and K. Keerthivasan, "Design of economic dispatch model for gencos with thermal and wind powered generators," *Int. J. Electr. Power Energy Syst.*, vol. 68, pp. 222–232, Jun. 2015.

[31] R. Azizipanah-Abarghooee, T. Niknam, A. Roosta, A. R. Malekpour, and M. Zare, "Probabilistic multiobjective wind-thermal economic emission dispatch based on point estimated method," *Energy*, vol. 37, no. 1, pp. 322–335, Jan. 2012.

[32] J. Meng, G. Li, and Y. Du, "Economic dispatch for power systems with wind and solar energy integration considering reserve risk," in *Proc. IEEE PES Asia–Pacific Power Energy Eng. Conf. (APPEEC)*, Dec. 2013, pp. 1–5.

[33] X. Liu and W. Xu, "Economic load dispatch constrained by wind power availability: A Here-and-Now approach," *IEEE Trans. Sustain. Energy*, vol. 1, no. 1, pp. 2–9, Apr. 2010.

[34] S. S. Reddy, A. R. Abhyankar, and P. R. Bijwe, "Market clearing for a wind-thermal power system incorporating wind generation and load forecast uncertainties," in *Proc. IEEE Power Energy Soc. Gen. Meeting*, Jul. 2012, pp. 1–8.

[35] J. Hetzer, D. C. Yu, and K. Bhattarai, "An economic dispatch model incorporating wind power," *IEEE Trans. Energy Convers.*, vol. 23, no. 2, pp. 603–611, Jun. 2008.

[36] S. S. Reddy, B. K. Panigrahi, R. Kundu, R. Mukherjee, and S. Debchoudhury, "Energy and spinning reserve scheduling for a wind-thermal power system using CMA-ES with mean learning technique," *Int. J. Electr. Power Energy Syst.*, vol. 53, pp. 113–122, Dec. 2013.

[37] K. Zhang, L. Xu, M. Ouyang, H. Wang, L. Lu, J. Li, and Z. Li, "Optimal decentralized valley-filling charging strategy for electric vehicles," *Energy Convers. Manage.*, vol. 78, pp. 537–550, Feb. 2014.

[38] L. Jian, Y. Zheng, and Z. Shao, "High efficient valley-filling strategy for centralized coordinated charging of large-scale electric vehicles," *Appl. Energy*, vol. 186, pp. 46–55, Jan. 2017.

[39] P. Benalcázar, M. E. Samper, and A. Vargas, "Short-term economic dispatch of smart distribution grids considering the active role of plug-in electric vehicles," *Electr. Power Syst. Res.*, vol. 177, Dec. 2019, Art. no. 105932.

[40] E. Ramos Muñoz, G. Razeghi, L. Zhang, and F. Jabbari, "Electric vehicle charging algorithms for coordination of the grid and distribution transformer levels," *Energy*, vol. 113, pp. 930–942, Oct. 2016.

[41] Z. Hu, K. Zhan, H. Zhang, and Y. Song, "Pricing mechanisms design for guiding electric vehicle charging to fill load valley," *Appl. Energy*, vol. 178, pp. 155–163, Sep. 2016.

[42] H. Hou, M. Xue, Y. Xu, Z. Xiao, X. Deng, T. Xu, P. Liu, and R. Cui, "Multi-objective economic dispatch of a microgrid considering electric vehicle and transferable load," *Appl. Energy*, vol. 262, Mar. 2020, Art. no. 114489.

[43] L. T. Al-Bahrani, B. Horan, M. Seyedmahmoudian, and A. Stojcevski, ''Dynamic economic emission dispatch with load dema nd management for the load demand of electric vehicles during crest shaving and valley filling in smart cities environment,'' *Energy*, vol. 195, Mar. 2020, Art. no. 116946.

[44] H. Liang, Y. Liu, F. Li, and Y. Shen, ''Dynamic economic/emission dispatch including PEVs for peak shaving and valley filling,'' *IEEE Trans. Ind. Electron.*, vol. 66, no. 4, pp. 2880–2890, Apr. 2019.

[45] V. Suresh, S. Sreejith, S. K. Sudabattula, and V. K. Kamboj, ''Demand response-integrated economic dispatch incorporating renewable energy sources using ameliorated dragonfly algorithm,'' *Electr. Eng.*, vol. 101, no. 2, pp. 421–442, Jun. 2019.

[46] V. Suresh and S. Sreejith, ''Generation dispatch of combined solar thermal systems using dragonfly algorithm,'' *Computing*, vol. 99, no. 1, pp. 59–80, Jan. 2017.

[47] K. Abinaya, V. Suresh, S. K. Sudabattula, and S. Kaveripriya, ''Dynamic economic dispatch incorporating commercial electric vehicles,'' in *Advances in Smart Grid Technology*. Cham, Switzerland: Springer, 2020, pp. 65–75.

[48] S. Mirjalili, ''Moth-flame optimization algorithm: A novel nature-inspired heuristic paradigm,'' *Knowl.-Based Syst.*, vol. 89, pp. 228–249, Nov. 2015.

[49] M. A. Taher, S. Kamel, F. Jurado, and M. Ebeed, ''An improved moth-flame optimization algorithm for solving optimal power flow problem,'' *Int. Trans. Electr. Energy Syst.*, vol. 29, no. 3, p. e2743, Mar. 2019.

[50] Z.-L. Gaing, ''Particle swarm optimization to solving the economic dispatch considering the generator constraints,'' *IEEE Trans. Power Syst.*, vol. 18, no. 3, pp. 1187–1195, Aug. 2003.

[51] L. Wang and L.-P. Li, ''An effective differential harmony search algorithm for the solving non-convex economic load dispatch problems,'' *Int. J. Electr. Power Energy Syst.*, vol. 44, no. 1, pp. 832–843, Jan. 2013.

[52] S. Pothiya, I. Ngamroo, and W. Kongprawechnon, ''Application of multiple tabu search algorithm to solve dynamic economic dispatch considering generator constraints,'' *Energy Convers. Manage.*, vol. 49, no. 4, pp. 506–516, Apr. 2008.

[53] A. I. Selvakumar and K. Thanushkodi, ''A new particle swarm optimization solution to nonconvex economic dispatch problems,'' *IEEE Trans. Power Syst.*, vol. 22, no. 1, pp. 42–51, Feb. 2007.

[54] B. R. Adarsh, T. Raghunathan, T. Jayabarathi, and X.-S. Yang, ''Economic dispatch using chaotic bat algorithm,'' *Energy*, vol. 96, pp. 666–675, Feb. 2016.

[55] D. C. Secui, ''A new modified artificial bee colony algorithm for the economic dispatch problem,'' *Energy Convers. Manage.*, vol. 89, pp. 43–62, Jan. 2015.

[56] I. Ciornei and E. Kyriakides, ''A GA-API solution for the economic dispatch of generation in power system operation,'' *IEEE Trans. Power Syst.*, vol. 27, no. 1, pp. 233–242, Feb. 2012.

[57] M. S. P. Subathra, S. E. Selvan, T. A. A. Victoire, A. H. Christinal, and U. Amato, ''A hybrid with cross-entropy method and sequential quadratic programming to solve economic load dispatch problem,'' *IEEE Syst. J.*, vol. 9, no. 3, pp. 1031–1044, Sep. 2015.

[58] X. He, Y. Rao, and J. Huang, ''A novel algorithm for economic load dispatch of power systems,'' *Neurocomputing*, vol. 171, pp. 1454–1461, Jan. 2016.

[59] A. Srinivasa Reddy and K. Vaisakh, ''Shuffled differential evolution for economic dispatch with valve point loading effects,'' *Int. J. Electr. Power Energy Syst.*, vol. 46, pp. 342–352, Mar. 2013.

[60] L. C. Cagnina, S. C. Esquivel, and C. A. C. Coello, ''A fast particle swarm algorithm for solving smooth and non-smooth economic dispatch problems,'' *Eng. Optim.*, vol. 43, no. 5, pp. 485–505, May 2011.

[61] M. Kumar and J. S. Dhillon, ''Hybrid artificial algae algorithm for economic load dispatch,'' *Appl. Soft Comput.*, vol. 71, pp. 89–109, Oct. 2018.

[62] J. J. Q. Yu and V. O. K. Li, ''A social spider algorithm for solving the non-convex economic load dispatch problem,'' *Neurocomputing*, vol. 171, pp. 955–965, Jan. 2016.

[63] P. K. Roy, S. Bhui, and C. Paul, ''Solution of economic load dispatch using hybrid chemical reaction optimization approach,'' *Appl. Soft Comput.*, vol. 24, pp. 109–125, Nov. 2014.

[64] S. Sreejith and S. P. Simon, ''Cost benefit analysis on SVC and UPFC in a dynamic economic dispatch problem,'' *Int. J. Energy Sector Manage.*, vol. 8, no. 3, pp. 395–428, Aug. 2014.

[65] *Solar Irradiation Data*. Accessed: Jun. 15, 2020. [Online]. Available: https://maps.nrel.gov/nsrdb-viewer/

[66] J.-H. Teng, S.-W. Luan, D.-J. Lee, and Y.-Q. Huang, ''Optimal charging/discharging scheduling of battery storage systems for distribution systems interconnected with sizeable PV generation systems,'' *IEEE Trans. Power Syst.*, vol. 28, no. 2, pp. 1425–1433, May 2013.

[67] S. Velamuri and S. Sreejith, ''Reserve constrained economic dispatch incorporating solar farm using particle swarm optimization,'' *Int. J. Renew. Energy Res.*, vol. 6, no. 1, pp. 150–156, 2016.

VELAMURI SURESH (Member, IEEE) received the B.Tech. and M.Tech. degrees in electrical and electronics engineering from JNTU, Kakinada, in 2008 and 2011, respectively, the Ph.D. degree from the Vellore Institute of Technology, Vellore, in 2018. He is an Assistant Professor with the Power System Research Group, Department of Electrical and Electronics Engineering, SASTRA Deemed University, Thanjavur, India. His research interests include demand side management, application of artificial intelligence techniques to power system problems, and control of microgrids.

S. SREEJITH (Member, IEEE) received the bachelor's degree in electrical and electronics engineering from the Noorul Islam College of Engineering and the master's degree in power electronics and drives from the Mepco Schlenk Engineering College, Sivakasi, and the Ph.D. degree in power electronics application to power system with the National Institute of Technology Tiruchirappalli. He is currently an Assistant Professor with the Department of Electrical Engineering, National Institute of Technology, Silchar. He was an Associate Professor with the Department of Energy and Power Electronics, School of Electrical Engineering, Vellore Institute of Technology, Vellore. He has authored or coauthored more than 50 articles in refereed international journals and conferences. He is a reviewer of the IEEE, IET, Elsevier, Taylor and Francis, Springer, and lot of other journals. He is serving as an editorial board member in a few journals. He has given a number of lectures and hands on training on power electronics, power systems, drives, FACTS & HVDC, and smart grid. He is a member in board of studies in various institutions. He is guiding a number of B.Tech., M.Tech., and Ph.D. scholars. His areas of interest are power electronics, power systems, renewable energy sources, drives, smart grid, optimization techniques, FACTS and HVDC, and electric vehicles.

SURESH KUMAR SUDABATTULA (Member, IEEE) received the B.Tech. and M.Tech. degrees in electrical and electronics engineering from JNTU, Kakinada, in 2007 and 2011, respectively, the Ph.D. degree from the Vellore Institute of Technology, Vellore, in 2018. Since 2017, he has been an Associate Professor in power systems domain with the School of Electronics and Electrical Engineering, Lovely Professional University, Punjab, India. His research interests include distributed generation, electric vehicles, and power system optimization.

S. HARI CHARAN CHERUKURI (Student Member, IEEE) received the B.E. degree in electrical and electronics engineering from Anna University, Chennai, in 2011, the M.Tech. degree in power systems from SASTRA University, Thanjavur, in 2014, and the Ph.D. degree from the Vellore Institute of Technology, Vellore, in 2019. He is currently a Research Associate with the Power Systems and Smart Grid Laboratory, Discipline of Electrical Engineering, IIT Gandhinagar, Palaj. His research interests include energy management in grid interactive micro grids, electric springs and demand side management, home energy management, and application of optimization techniques to power system problems.

NATARAJAN PRABAHARAN (Member, IEEE) received the B.E. degree in electrical and electronics engineering and the M.E. degree in power electronics and drives from the affiliated college of Anna University, Chennai, India, in 2012 and 2014, respectively, and the Ph.D. degree in energy and power electronics from the Vellore Institute of Technology, Vellore, India, in 2017. He is currently an Assistant Professor with the Department of Electrical and Electronics Engineering, SASTRA Deemed University, Thanjavur, India. His research interest includes power electronics, new topologies for inverter and converters, grid integration of renewable energy sources and its controllers, photovoltaic system, and microgrid. He was a recipient of two prestigious travel grants under the category of Young Scientist from the Science and Engineering Research Board and the Asian Development Bank in 2015 and 2016, respectively. He was a recipient of the University Merit Ranker Award in 2014. He serves as an Associate Editor for the *IET Renewable Power Generation*, *International Transactions on Electrical Energy Systems*, IEEE Access, the *Journal of Power Electronics*, and the *International Journal of Renewable Energy Research*. He is a technical program committee member for many reputed international conferences.

PIERLUIGI SIANO (Senior Member, IEEE) received the M.Sc. degree in electronic engineering and the Ph.D. degree in information and electrical engineering from the University of Salerno, Salerno, Italy, in 2001 and 2006, respectively. He is currently a Professor and the Scientific Director of the Smart Grids and Smart Cities Laboratory, Department of Management and Innovation Systems, University of Salerno. His research activities are centered on demand response, energy management, the integration of distributed energy resources in smart grids, electricity markets, and planning and management of power systems. In these research fields, he has co-authored more than 500 articles, including more than 300 international journal articles that received in Scopus more than 9450 citations with an h-index equal to 47. He received the award as a 2019 Highly cited Researcher by the ISI Web of Science Group. He has been the Chair of the IES TC on smart grids. He is an Editor of the Power and Energy Society Section of IEEE Access, the IEEE Transactions on Industrial Informatics, the IEEE Transactions on Industrial Electronics, the IEEE Open Journal of IES, and *IET Renewable Power Generation*.

HASSAN HAES ALHELOU (Senior Member, IEEE) is currently a Faculty Member with Tisheen University, Lattakia, Syria. He has authored or coauthored more than 100 research articles in high-quality peer-reviewed journals and international conferences. He has participated in more than 15 industrial projects. His major research interests are power systems, power system dynamics, power system operation and control, dynamic state estimation, frequency control, smart grids, microgrids, demand response, load shedding, and power system protection. He was a recipient of the Outstanding Reviewer Award from the *Energy Conversion and Management* journal in 2016, the *ISA Transactions* journal in 2018, the *Applied Energy* journal in 2019, and many other awards. He was a recipient of the Best Young Researcher in the Arab Student Forum Creative among 61 researchers from 16 countries at Alexandria University, Egypt, in 2011. He has also performed more than 500 reviews for high prestigious journals, including the IEEE Transactions on Industrial Informatics, IEEE Transactions on Power Systems, IEEE Transactions on Industrial Electronics, Energy Conversion and Management, Applied Energy, the *International Journal of Electrical Power & Energy Systems*. He is included in the 2018 and 2019 Publons list of the top 1% best reviewer and researchers in the field of engineering.