Multi Objective Dynamic Economic Emission Dispatch with Renewable Energy and Emissions

Moses peter Musau[1]
Department of Electrical and Information Engineering
The University of Nairobi
Nairobi, Kenya
pemosmusa@uonbi.ac.ke[1]

Nicodemus Abungu Odero[2],Cyrus Wabuge Wekesa[3]
Department of Electrical and Information Engineering
The University of Nairobi
Nairobi, Kenya
abunguodero@uonbi.ac.ke[2], cwekesa@uonbi.ac.ke[3]

Abstract: In this paper, a fully-constrained five objective multi objective dynamic economic emission dispatch (MODEED) problem with thermal, wind, solar, line losses and emissions is considered. More accurate cubic cost functions for thermal, losses and emissions objectives and high potential renewable energy (RE) have been used. Modified Firefly Algorithm with Levy Flights and Derived Mutation (MFA-LF-DM) illustrates the optimization of MODEED on IEEE 6-unit system. MATLAB simulation results reveal that MODEED distributes thermal and renewable power production to optimize fuel cost and pollutants simultaneously. Wind power led to the best reduced emissions, solar resulted in the best reduced cost but RE-mix resulted in optimal cost and emission.

Keywords: Cubic cost functions, Emissions, Modified Firefly Algorithm with Levy Flights and Derived Mutation (MFA-LF-DM), Multi objective dynamic economic emission dispatch (MODEED), Renewable Energy (RE)

I: INTRODUCTION

Due to the increase of public awareness on environmental protection, utilities have been forced to use renewable sources with hybrid power system and to modify their operation strategies in order to reduce the pollution and atmospheric emission of power plants. MODED with RE is the proposed alternative as active and reactive production among the power stations and REs is distributed to meet the minimization of both fuel cost and pollutant emissions simultaneously. In this approach, the amount of dispatching renewable power is calculated, based on the data conveyed by the environmental information systems and load dispatch centers, using any commercially available software package; MATLAB in this case.

The objectives considered in MODEED formulation include thermal (T), Wind (W), Solar(S), Emissions (E) and Transmission line losses (TL). Works with T& E include Particle Swarm Optimization (PSO)[1-2], Evolutionary Programming (EP) and Fuzzy Logic (FL)-(EP-FL)[3], Elitist Non-Dominated Sorting Genetic Algorithm-II (ENSGA-II)[4], Preference-based Non-Dominated Sorting Genetic Algorithm (PNDSGA)[5], Bacterial Foraging(BF)-PSO-Differential Evolution-(DE)- (BF-PSO-DE)[6], Pattern Search (PS)[7] and Multi Objective Computer Programming Based Method(MOCPBM)[8]. Works with T&TL include Strength Pareto Evolutionary Algorithm (SPEA)[9], SPEA and Strength Pareto Genetic Algorithm (SPGA)-(SPEA-SPGA)[10] and Penalty-Based Algorithm (PBA)[11]. Methods employed on researches with T,E &TL include Multi Objective Particle Swarm Optimization (MOPSO)[12] and Sequential Approach with Matrix Framework (SAMF)[13]. In all these works however Renewable Energy has been ignored.

Several works have considered MODEED with RE. Methods used in T&W scenarios include Simulated Annealing (SA) and Direct Search Method (DSM)-(SA-DSM) [14] and Variable Time Resolution (VTR) and Scheduling Horizon (SH)-(VTR-SH) [15]. T, W& S objectives have been considered in [16] using Model Predictive Control (MPC). Two works have considered T, W, S&E, using Non Linear Constrained Method (NLCM)[17] and Weighted Aggregation (WA) and PSO-(WA-PSO)[18]. So far, only the less accurate quadratic functions have been considered with only at most four objectives. Further, there is need to use more advanced hybrid methods for better results in complex problems involving RE cost functions and stochastic variables. Table 1.0 summarizes the objectives included in MODEED so far where n represents the number of research works. From the table, it is apparent that, no work on five-objective MODEED exist. Most researches (43.75%) have considered thermal and emissions while the works with transmission losses and solar are not common. This is due to the challenge in determining the B-coefficients for the practical systems and the periodic availability of solar energy.

TABLE 1:0: MODED SUMMARY

N	n	%
T,E,	7	43.75
T,E	1	6.25
T,TL	3	18.75
T.W,S,E	2	12.5
T,W,S,E,TL	0	0.00
T,W,S	1	6.25
T,W	2	12.5
T,S	0	0.00
T,W,S,TL	0	0.00
T,W,TL	0	0.00
T,S,TL	0	0.00

Need for Cubic Cost Functions: ED with cubic cost functions has been studied in the recent past. A very crucial issue in MODEED is to determine the order and the approximate coefficients of the polynomial used to model emissions, losses and cost functions. This helps in reducing the error between the approximated polynomial along with its coefficients and the actual functions. To obtain accurate ED results, a third order polynomial is realistic in modelling the non-monotonically increasing curves [19]

Contributions: Fully constrained five-objective MODEED with more accurate cubic cost functions has been considered for the first time with high RE penetration, emissions and transmission losses. A new method modified firefly algorithm with levy flights and derived mutation (MFA-LF-DM) has also been applied.

The authors gratefully acknowledge The Deans Committee Research Grant (DCRG), The University of Nairobi, for funding this research.

978-1-4673-9981-4/16/$31.00 ©2016 IEEE

Paper Organization: The rest of this paper is organized as follows; section II is the problem formulation, section III is the MFA-LF-DM methodology, section IV is a discussion and analysis of results and finally section V is the conclusion.

II: PROBLEM FORMULATION

A: Thermal Cost function: The general form of thermal dynamic economic dispatch (DED) is given by [20]

$$\mathrm{F}(P_{ij}) = \left\{ a_{0,i} + \sum_{j=1}^{J} a_{ji}\, P_{t,i}^{j} + r_i \right\} + \left| e_i \sin f_i (P_i^{min} - P_i) \right| \quad (1)$$

where $a_{0,i,} a_{j,i}, e_i$ and f_i are the cost coefficients of the i^{th} unit, $P_i^{min}$is the lower generation bound for the i^{th}unit and $r_i$is the error associated with the ith equation. Equation (1) represents the industrially applicable thermal cost function which can be applied to first order(j=1) ,quadratic (j=2),cubic(j=3) and higher order cost functions , with increasing accuracy .The formulation considers valve points (represented by the sine term) and prohibiting zones.

B: Renewable Cost Functions: The operational cost objective function for wind power generation is formulated as [21]

$$F(w_{ij}) = F_{wi}(w_{ij}) + F_{p,wi}(w_{ij,av} - w_{ij}) + F_{r,wi}(w_{ij} - w_{ij,av}) \quad (2)$$

where w_{ij} is the scheduled output of the i^{th} wind generator in the j^{th} hour, $F_{wi}(w_{ij})$ is the weighted cost function representing the cost based on wind speed profile, $F_{p,wi}(w_{ij,av} - w_{ij})$ is *the penalty cost for not using all the available wind power* and $F_{r,wi}(w_{ij} - w_{ij,av})$ is the *penalty reserve requirement cost* which is due to the fact that that actual or available power is less than the scheduled wind power. Similarly, the operational cost objective function for the PV power generation plant is formulated as [18]

$$F(PV_{ij}) = F(PV_{ij}) + F_{p,PVi}(PV_{ij,av} - PV_{ij}) + F_{r,PVi}(PV_{ij} - PV_{ij,av}) \quad (3)$$

$F_{PVi}(PV_{ij})$ is the weighted cost function representing cost based on solar irradiance. The other two are the respective penalty cost for not using all the available PV power and reserve requirement cost respectively.

It should be noted that wind is available throughout the day at different locations with varying speed while sunlight is available only for a particular duration of the day. The aim of introducing solar cost function is to extract maximum amount of power from solar reactor during its available period (T_a). some part of solar power generated during this period is stored using some available storage devices called Renewable Reserve. This stored power is delivered during unavailable period (T_u) of sunlight. The power extracted from the renewable source varies and can be considered as a variable (intermittent) load. Therefore this power $(PV_{ij,av} + w_{ij,av})$ is deducted from the total demand (P_D^t) and also the stored power (P_R) is added to it (duringT_a) or subtracted from it (during T_u)to obtain the actual demand(P_D^a)which is distributed among the available generating units. The dispatched amount of renewable power is limited to some part (x) of the total actual demand. The stored power is the difference of the total extracted and dispatched amount of renewable power during Ta. During T_u it must not exceed some part (y) of the total stored renewable power of T_a period. Moreover, the sum of total power delivered from the storage devices during T_u must not exceed the total power stored during T_a [22]

C: Transmission Loss Cost Function: Transmission losses is one important objective since the generating centers and the connected load exist in geographically distributed scenario. Since the power stations are usually spread out geographically, transmission network losses must be taken into account to achieve realistic MODEED network loss.It is assumed that the losses due to the REs are negligible since they are located near the load center. The cost of transmission line losses between plants are accounted with the actual fuel cost function by using a price factor g_i .This factor is defined as the ratio between the fuel cost at its maximum power output to the maximum power output. Thus, the cost function for the losses at a particular time becomes

$$\mathrm{F}(P_{L,i}) = \sum_{i=1}^{n} g_i(\alpha_{3,i}\, P_{t,i}^3 + \alpha_{2,i}\, P_{t,i}^2 + \alpha_{1,i} P_{t,i} + \alpha_{0,i} P_{t,i}) \quad (4)$$

D: Emissions Function: The three main emissions that are considered include NO_X , SO_2 and CO_2 for the power plants in the MODEED system. The emissions cubic function is given by

$$\mathrm{E}(P_{i,3}) = \beta_{3,i} P_{t,i}^3 + \beta_{2,i} P_{t,i}^2 + \beta_{1,i} P_{t,i}^1 + \beta_{0,i} + \zeta_{3,i} \exp(\lambda_{3,i}\ P_i) + \zeta_{2,i} \quad (5)$$

Using equations (1) to (5), MODEED problem is then summarized as

$$\min f = \min[h\, F + (1-h)\, E] \quad (6)$$

Where

$$F = \sum_{i=1}^{n} F(P_{ij}) + \sum_{i=1}^{W} F(w_{ij}) + \sum_{i=1}^{S} F(PV_{ij}) + \mathrm{F}(P_{L,i}) \text{ and}$$

$$E = \sum_{i=1}^{n,W,S} E(P_{ij}, PV_{ij}, w_{ij}) \quad (7)$$

Subject to the constraints

$$\sum_{i=1}^{n} P_{ij} + \sum_{i=1}^{W} Pw_{ij} + \sum_{i=1}^{S} PV_{ij} = P_{Dj}^a + P_{loss\ j} \quad (8)$$

$$P_i^{min} \le P_i \le P_i^{max} \quad (9)$$

$$0 \le w_i \le w_{ri} \quad (10)$$

$$0 \le PV_i \le PV_{K_{t\ max}} \quad (11)$$

$$P_{ij} - P_{ij-1} \le UR_i \quad (12)$$

$$P_{ij-1} - P_{ij} \le DR_i \quad (13)$$

$$-P_l^{max} \le P_{lj} \le P_l^{max}\ l = 1,2,3 \ldots\ldots L \quad (14)$$

$$P_i \le P^{PZ,LOW} \quad (15)$$

$$P_i \ge P^{PZ,HIGH} \quad (16)$$

$$P_r\left[\sum_{i}^{n} P_{im} + \Omega(w_{ij} + PV_{ij})\right] \leq P_{Dj}^{a} + P_{loss\ j} \leq P_a \qquad (17)$$

$$P_D^a = P_D^t - \left(PV_{ij,av} + w_{ij,av}\right) \pm P_R \qquad (18)$$

$$(PV_{ij} + w_{ij})_d \leq xP_D^a \qquad (19)$$

$$P_R \leq \left(PV_{ij,av} + w_{ij,av}\right)_g - \left(PV_{ij} + w_{ij}\right)_d \qquad (20)$$

$$P_R \leq y\sum_{T_a}\left(PV_{ij,av} + w_{ij,av}\right)_g - \left(PV_{ij} + w_{ij}\right)_d \qquad (21)$$

$$\sum_{T_u} P_R \leq \sum_{T_a} P_R \qquad (22)$$

where h is a non-negative weight used to make tradeoff between emission security and total fuel cost considering the three fuels and is the algebraic sum of the individual weight of the four objectives, n, W and S are the number of thermal wind farm and PV power plants.

III: MFA-LF-DM METHODOLOGY

Many heuristic methods have been used in the recent past to handle the MODED. In this paper, MFA-LF-DM is proposed as it outperforms the more popular Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC) etc., since it converges more quickly, deals with global optimization more naturally, it is more efficient and has higher success rates. The method can handle *NP Hard Problems* and further, it is well fitted for the intermittent search strategy [23-24].

A: Firefly Algorithm (FA)

Fireflies are the most charismatic species among the insects and their spectacular display have inspired engineers and scientists. They produce short rhythmic patterns of flashing lights which are unique, varying from species to species, and the flashing light is produced by a *bioluminescence* process. The flashing behavior of fireflies plays a key role in reproduction, protection, communication and feeding [23].

Firefly Algorithm (FA) is a new nature inspired algorithm developed by Xin-She Yang in the year 2007, based on the flashing behavior of fireflies. The flashing signifies the signal to attract other fireflies, where the *objective function* is associated with the flashing light or the light intensity which helps the fireflies to move to brighter and more attractive locations to achieve optimal solution. FA has three idealized rules which have been developed to define the characteristics of fireflies: These include the law of attraction, the law of separation, and the law of objective function [23].

FA is so popular and successful because of several reasons [23]; It automatically divides its population into subgroups, because of the fact that local attraction is stronger than long distance (global) attraction; It does not use historical individual best and explicit global best. This reduces the potential drawbacks of premature convergence. Further, it does not use the velocities hence problems associated with velocities in PSO is automatically eliminated. Lastly, the method has an inbuilt ability to modify and therefore to control the parameters such as γ, leading to improved results. Hence FA is more efficient in respects of controlling parameters, local search ability, robustness and elimination of premature convergence.

However the basic FA is poor in global searching and optimization, long convergence time, requires more iterations, and low computational speed. These problems can be addressed by using modified FA [24] and using heuristic and deterministic methods to form hybrid FA [25]. In a hybrid method the weaknesses of the base method are suppressed while its strengths are exalted leading to better realistic results and improved performance of the method .In this paper therefore, an hybrid of Modified FA (MFA) with Levy-Flights (LF)[MFA-LF] coupled with Derived Mutation (DM);[MFA-LF-DM] is proposed.

B: Characteristics of MFA-LF-DM

There are six characteristics of the proposed MFA-LF-DM. These include brightness, distance, attractiveness, movement, randomness reduction and mutation. The first three are as in [23].This paper considers the later three.

Movement: The movement of a firefly i is attracted to another more attractive (brighter) firefly j by the relation

$$x'_{i+1} = x_i + \beta_0\, r\, e^{-\gamma r^2} + \alpha\, \mathrm{sign}\left[rand - \frac{1}{2}\right] \qquad (23)$$

where x_i is the current position of a firefly, the second term defines the fireflies attractiveness to light intensity as seen by the adjacent firefly and the third term is for the random movement of a firefly if no brighter firefly is left, α is a randomization parameter, rand is a random number generator uniformly distributed over the space [0, 1], that is, $rand \in [0,1]$.In general the solutions can be improved by reducing the randomness by

$$\alpha = \alpha_\infty + (\alpha_0 - \alpha_\infty)e^{-t} \qquad (24)$$

where $t \in [0, t_{max}]$ is the pseudo time for simulation and t_{max} is the maximum number of generations, α_∞ and α_0 are the final and initial values of the randomness parameter

Randomness Reduction: Levy flight is a random walk of step lengths having direction of the steps as isotropic and random. The concept propounded by Paul Pierre Levy (1886-1971) is very useful in stochastic measurements and simulations of random and pseudo-random phenomena

The movement of a firefly i with Levy Flights is defined by

$$x'_{i+1} = x_i + \beta_0\, r\, e^{-\gamma r^2} + \alpha\, \mathrm{sign}\left[rand - \frac{1}{2}\right] \oplus \mathrm{Levy} \qquad (25)$$

where the second term is due to attraction, while the third term is randomization via the Levy Flights with α being the randomization parameter.The product ⊕ means entry wise multiplication. The sign $\left[rand - \frac{1}{2}\right]$ where $rand \in [0,1]$ essentially provides a random sign or direction while the random step length is drawn from a Levy distribution with infinite variance and infinite mean given by

$$Levy \sim u = t^{-\lambda}, (1 < \lambda \leq 3) \qquad (26)$$

where λ is the levy distribution parameter.

Mutation: To further improve the exploration of or diversity of the candidate solution, the simple mutation corresponding to α from the Ant Colony Optimization (ACO), Genetic Algorithm (GA) and Evolutionary Programming (EP) and Differential Evolution (DE) is adopted in the MFA-LF process. This enhances the optimum results in solving the fully-constrained SODED problem. In this method the initial solution is generated randomly within the feasible range, the MFA-LF parameters used in the MAMODED problem are as shown in table 2.0

TABLE 2.0 PARAMETERS FOR MFA-LF-DM

Parameter	Value
Brightness	$F(x)$
Alpha (α)	0.9
Beta (β)	0.5
Gamma (γ)	1.0
Number of fireflies (n)	50
Maximum no. of iterations	100
Attraction at $r = 0$, (β_0)	2.5
Lambda (λ)	1.5

IV: RESULTS DISCUSSION AND ANALYSIS

There are three options for supplying the demand of its customers namely; thermal generating units, wind power generation and finally solar power systems. The line losses and the emissions are accounted for after the REs have been accounted for. There are six thermal sources whose cubic cost coefficients and emission coefficients (for SO_2, NO_X and CO_2) are as in [23] .The necessary wind and solar power parameters are as in [26]. Solar power dominates variability and wind power dominates uncertainty. Cost (C) emission (E) line losses (PL) and time taken (t) in seconds are considered. The results are tabulated as follows: Table 3.0- Pure thermal system. Table 4.0-Thermal wind wind, Table 5.0-Thermal with solar and Table 6.0 –Thermal with RE mix.

A: Cost Reduction by RE Penetration

In the tabulated results C_N, C_W, C_S , $C_{W\&S}$ and $C_{R\&S}$ denotes cost without RE, cost with wind, cost with solar, cost with wind and solar and cost with renewable and storage respectively. As shown in table 4.0, the integration of wind generating units resulted in reduction in load sharing by the thermal generating units hence reduced losses and cost as compared to the thermal scenario. This is because wind generators reduce cost by forcing the most inflexible thermal power plants offline and causing them to be replaced by more efficient and flexible types of generation especially the RE systems. More efficient systems mean reduced losses and reduced cost. The cost function converged at fewer iterations hence reduced cost. As seen in table 5.0, use of PV units resulted in significantly reduced cost which are approximately better compared to the reduction caused by the wind turbines. The optimal cost are realized with RE mix as shown in table 6.0.

The variation in power cost due to RE penetration can be explained using the *cycling principle* of thermal generators and the *free nature* of renewable sources [28]. *Cycling* includes both *starting* and *ramping*. Starting is defined as starting a unit that is offline while ramping is load-following operation in which a generating unit increases its production. Adding wind and solar affects the operation of the thermal plants and high RE penetrations induces cycling of such fossil-fueled generators. Frequent cycling of thermal plants creates thermal and pressure stresses in the plant components leading to increased operation and maintenance costs, more frequent repairs, reduced component life, and more frequent forced outages. Power plants that were designed for base loaded operation suffer much more wear-and-tear damage from cycling. Over time, these can result in premature component failure and increased maintenance and repair. Utilities are concerned that cycling effects can significantly negate the benefits that RE bring to the system. And to plan accordingly, power plant owners need to understand the magnitude of cycling impacts. For average fossil-fueled plant considered in this case, 30% RE in MODEED penetration causes cycling costs to increase by $\$0.47–\$1.28/MWh$ compared to total savings in fuel and variable operations and maintenance costs of $\$27–\$28/MWh$ which is displaced by using renewable resources which are free in nature[27].

B: Emission Reduction

In the tabulated results E_N, E_W, E_S , $E_{W\&S}$ and $E_{R\&S}$ denotes emissions without RE, emissions with wind, emissions with solar, emissions with wind and solar and emissions with renewable and storage respectively.The emissions are the highest in Table 3.0 since all the major emissions are maximally available in pure thermal base case. With wind penetration as shown in Table 4.0, there are less emissions as compared to Table 3.0. Obtaining 6% of electric power from wind energy would reduce emissions CO_2-4.5%,SO_2-6.0% and NO_X-6.0% [27,28] .Coal and natural gas consumption are reduced by 3% and 14% respectively.

With penetration of solar as shown in Table 5.0 there is reduced emission but these emissions are slightly higher as compared to high wind penetration case. While there are no global warming emissions associated with solar power generation directly, there are emissions associated with other stages of the solar PV life-cycle, including manufacturing, materials transportation, installation, maintenance, decommissioning and dismantlement. Most estimates for concentrating solar power range from $0.04 - 0.10\ kg\ CO_2/KWh$.. In both cases, this is far less than the lifecycle emission rates for natural gas $0.30 - 1.0\ kg\ CO_2/KWh$ and coal $0.7 - 1.8\ kg\ CO_2/KWh$[27,28]. The main components of solar PV panels are made from crystalline silicon. Manufacturing these components is an energy-intensive process which accounts for 60% of the total energy used to make solar panels. However the NO_x and SO_2 emissions remain almost the same as in wind power penetration.The lowest emissions are in Table 6.0 due to the RE mix. Cycling of thermal power plant due to RE mix penetration results in change of emissions. Starting a generator or increasing its output can increase emissions compared to noncyclic operation. Also, operating a generator at part-load also affects emissions rates. Up to 33% RE avoids 29– 34% CO_2, 16–22% NO_x and 14– 24% SO_2. Cycling had very little $(< 5\%)$ impact on the CO_2, NO_x, and SO_2 emissions reductions from wind and solar. For the average fossil-fueled plant, RE-induced cycling can have a positive or negative impact on CO_2, NO_x, and SO_2 emissions rates, depending on the RE mix and penetrations. Average overall emissions in the hybrid system is lower compared to the purely thermal system since the CO_2, NO_x, and SO_2 emissions red more significantly as compared to the cycling emissions.

C: Comparison of Cost and Emissions during T_a and T_u.

The comparison is done using the pure thermal as the base case. Figure 1.0 shows the percentage change in cost and emissions for a given load curve . The ranges of the times are $0 < T_u 7, 7 < T_a 18$, and $18 < T_u 24$.From the figure , it is clear that 40% of the fuel cost is saved during T_u with both reserve and RE while the saving is less than 20% with only RE.It should be noted that $C_{R\&S} < C_R < C_N$ and $E_{R\&S} < E_R < E_N$. Further, the changes in emissions are very small and sometimes negative as compared to the changes in the optimal cost[22]

V: CONCLUSION

In this paper, MODEED problem is formulated for a hybrid system which includes thermal generating units, solar, wind, line losses and emissions, plus all the possible technical constraints. More accurate cubic cost functions for the thermal and emissions have been used for the first time in MODEED formulation. The MFA-LF-DM hybrid has been used to validate the proposed formulation. Analysis was carried out using MATLAB simulation for a high RE penetration. MODEED with RE is the more efficient and realistic way to fulfill future demand with reduced cost and emissions.

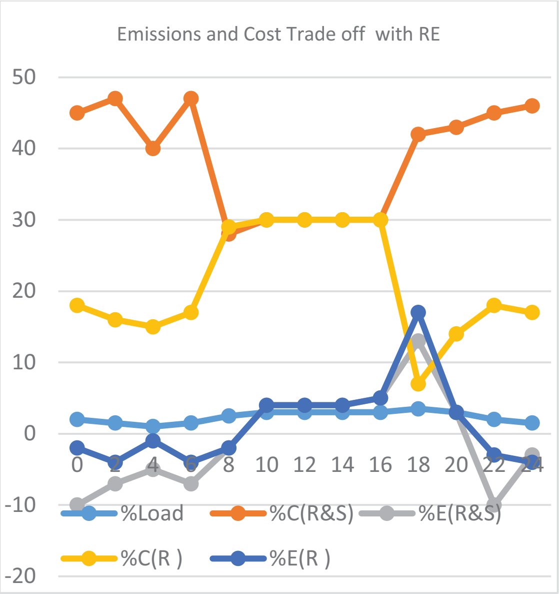

Figure 1.0: Emissions and Cost Trade off

TABLE 4.0: MODED WITH 5 THERMAL UNITS

P_D (MW)	n (MW))						C_N (\$/h)	E_N (ton/h)	$P_{L,N}$ (MW)	t(s)
	1	2	5	6	11	12				
150	11.34	11.42	12.23	10.55	7.55	7.68	**790.91**	**3.6679**	**0.51**	2.19
250	20.50	21.15	18.35	11.45	19.56	21.03	**967.89**	**3.6695**	**0.85**	2.20
350	23.02	29.64	26.34	12.56	23.61	23.26	**1105.04**	**3.6819**	**1.18**	1.28
450	29.83	40.56	32.97	13.80	23.77	24.28	**1283.03**	**3.7106**	**1.69**	1.30
550	52.37	56.95	42.31	15.50	25.26	25.92	**1646.81**	**3.7151**	**3.29**	2.57
650	53.88	57.08	43.09	16.80	26.55	26.67	**1655.98**	**3.7198**	**3.41**	2.68

TABLE 5.0: MODED WITH 3 THERMAL UNITS AND 2 WIND UNITS

P_D (MW)	n (MW)				W (MW)		C_W (\$/h)	E_W (ton/h)	$P_{L,W}$ (MW)	t(s)
	1	2	5	12	6	11				
150	11.34	11.42	12.23	8.90	7.55	7.68	**760.91**	**3.0678**	**0.49**	2.08
250	20.50	21.15	18.35	12.35	19.51	21.03	**937.89**	**3.0690**	**0.80**	2.14
350	23.02	29.64	26.34	18.45	23.61	23.26	**1075.04**	**3.0810**	**1.14**	1.18
450	29.83	40.56	32.97	20.50	23.77	24.28	**1253.03**	**3.1108**	**1.67**	1.24
550	52.37	56.95	42.31	23.45	25.26	25.92	**1616.81**	**3.1156**	**3.09**	2.27
650	53.89	57.09	43.44	24.55	25.30	25.98	**1618.87**	**3.1178**	**3.11**	2.50

TABLE 6.0: MODED WITH 3 THERMAL UNITS AND 2 SOLAR UNITS

P_D (MW)	n (MW)				S (MW)		C_S (\$/h)	E_S (ton/h)	$P_{L,S}$ (MW)	t(s)
	1	2	5	12	6	11				
150	10.99	11.75	11.30	15.56	8.23	7.94	**749.84**	**3.0755**	**0.21**	2.38
250	19.77	19.34	19.91	20.68	20.21	21.29	**926.81**	**3.0775**	**0.51**	1.41
350	23.51	28.74	27.59	25.50	22.61	23.41	**1063.20**	**3.0850**	**0.87**	1.42
450	30.35	39.57	33.11	30.80	23.62	24.75	**1240.91**	**3.1790**	**1.40**	1.67
550	49.63	56.91	45.37	25.90	26.08	24.80	**1605.99**	**3.1800**	**2.78**	1.38
650	50.23	57.34	46.23	26.12	26.34	24.90	**1608.78**	**3.1823**	**2.90**	1.42

TABLE 7.0: MODED WITH 3 THERMAL UNITS, 1 SOLAR UNIT AND 1 WIND UNIT

P_D (MW)	n (MW)				W (MW)	S (MW)	$C_{W\&S}$ (\$/h)	$E_{W\&S}$ (ton/h)	$P_{L,W\&S}$ (MW)	t(s)
	1	2	5	12	6	11				
150	10.90	12.33	11.14	13.50	7.36	8.48	**758.49**	**3.0737**	**0.21**	2.66
250	21.13	19.83	18.79	15.89	20.71	20.08	**936.52**	**3.0755**	**0.53**	2.43
350	23.18	30.96	26.07	16.80	21.52	24.16	**1071.95**	**3.0834**	**0.90**	1.57
450	34.08	40.66	28.39	28.55	23.46	24.87	**1249.56**	**3.1598**	**1.45**	1.39
550	47.63	61.01	42.06	30.56	25.09	27.00	**1615.20**	**3.1782**	**2.80**	1.41
650	47.98	61.23	43.11	30.66	25.16	27.54	**1615.58**	**3.1800**	**2.90**	1.55

REFERENCES

[1] M. Basu, "Particle Swarm Optimization Based Goal-Attainment Method for Dynamic Economic Emission Dispatch," *Electric Power Components and Systems,* Vol. 34, No. 9, pp. 1015-1025, 2006.

[2] Amitah Mahor et al "Economic dispatch using particle swarm optimization: A review" *Renewable and Sustainable Energy Reviews*, Vol 11, pp. 2134-2141,2009

[3] M. Basu, "Dynamic Economic Emission Dispatch using Evolutionary Programming and Fuzzy Satisfying Method," *International Journal of Emerging Electric Power Systems,* Vol. 8, No. 4, pp. 1-15, 2007

[4] M. Basu, "Dynamic Economic Emission Dispatch using Non dominated Sorting Genetic Algorithm-II," *International Journal of Electrical Power & Energy Systems,* Vol. 30, No. 2, pp. 140-149, 2008.

[5] R.P. Brent, Algorithms for Minimization without Derivatives, N.J.: Prentice-Hall,Englewood Cliffs, 1973.

[6] Zwe-Lee Gaing and Ting-Chia Ou, "Dynamic Economic Dispatch Solution using Fast Evolutionary Programming with Swarm Direction," *Industrial Electronics and Applications, 2009. ICIEA 2009. 4th IEEE Conference on,* pp. 1538-1544, 2009.

[7] J.S. Alsumait, M. Qasem, J.K. Sykulski and A.K. Al-Othman, "An Improved Pattern Search Based Algorithm to Solve the Dynamic Economic Dispatch Problem with Valve-Point Effect," *Energy Conversion and Management,* Vol. 51, No. 10, pp. 2062-2067, 2010.

[8] Soubache ID and Sudhakara Reddy "Combined Economic and Emission Dispatch" *American Journal of Engineering Science and Research* Vol 1, No 1, pp 1-5 2014.

[9] M.A. Abido and J.M. Bakhashwain " A Novel Multiobjective Evolutionary Algorithm for Optimal Reactive Power Dispatch Problem" in *Proceedings of the 2003 10th IEEE International Conference on Electronics, Circuits and Systems, 2003 (ICECS 2003)*, IEEE, Vol. 3, pp.1054--1057, December 2003.

[10] M.A. Abido." Multiobjective Optimal VAR Dispatch Using Strength Pareto Evolutionary Algorithm" in *2006 IEEE Congress on Evolutionary Computation (CEC'2006)*, pp. 2745--2751, IEEE, Vancouver, BC, Canada, July 2006.

[11] Haiwang Zhong; Qing Xia; Yang Wang; Chongqing Kang, "Dynamic Economic Dispatch Considering Transmission Losses Using Quadratically Constrained Quadratic Program Method," *Power Systems, IEEE Transactions on* , Vol.28, No.3, pp.2232-2241, Aug. 2013

[12] Zhao Bo and Cao Yi-Jia "Multiple objective particle swarm optimization technique for economic load dispatch" *Journal of Zhejiang University of Science and Technology* Vol.6 No.5 pp.420-427 2005

[13] S Subramanian and S Ganesan. "A Simple Approach for Emission Constrained Economic Dispatch Problems" *International Journal of Computer Applications* Vol. 8, No. 11 pp39–45, October 2010.

[14] C. Chen, "Simulated Annealing-Based Optimal Wind-Thermal Coordination Scheduling," *Generation, Transmission & Distribution, IET,* Vol. 1, no. 3, pp. 447-455, 2007.

[15] Bakirtzis, E.A; Ntomaris, AV.; Kardakos, E.G.; Simoglou, C.K.; Biskas, P.N.; Bakirtzis, AG., "A unified unit commitment — Economic dispatch model for short-term power system scheduling under high wind energy penetration," *European Energy Market (EEM), 2014 11th International Conference on the* , Vol.4,pp.1,6, 28-30 May 2014.

[16] Chunghun Kim; Yonghao Gui; Chung Choo Chung; Yong-Cheol Kang, "Model predictive control in dynamic economic dispatch using Weibull distribution," *Power and Energy Society General Meeting (PES), 2013 IEEE* , Vol.10, pp.1,5, 21-25 July 2013

[17] Faisal A. Mohamed et al "Environmental/Economic Power Dispatch of Micro Grid Using Multiobjective Optimization" *International Conference on Renewable Energies and Power Quality* (ICREPQ'09) Valencia (Spain), 15th to 17th April, 2009

[18] Azza a. Eldesouky,"Security and stochastic economic dispatch of power system including wind and solar resources with environmental consideration" *International journal of renewable energy research* Vol.3, No.4 pp. 951-958, 2013

[19] Krishnamurthy, S.; Tzoneva, R., "Impact of price penalty factors on the solution of the combined economic emission dispatch problem using cubic criterion functions," *Power and Energy Society General Meeting, 2012 IEEE* , vol., no., pp.1,9, 22-26 July 2012

[20] Yusuf Sonmez "Estimation of Fuel cost curve parameters for thermal power plants using the ABC Algorithm" ,*Turkish Journal Of Electrical Engineering and Computer Science* ,Vol .21 pp. 1827-1841,2013

[21] John Hetzer et al "An Economic Dispatch Model Incorporating Wind Power "*IEEE Transactions on Energy Conversion*, Vol .23, No.2 June 2008

[22] Debra Lew and Greg Brinkman "The Western wind and solar integration study phase 2: Executive Summary"National Renewable Energy Laboratory, Technical Report NREL/TP-5500-58798,Sept 2013.

[23] Yang X.S., "Firefly Algorithm: Recent Advancements And Applications", *International Journal of Swarm Intelligence*, vol. , pp. 36-50, 2013.

[24] X.-S. Yang,"Firefly algorithm, L´evy flights and global optimization", in: *Research and Development in Intelligent Systems* XXVI (Eds M. Bramer, R. Ellis, M. Petridis), Springer London, pp. 209-218 ,2010.

[25] Younes M., "A Novel Hybrid FFA-ACO Algorithm for Economic Power Dispatch", *Journal of Control Engineering And Applied Informatics*, Vol. 15, Issue 2, Pp. 67-77, 2013.

[26] Moses Peter Musau, Nicodemus Odero Abungu, Cyrus Wabuge Wekesa. "Multi Objective Dynamic Economic Dispatch with Cubic Cost Functions" *International Journal of Energy and Power Engineering*. Vol. 4, No. 3, pp. 153-167, 2015

[27] IPCC, 2011: Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change,Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 pp. (Chapter 7 & 9).

[28] Debra Lew and Greg Brinkman "The Western wind and solar integration study phase 2: Executive Summary"National Renewable Energy Laboratory, Technical Report NREL/TP-5500-58798,Sept 2013.