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Multi-Objective Fuzzy Index based optimal scheduling of a Micro-Grid With CHP and Wind Power Units

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Abstract— Present world is starving for the new and renewable energy resources to meet many global warming and clean air challenges and this make the energy researchers for doing more and more research for recyclable and biodegradable energy resources like wind energy .Power system industry plays a pivotal role in the growth of developing world .In the area of research in power, each and everyone is searching for economic and eco friendly ways to dispatch the power. The main aim of economic load dispatch is to find the optimum allocation of the myriad number of power generators which may be the each of or the combination of the combined heat and power CHP, Wind energy conversion system, Bio diesel power generators and solar power plants etc. which are available there to serve the load in micro grid. When various renewable power generators gets integrated with the traditional one, then it became very hard to maintain the reliability of the power system. Optimal power scheduling of the renewable power generators is a very important task in a micro grid. This paper generally conveys the multi objective optimal scheduling of a micro grid with CHP and wind power units with static and dynamic load which is based on fuzzy indexing.

Keywords—
Keyword_1 *Time Varying Differential Evolution*
Keyword_2, *Fuzzy ranking/indexing,*
Keyword_3 *Multi objective optimization*
Keyword_4 *Static economic load dispatch*
Keyword_5 *Optimal dispatch*
Keyword_6 Dynamic economic load dispatch
Keyword_7 Single objective optimization

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1 INTRODUCTION

The economic load dispatch is having as much importance as the generation techniques have, it is generally represented as the constrained optimization problem , which is having the objective of the optimal allocation of various generators to minimize the cost of power ,loss and the emission in micro grid .Conventional methods were usually having the linear characteristics but the state of the art power generators are having variety of nonlinearities in their cost and emission curve and to solve them traditional methods do not work well ,therefore in this paper the sequential quadratic programming (SQP) /Tıme varying DE is used to solve the multiobjective optimization problem, in which there are four objectives taken to optimize that are cost,emission,loss and heat.Wind energy contribution is increasing in very fast pace because of the various environmental issues related to green house gas emissions, and the kyoto protocol etc. Also conventional power generators are having various types of constraints like ecological i.e. global warming, economical i.e. the cost of maintenance and capital investments in traditional generators, Therefore in order to ensure pure air and water and overall natural resources for our future generations it is the right time to install myriad number of renewable energy resources by replacing the conventional energy generating plants so that todays increasing energy demand can be meet alongwith keeping secure our environment as well.

An heuristic optimization technique namely adaptive variable population particle swarm optimization (Adaptive PSO) is used to solve the economic load dispatch problem which is novel evolutionary approach itself [31].An economic load dispatch model is elaborated including the wind energy conversion system in [30] where Hetzer used the weibull probability distribution function to describe the stochastic nature of wind.[2] assessed the value of load dispatch of off-grid microgird which is forecast based dispatch and gave the result in significant cost saving. [10] presents the analysis of the operation of microgrid for islanded and grid connected mode and the results are compared by Matlab simulator.Optimization is done for economic emission dispatch problem in [1] by using collective neurodynamic optimization ,here the valvepoint effect in microgrid is also considered.[3] developed an optimization model for economic dispatch problem which integrates a single micro gas turbine in to the grid under combined heat and power operation.A novel very short term wind power prediction method is given in [4] with hybrid strategy, which is based on risk measurement or evaluation, as this technique is the necessity of today's electricity market for producers and consumers both. This technique makes the wind power more reliable and secure by reducing the uncertainties attached to the wind power. [5] gives the modeling of the system which operates in parallel with the other system in the rural area where the grid supply is limited. In this paper the modeling is done for a hybrid system incorporating the wind and the biogas. An adapted approach ,in which a fraction of power is transferred from generator to load and other part to the remaining network, is projected in [6] .Actually this paper considered the impact of wind or other renewable energy ,which flows from a particular generator to the different loads,to the power network.[7] presents a comprehensive review for renewable energy especially wind and hybrid systems, their softwares which are being used all over the world, gives the viability study and wind prospectives. A hybrid method is presented in [8] which may be used to predict the operating reserve capacity in the day ahead market, here the support vecor machine (SVM) and the fuzzy interface system (FIS) are the two important and significant elements of this method. [9] gives the implications of the inclusion of the renewable enery resources especially the wind energy and how this renewable inclusion affects the overall cost of energy in the power system grid.

A formulation of multi objective optimization problem with stretchy loads in micro grid is done in [11] with existing constraints and with or without utility participation with inclusion of the economic power scheduling uncertainty and the overall effects like peak load reduction & net saving in cost have been analyzed. A multi objective optimization problem of Micro grid ,which contains the fuel cell units and combined heat & power generating units, battery storage systems and Boilers, is solved in [12] ,where the account of uncertainties related to load & price variation and the implications regarding the demand response is included.[13] presented an optimal dispatch (cost is optimized) of the micro grid which is connected to the main grid, this micro grid includes the wind ,solar and the diesel generator system, a demand response program is integrated in the grid which is based on the incentives. A virtual energy storage system is developed in [14] ,this dynamic economic dispatch model is based on the building and employs the heat storage competence of the building. Actually this paper explores the effects of the complexities associated with the hybrid micro grid which consists of the various distributed generators ,renewable energy resources and the low carbon buildings as well. In [18] an optimal economic dispatch problem is solved in power network which includes the wind power generation, by using the particle swarm optimization technique and the results have been compared with and without wind power.[22] studies the different static and dynamic economic emission dispatch problems and also provides the detailed comparative analysis of the application of the differential evolutionary algorithm in them. Here it also elaborates myriad number of advantages of the DE algorithm. [15] introduces a novel Ant Lion optimization method to solve the multiobjective problem ,here many objectives like cost, various type of gas emissions, power loss etc. have been optimized simultaneously and ultimately these are ranked to get the best compromise solution which may help to ease the decision making for power system operators.This multiobjective dispatch model is tested on the hybrid power system which consists of the hydro thermal and the wind generator units, results of this work shows the superior and comparable performance of the Ant Lion optimization method as compared to the othe already established evolutionary algorithms like Diferential Evolution, Artificial Bee colony optimization methods etc..A self adptive differential evolution and real coded genetic algoithm is applied to solve the dynamic economic dispatch problem and the results are compared with each other and many other modern techniques in [16] and results are found reliable and promising. Two optimization methods have been utilized to schedule the unit commitment and optimal dispatch in micro grid in [17] ,one is the real-coded genetic algorithm and the other one is the mixed nteger linear programming .In [19] an improved adaptive genetic algorithm (IAGA) is proposed for multi objective optimal allocation in microgrid ,the proposed technique results in to avoid premature convergence.[20] gives the detail analysis of the impacts of planned use of CHP based DERs in the modern grid i.e. micro grid in conventional terms of reliability ,stability etc..Dynamic economic dispatch problem in micro grid is solved using a combination of two techniques i.e. an improved particle swarm optimization technique and a monte carlo simulation method in [21].This paper gave the impacts in the islanded mode of micro grid. Papers [23] and [24] gives the detail analysis of the issues related to the wind power technology i.e. the challenges in wind capacity building ,status for each state of India, market and the development of the wind power in India. Dynamic economic dispatch problem of an integrated wind thermal power system is solved using particle swarm optimization algorithm in [25] considering all practical constraints and the results found by this are validated using time varying differential evolution algorithm. [26] presents a technique based on time-varying differential evolution (TVDE) for optimal scheduling of DERs in a micro-grid and a fuzzy decision making is carried out to rank the different solutions in order of their merit, considering both, cost and emission reduction objectives. Pareto optimal solution set is generated to cover the full operating range of DERs. [27] presents a complete formulation for dynamic economic emission dispatch with loss and heat optimization scheme of a Micro Grid (MG) with utility participation. The proposed problem is framed as a nonlinear inhibited multi-objective optimization problem. The proposed problem takes into consideration the process and upkeep cost, loss, heat as well as the emission reduction of noxious gases which are harmful to nature. Dynamic economic dispatch of thermal generators integrated with wind power generators with compressed air energy storage is projected in [28] and here an improved particle swarm optimization technique is used for optimzation objective.Modelling of solar is done using beta distribution function and the modelling of wind plant is done using weibull distribution functions, so [29] analyzes the impacts of these renewable energy plants on the power flow control.

This paper presents a static and dynamic economic dispatch analysis for Micro Grid including wind and CHP power generators. Three cases have been analyzed for optimization in micro grid with many equality/inequality constraints. A Time Varying DE technique is used to solve this multifaceted problem.

Time varying differential evolution

Optimization problems which are nonlinear, non continuous, etc can be resolved by DE technique. The major process in DE is the formation of trial vector. The making of a trial vector is established by the both the key processes of mutation and crossover. The creation of trial vector is the key process of DE. Consider target vector in a population of size N of D-dimensional vectors. The creation of a trial vector is established by both the mutation and crossover method.

i) A mutant vector is produced by connecting three randomly chosen vectors from the population of vectors without the target vector. This process of connecting the three randomly selected vectors to form the mutant vector V is defined as

$$V \;= X_1(t) + F.(X_2(t) - X_3(t)) \qquad (1)$$

where X1 ,X2 , and X3 are three randomly selected vectors from the population and F is a multiplier which is the main parameter of the DE algorithm. The job to outline the mutant vector V is called mutation.

ii) Generate the trial vector by crossover between the mutant & the target vector. There are two crossover procedures in DE: binomial and exponential crossover. A small crossover chance clue to a trial vector that is more equivalent to the target vector while the other favors the mutant vector.

Step (1): Setting up of parameters: Creation of a mutant vector, crossover rate, stopping criterion, size of population, and boundary constraints for decision variables by mutation of three randomly selected vectors.

Step (2): Population Initialization: Population are initialized at random surrounded by the specified upper & lower bounds.

Step (3): Population Evaluation: correctness of all individual is evaluated.

Step (4): Mutation: The trial vector is formed by crossover to create offspring of DE mutation vector for each individual of the current population by transforming a target vector with weighted differential operators.

Step (5): Crossover: DE crossover operator is useful to execute a discrete mix of trial vector ui(t) and parent vector xi(t) to generate offspring. $x'_{i1}(t)$

The crossover is used as given below:

$$x_{ij}(t) = \begin{cases} u_{ij}(t) \;\; if \;\; rand(j) \le CR \\ x_{ij}(t) \;\; if \;\; rand(j) > CR \end{cases} \qquad (3)$$

Where xij(t) represents the jth element of vector xi(t). uij(t) and $x'_{ij}(t)$ are defined accordingly rand (.) produces a random number in the range [0,1] ,CR is the recombination rate in the range [0, 1].

Step (6): Selection. The deterministic choice method is used to build the population of the next generation and if the suitability of the offspring is superior than its parent the offspring replaces the parent; otherwise the parent continues to the next generation. In case of minimum optimization problems, selection of vectors is implemented as given below:

$$x_{ij}(t+1) = \begin{cases} x'_i(t) \;\; f \;\; f(x'_i(t) < f(x_i(t)) \\ x_i(t) \;\; otherwise \end{cases} \qquad (4)$$

where f (.) denotes the objective function of DE. This set-up confirms that the usual population fitness shall get well.

Step (7) :If the above criterion is not fulfilled then go to step 3, otherwise coming back the specific with the maximum fitness as the result. The scaling factor must be reduced with growing population size. The first β is chosen huge for increasing search. Therefore, along the iterations for good exploitation it is reduced linearly:

$$\beta(iter) = c_1 - c_2\left(\frac{iter}{miter}\right) \qquad (5)$$

Here c1 and c2 are constant, iter is the counter of iteration and miter is the maximum iteration of algorithm.CR is changed along the evolution process as given below.

$$CR(iter) = ku_1 - ku_2\left(\frac{iter}{miter}\right) \qquad (6)$$

where ku1 and ku2 are user listed and dependent factors.

Problem Formulation

First each of the four objectives is separately optimized using single objective optimization technique. After that two of the all four objectives are combined into a single function and solved using an assigned weight and price penalty factor approach.The fuzzy ranking is done for each objective for every solution because for the operator it is difficult to choose the best solution when he has multiple objectives to optimize simultaneously. The overall ranking is found based on the minimum level to meet the required level of each of the four or many objectives.

This paper includes the wind power generator as one of the 5 DERs and analyzes the effects of that inclusion using weighted sum and the fuzzy ranking approaches and then compared the results obtained from both of them. Both static and Dynamic economic emission dispatch is done with loss and heat optimization simultaneously, using the TVDE which is the modified version of traditional DE Technique.

Minimum Cost Dispatch

First, cost objective given in (8) is minimized individually using SOO problem formulation.

$$C_i = \sum_{i=1}^{M}(a_i + b_i \times PG_i + c_i PG_i^2) \tag{7}$$

$$\sum_i^M C_i(p_{gi}) + \sum_i^N C_{wj}(\omega_i) + \sum_i^N C_{p,w,i}(W_{i,av} - \omega_i) + \sum_i^N C_{r,w,i}(\omega_i - W_{i,av}) \tag{8}$$

Minimum Emission Dispatch

Then the emission objective given in (9) is minimized individually using SOO problem formulation.

$$Of_2 = \sum_{i=1}^{N}(\alpha_i + \beta_i \times PG_i + \gamma_i PG_i^2) \tag{9}$$

Minimum loss Dispatch

Here loss objective given in (10) is minimized individually using SOO problem formulation.

$$Of_3 = \sum_{j=1}^{N}(a_j + b_j \times PG_j + c_j PG_j^2) \tag{10}$$

Maximum Heat Dispatch

Here Heat objective given in (11) is maximized individually using SOO problem formulation.

$$Of_4 = \sum_{j=1}^{N}(\alpha_j + \beta_j \times PG_j + \gamma_j G_j^2) \tag{11}$$

Multi-objective optimization

Then cost, emission, loss & Heat are simultaneously optimized using price penalty factor (PPF) approach to solve MOO problem given in equation (12).

$$O.F. = w_1 * fc_{(i)} + ppf_1 * w_2 * em_{(i)} + ppf_2 * w_3 * Heat_{(i)} + ppf_3 * w_4 * loss_{(i)} + \alpha * (sum(x_1) + PW - PD) \wedge 2 \tag{12}$$

$$w_1 + w_2 + w_3 + w_4 = 1 \tag{13}$$

$$p_{i,min} \le p_i \le p_{i,max} \tag{14}$$

$$0 \le \omega_i \le \omega_{r,i} \tag{15}$$

$$\sum_i^M pg_i + \sum_i^N \omega_i = L \tag{16}$$

Where,

M	number of conventional power generators;
N	number of wind-powered generators;
pg_i	power from the ith conventional generator;
ω_i	scheduled wind power from the ith wind-powered generator;
$W_{i,av}$	available wind power from the ith wind-powered generator.This is a random variable, with a value range of $0 \le W_{i,av} \le w_r$ and probabilities varying with the given pdf. We considered Weibull pdf for wind variation;
$\omega_{r,i}$	rated wind power from the ith wind-powered generator;
C_i	cost function for the ith conventional generator;
$C_{w,i}$	cost function for the ith wind-powered generator. This factor will typically take the form of a payment to the wind farm operator for the wind-generated power actually used;
$C_{p,w,i}$	penalty cost function for not using all available power from the ith wind-powered generator;
$C_{r,w,i}$	required reserve cost function, relating to uncertainty of wind power. This is effectively a penalty associated with the overestimation of the available wind power;
L	system load and losses.

$$C_i(pg_i) = \frac{a_i}{2}p_{gi}^2 + b_i pg_i + c_i \tag{17}$$

where ai , bi , and ci are cost coefficients for the ith conventional energy source

$$C_{\omega,i}(\omega_i) = d_i\omega_i \tag{18}$$

where di is the direct cost coefficient for the ith wind generator.

$$C_{p,w,i}(W_{i,av} - \omega_i) = k_{p,i}(W_{i,av} - \omega_i) = k_{p,i}\int_{\omega_i}^{\omega_{r,i}}(\omega - \omega_i)f_W(\omega)d\omega \tag{19}$$

where

$k_{p,i}$	penalty cost (underestimation) coefficient for the ith wind generator;
$f_W(\omega)$	WECS wind power pdf.

$$C_{r,w,i}(\omega_i - W_{i,av}) = k_{r,i}(\omega_i - W_{i,av}) = k_{r,i}\int_0^{\omega_i}(\omega_i - \omega)f_W(\omega)d\omega \tag{20}$$

where

$k_{r,i}$	is the reserve cost (overestimation) coefficient for the ith wind-powered generator.

$$f_V(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)(k-1)e^{-(vc)}, \quad 0<v<\infty \tag{21}$$

where

V	wind speed random variable;

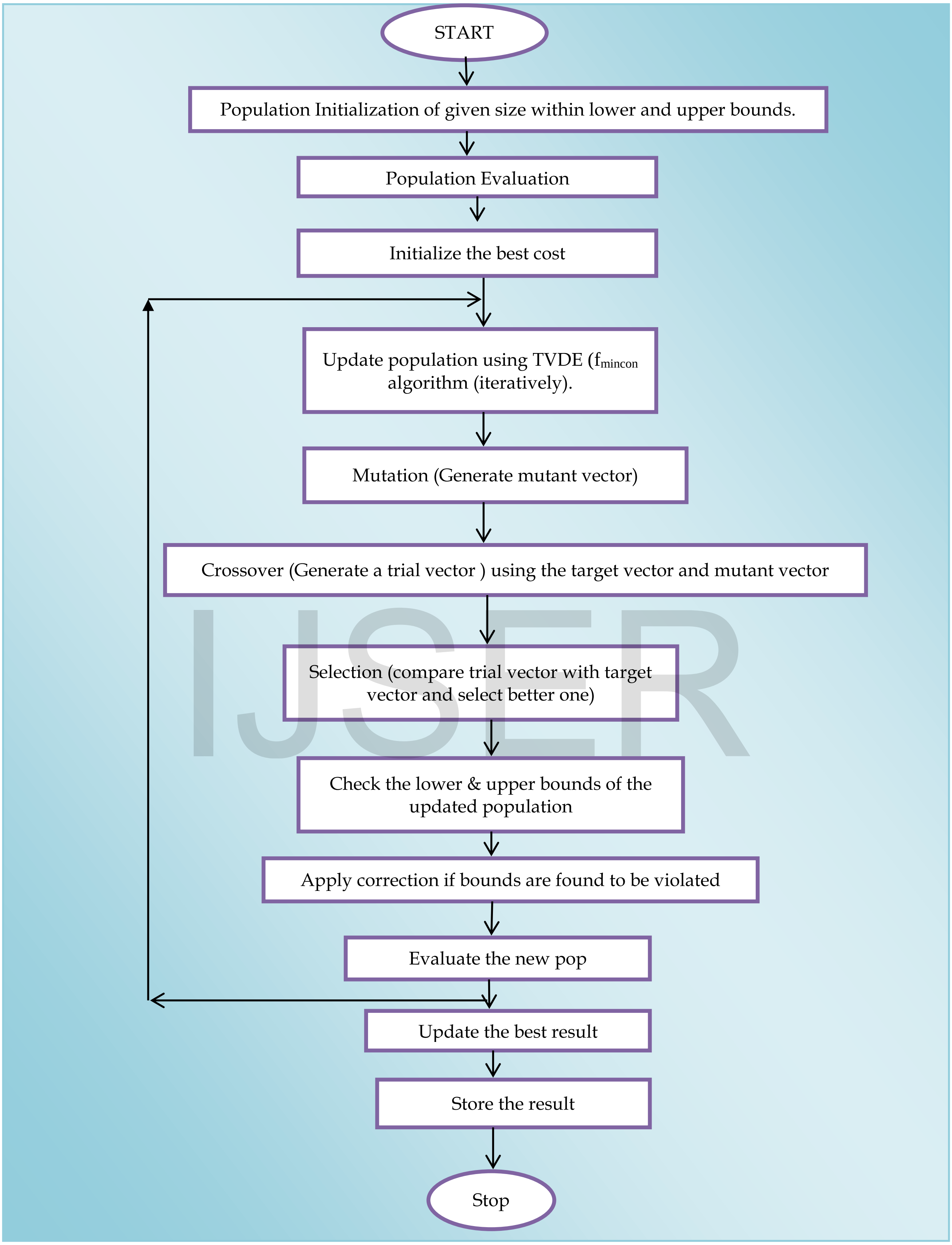

Fig. 1 Flow chart of Time Varying DE technique

v wind speed;
c scale factor at a given location (units of wind speed);
k shape factor at a given location (dimensionless).

$$F_V(v) = \int_0^v f_v(\tau)d\tau = 1 - e - (v/c)\ k \tag{22}$$

The mean of the Weibull function is

$$\mu = c\Gamma(1 + \mathrm{k}^{-1}) \tag{23}$$

and the variance is

$$\sigma_v^2 = c^2\Gamma(1 + 2\mathrm{k}^{-1}) - \mu^2 \tag{24}$$

and where the gamma function is

$$\Gamma(\mathrm{x}) = \int_0^\infty \mathrm{y}^{\mathrm{x}-1}\,\mathrm{e}^{-\mathrm{y}}\mathrm{dy},\ \ \mathrm{y} > 0 \tag{25}$$

For the Rayleigh distribution, k = 2 and
$\mu = \sqrt{\pi}/2$
and

$$\sigma_v^2 = C^2\left(1 - \frac{\pi}{4}\right) \tag{26}$$

$w = 0$ for v<vi and v>v0

$\omega = \omega_r\ \frac{(v-vi)}{(vr-vi)}$ for $vi \le v \le vr(25)$

$$\omega = \omega_r \text{ for } vr \le v \le vo \tag{27}$$

Where
w WECS output power (typical units of kilowatt or megawatt);
w_r WECS rated power;
v_i cut-in wind speed (typical units of miles/hour or miles/second);
v_r rated wind speed;
v_o cut-out wind speed.

$W = T(V) = aV + b$
and

$$f_w(\omega) = f_v[T^{-1}(\omega)]\left[\frac{dT^{-1}(\omega)}{d\omega}\right] = f_V\ \left(\frac{\omega-b}{a}\right)\left|\frac{1}{a}\right| \tag{28}$$

where
T a transformation, in general;
W wind power random variable;
V wind speed random variable;
ω wind power (a realization of the wind power random variable);
v wind speed (a realization of the wind speed random variable).

$$P_r\{W = 0\} = F_V(v_0)) = 1 - exp\left(-\left(\frac{v_i}{c}\right)k\right) + exp\left(-\left(\frac{v_o}{c}\right)k\right) \tag{29}$$

and

$$P_r\{W = \omega_r\} = F_V(v_0) - F_V(v_r) = exp\left(-\left(\frac{v_r}{c}\right)k\right) - exp\left(-\left(\frac{v_o}{c}\right)k\right) \tag{30}$$

To make the transformation from the wind speed random variable to the WECS power output random variable in the linear portion of the curve a bit less cumbersome, the following ratios are defined:

$\rho = \frac{\omega}{\omega_r}$ ratio of wind power output to rated wind power;
and $\rho = \frac{(v_r-v_i)}{v_i}$ ratio of linear range of wind speed to cut-in wind speed.

$$f_W(\omega) = \frac{klv_i}{c}\left(\frac{(1+\rho l)v_i}{c}\right)k - 1\ \exp\left(-\left(\frac{(1+\rho\mathrm{l})v_i}{\mathrm{c}}\right)\mathrm{k}\right) \tag{31}$$

Equality and inequality constraints

Static and Dynamic economic emission dispatch with heat & loss optimization is done for a micro grid having CHP units with or without wind both the the cases; optimal dispatch is computed for an assumed load profile. The objectives specified in (7)-(11) are optimized subject to the subsequent constraints.

Power Balance constraints

$$\sum_{i=1}^{N} PG_i - P_D - P_L = 0 \tag{32}$$

Network Loss PL can be considered using Kron'sLoss Method given below:

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\ PG_iB_{ij}PG_j + \sum_{i=1}^{N}B_{0i}PG_i + B_{00} \tag{33}$$

Where Bij,,ij=1,………N are called loss co-efficient; their units are MW-1

DERs Capacity Limits Constraint

Power produced by other DERs and the wind generator shall be within the defined lower limit PG_{imin} and upper limit $PG_{imax,}$ so that

$$PG_{i\min} \le PG_i \le PG_{i\max} \tag{34}$$

$$0 \le \omega_i \le \omega_{r,i} \tag{35}$$

Ramp Rate Limits Constraint

$$P_{mn} = \max\ \ (P_{\min}\ ,(P_o - rr_{ld})) \tag{36}$$

$$P_{mx} = \min\ \ (P_{\max}\ ,(P_o + rr_{lu})) \tag{37}$$

$$P_{\min} = P_{mn}\ ,\ P_{\max} = P_{mx} \tag{38}$$

Heat Balance Inequality Constraint

Heat output (HO) of Diesel Generator (Dg) and Micro turbine (Mt) are proportional to their respective electrical output,

$$H_o = Total\ \ Heat\ \ Output = \sum\nolimits_{i=1}^{N}\theta_i PG_i \qquad (39)$$

Heat Balance inequality constraint is as follows:

$$\sum\nolimits_{i=1}^{N}\theta_i PG_i \geq H_D \qquad (40)$$

θ_i is proportionality constant

$$\theta_i = \frac{HeatRate(\frac{kJ}{kWh})}{3600}\times\eta_{ith}\times\eta_{ex} \qquad (41)$$

Previously various techniques were recommended to minimize the emission for economic dispatch. In this paper A TVDE technique is used to optimize the cost, emission, loss minimization and heat maximization. Efficiency of heat exchanger is taken as 90% here.

The MOO problem is converted into SOO problem all the way through price penalty factor (PPF) by the formula described as:

$$PPF(i) = \frac{\sum_{i=1}^{N}(a_i + b_i \times PG_{i\max} + c_i\ PG_{i\max}^2)}{\sum_{i=1}^{N}(\alpha_i + \beta_i \times PG_{i\max} + \gamma_i PG_{i\max}^2)} \qquad (42)$$

With the aim of finding the optimum cost, emission, generated Heat and the energy loss are to be considered at the same time. The complex MOO can be formulated as:

$$Min\ C = \left[O.F._1(P_i), O.F._2(P_i), O.F._3\ (P_i), O.F._4(P_i)\right] \qquad (43)$$

Above functions are correspond to economic fuel cost, emission, Loss ,& Heat respectively. When weigh factor and price penaly factors considered the MOO problem gets converted into SOO problem which can be formulated as:

$$Min\ C = \left[Rank_{cost}(P_i), Rank_{emission}(P_i), Rank_{loss}(P_i), Rank_{Heat}(P_i)\right] \qquad (44)$$

Fuzzy Ranking

In MOO problem it is very difficult to find out the best solution as one objective may be better in a solution but in the other solution ,it may be better. Therefore a fuzzy Rank is assigned to all solution to help the operator in finding the best decisive solution. The Rank is assigned based on the extreme solutions achieved for minimum/maximum cost , emission ,loss, and Heat i.e. f1min, f1max and f2min, f2max .The membership value of cost and emission $Rank_{cost}$ and $Rank_{emission}$ can be calculated as

$$Rank(F_i) = \begin{cases} 1;\ F_i \leq F_i^{\min} \\ \dfrac{F_i^{\max} - F_i}{F_i^{\max} - F_i^{\min}};\ F_i^{\min} < F_i < F_i^{\max} \\ 0;\ F_i \geq F_i^{\max} \end{cases} \qquad (45)$$

The overall Ranking of a solution is found using the fuzzy min-max logic as below.

$$Rank(i) = \min(\ Rank_{cost}, Rank_{emission}) \qquad (46)$$

$$Rank_{overall} = \max(\ Rank_i) \quad \vee\ all\ \ i \qquad (47)$$

Table-I
Fuel and emission coefficientts of distributed energy resources

Bus No.	1	2	3	4	5
DER Capacity (KW)	500 (Dg)	200(Dg)	80(Mt)	100(Dg)	30(Mt)
ai	10.193	2.035	0.5768	1.1825	0.338
bi	105.18	60.28	57.783	65.34	89.1476
ci	62.56	44.00	133.092	44.00	547.619
α i	26.55	14.4296	3.0358	19.38	1.0346
βi	16.1836	64.1535	57.3403	176.695	60.384
γi	7.0508	130.409	311.573	821.657	943.19
PGmax(Kw)	500	200	80	100	30
PGmin (Kw)	0	40	16	20	6
Heat Rate (KJ/Kwh)	10314	11041	11373	10581	12186

Table II.
Table for Cost Comparison with or without wind integration

Case	Load (KW)	Best Cost	Wind cost	Cost W_O	Cost W_U	Em	Loss	Heat	P1	P2	P3	P4	P5
W/O Wind	169	23.90	0	0	0	54.77	1.45	190.90	0	62.99	80.00	20.00	6.00
With Wind		21.94	7.46	1.82	5.63	43.23	0.42	207.94	0	39.42	80.62	21.52	29.23
W/O Wind	248	29.29	0	0	0	49.04	2.15	255.21	0	109.74	80.00	52.24	6.00
With Wind		26.95	8.72	6.32	2.40	35.68	2.77	262.68	0	116.73	79.10	41.28	13.65
W/O Wind	338	35.66	0	0	0	45.28	3.54	345.28	0	142.74	80.00	85.49	30.00
With Wind		33.03	10.89	10.21	0.67	38.23	7.07	347.53	0	172.89	77.23	68.60	26.33

Table III
Simultaneous Minimization of two objectives together(k=1; c=15; ;kr=0.1;kp=0.1;)

Description	Cost-EM	Cost-Heat	Cost-Loss	Em-Heat	Em-Loss	Heat-Loss
P1	5.55	8.86	16.70	38.75	30.35	31.26
P2	11.64	21.48	49.17	8.46	1.68	46.46
P3	6.54	67.29	53.15	36.78	47.41	40.15
P4	67.84	46.69	31.68	62.58	86.23	21.21
P5	63.24	25.33	18.56	24.13	6.00	30.00
Cost	23.08	22.86	23.30	25.01	24.55	24.13
Em	38.44	40.02	41.99	38.94	38.04	43.35
Heat	202.13	211.95	212.79	245.66	224.65	238.71
Loss	1.83	0.67	0.29	1.52	2.68	0.09
W_O	0.50	0.95	2.33	0.36	0.07	2.19
W_U	7.09	6.55	5.16	7.26	7.65	5.29
WC	7.59	7.51	7.50	7.63	7.72	7.48

PD=169KW,W$_{Cost}$: Wind Cost; W_O: Wind over estimation cost ; W_U: Wind under estimation cost

Results and discussion

Description of the Test Systems

Test Case I SOO : The TVDE approach which is actually an improved DE for static economic dispatch for micro grid integrated with wind and CHP units is tested on 5 DERs and 14-Bus Radial Micro Network with utility participation. The data is listed in Table1[23].Table II shows the comparison of the cost optimization results with or without wind for static load. The four objectives, cost, emission, loss and heat were individually optimized.Here we can see that with the integration of wind plants ,for 169 KW load ,fuel cost is lowered from 23.90 to 21.94$/hr. Similarly for other load same observations has been taken.

Test Case II TOO : Then the problem of two objectives optimization is taken and solved by converting it into single objective optimization problem using the price penalty factor approach. All possible combinations of the four objectives were taken, which resulted in six cases: Cost-Emission, Cost-Loss, Cost-Heat, Emission-Loss, Emission-Heat and Heat-Loss. Pareto fronts were plotted for all the six combinations to get a large number of trade off solutions in a wide range.

Test Case III MOO: Then the problem of multi(four) objectives optimization is taken and solved by converting it into single objective optimization problem using the price penalty factor approach. The four objectives, cost, emission, loss and heat were simultaneously optimized. The solutions were ranked using a fuzzy ranking method. Table-IV and Table III shows that the solution will have zero/one rank

if the corresponding objective achieved is at the worst/best possible value. The RankCost value of 0.7231 denotes that the cost objective has been attained upto 72.31% in comparison to the best cost solution.The RankOverall of a solution denotes the minimum attainment level of all four objectives. For the Case-I, the value of RankOverall is 0.4293; it means that the dispatch solution has at least 42.93% attainment/satisfaction level for all four objectives, while cost is satisfied up to 72.31% level, emission 42.93%, loss is 65.94% and heat is 55.89%. For the Case-II, the value of Rank

Overall is 0.3419; it means that the dispatch solution has at least 34.19% attainment/satisfaction level for all four objectives, while cost is satisfied up to 35.91% level, emission 34.19%, loss is 71.17% and heat is 55.97%.Similarly for the case III and IV minimum satisfaction level for all four objectives atleast upto 27.07% and 26.72 % respectively whereas the individual attainment level are different for each cases.

Table V shows Multi objective economic dispatch with wind integration in micro grid results for four different weightage conditions. However results obtained are the pareto optimal solutions it cannot be said that any result is better than the other.

Table IV
MOO-4 objective (Top five results of the four objective optimization using fuzzy ranking) All weights=0.25

Description	Sol-1	Sol-2	Sol-3	Sol-4	Sol-5
P1	26.88	36.83	35.18	34.77	36.83
P2	38.27	48.06	51.86	48.03	48.06
P3	58.40	34.89	36.37	47.02	34.89
P4	25.20	23.79	25.63	24.10	23.79
P5	20.45	25.53	20.08	15.27	25.53
Cost	23.66	24.40	24.39	23.09	24.49
Em	42.51	42.75	42.94	42.33	43.12
Heat	235.21	235.24	236.32	215.30	242.15
Loss	0.21	0.20	0.14	0.26	0.11
W_O	1.77	2.54	2.47	2.27	2.27
W_U	5.69	4.98	5.04	5.22	5.22
WC	7.46	7.52	7.51	7.49	7.49
Rank$_{Cost}$	0.7231	0.3591	0.3628	0.4697	0.3111
Rank$_{Em}$	0.4293	0.3419	0.2707	0.2672	0.2038
Rank$_{Loss}$	0.6594	0.7117	0.8996	0.6420	1.0000
Rank$_{Heat}$	0.5589	0.5597	0.5901	0.6566	0.7539
Rank$_{Overall}$	0.4293	0.3419	0.2707	0.2672	0.2038

Table V
MOO-4 objective (best ranking solution) Load=169 Watt for different weight given to each

Description	W_{cost} =W_{em}= W_{Loss}=W_{Ht} =0.25	W_{cost} = 0.3,W_{em}= 0.5,W_{Loss} =0.1,W_{Ht} =0.1	W_{Cost} = 0.4 W_{em}= 0.4 W_{Loss}= 0.1 W_{Ht} =0.1	W_{cost} = 0.1 W_{em}= 0.7 W_{Loss}= 0.1 W_{Ht} =0.1
P1	31.84	29.02	28.44	25.29
P2	51.12	42.80	28.94	38.01
P3	33.82	40.07	63.56	53.48
P4	23.42	33.29	31.31	24.45
P5	28.89	24.01	17.04	27.89
Cost	24.26	24.12	23.66	23.67
Em	43.26	41.86	42.67	41.62
Heat	235.12	230.25	238.49	234.62
Loss	0.10	0.20	0.31	0.15
W_O	2.43	2.00	1.30	1.75
W_U	5.07	5.47	6.16	5.70
WC	7.51	7.47	7.47	7.46

Table VI
Comparison of best results of FRM with WSM

CASE-I					
	Cost	Em	Loss	Heat	RankOverall
WSM	24.49	43.12	0.11	242.15	0.2038
M	23.66	42.51	0.21	235.21	0.4293
CASE-II					
WSM	24.04	43.47	0.12	230.33	0.1195
FRM	23.89	42.20	0.16	236.81	0.4593
CASE-III					
WSM	23.91	43.02	0.12	229.07	0.2239
FRM	24.34	42.56	0.13	240.48	0.4434
CASE-IV					
WSM	24.36	42.95	0.10	240.83	0.3448
FRM	24.02	42.39	0.14	233.08	0.4988

The best solution obtained by the weighted sum method (WSM) is compared with the best solution obtained by the Fuzzy Ranking Method (FRM) in Table VI for all four multi-objective optimization cases. It is observed that for all four cases the solution obtained by the FRM is superior to the solution obtained by the WSM because though both the solutions are non-dominating, the solution by FRM has a higher minimum level of attainment for the objectives.

Dynamic load dispatch for all four objectives is done and the results are tabulated in table VII. Load is changed in each hour , and the cost ,emission,loss ,heat and the cost of wind power over estimation and underestimation are calculated for each hour of the day.

Table VII
Solution of multi-objective optimal dynamic dispatch

S.n.	Load	P1	P2	P3	P4	P5	Cost	Em	Loss	Heat	W_O	W_U	W_C
1	169	36.25	49.93	41.56	23.72	17.71	24.34	43.07	0.18	239.72	2.37	5.13	7.50
2	248	52.48	76.04	46.07	46.92	27.06	30.12	39.76	0.59	342.27	3.82	3.96	7.78
3	338	56.12	126.02	56.91	71.98	29.25	35.91	37.43	2.28	431.65	6.93	2.08	9.01
4	350	102.26	97.85	33.14	95.06	24.62	39.84	36.57	2.95	504.79	5.12	3.09	8.22
5	297	115.81	32.40	56.23	80.19	16.05	36.90	36.36	3.69	493.48	1.47	5.99	7.46
6	295	99.58	38.43	69.71	66.40	3.45	35.40	36.96	2.58	476.13	1.77	5.68	7.46
7	302	68.32	59.50	65.96	84.81	25.29	34.35	36.50	1.90	425.08	2.88	4.69	7.57
8	308	68.44	70.93	67.45	72.65	29.87	34.50	37.01	1.35	434.27	3.52	4.18	7.71
9	310	64.27	71.73	77.74	73.54	24.04	34.19	36.95	1.34	430.64	3.57	4.15	7.72
10	350	221.08	28.45	63.27	33.54	21.77	47.36	38.51	18.13	743.36	1.28	6.19	7.47
11	430	207.78	59.70	80.00	67.72	27.09	50.85	35.20	12.30	793.95	2.89	4.68	7.58
12	460	269.40	37.92	59.26	96.88	18.08	58.58	33.65	21.56	914.74	1.75	5.71	7.46
13	465	261.44	74.10	49.93	70.80	26.87	57.93	34.83	18.15	903.60	3.70	4.05	7.75
14	462	261.43	79.77	66.69	64.70	9.25	57.32	35.34	19.86	900.42	4.03	3.81	7.85
15	455	250.84	101.11	79.50	37.55	6.65	55.54	37.95	20.66	883.49	5.32	2.97	8.30
16	430	181.78	106.77	76.05	66.27	7.01	48.66	36.5	7.90	728.55	5.68	2.76	8.44
17	435	196.37	89.37	57.35	86.38	10.86	50.50	35.15	8.48	747.10	4.61	3.41	8.03
18	456	260.64	67.74	47.75	83.60	14.22	57.42	34.53	17.98	884.08	3.34	4.32	7.67
19	452	266.00	72.20	69.99	49.28	17.04	57.12	36.23	22.54	910.26	3.59	4.13	7.73
20	446	179.54	111.73	64.25	81.81	15.1	49.95	35.27	6.47	734.80	6.00	2.58	8.58
21	435	260.80	21.48	70.69	96.95	7.26	56.06	33.96	22.21	878.79	0.95	6.55	7.51
22	426	227.10	66.90	74.82	56.95	15.81	52.15	36.02	15.60	816.65	3.29	4.36	7.66
23	407	148.70	105.23	58.82	74.00	24.23	45.51	35.96	4.01	649.86	5.58	2.81	8.40
24	370	113.62	115.56	53.56	65.46	24.34	41.02	37.12	2.19	553.34	6.24	2.44	8.69

Fig. 2,,3,4,5,6,7 and 8 shows the effect of wind uncertainty coeffecients on optimal wind scheduling for five different cases i.e. (i) Minimum cost schedule (ii) Minimum emission schedule (iii) Minimum loss schedule (iv) Maximum heat schedule and (v) Schedule for multiobjectve optimization for three different loading conditions i.e. the low load,medium load and he high loading conditons.

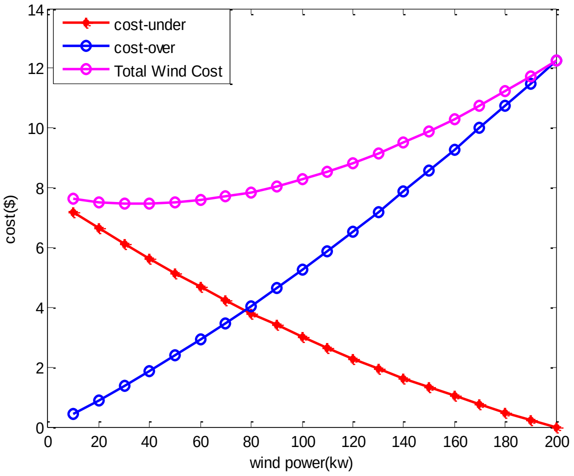

Fig. 2 Wind power cost variation with scheduled wind power for maximum heat scheduling (169 kW load)

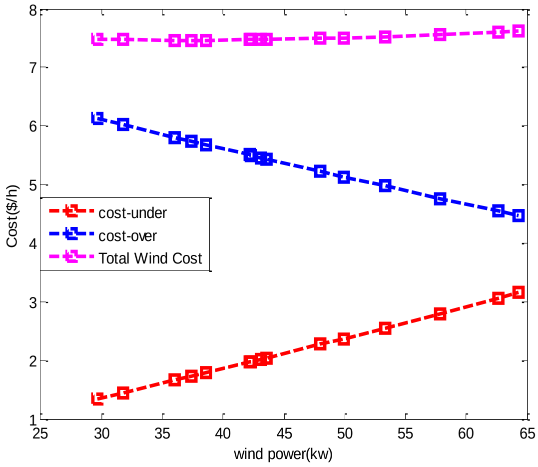

Fig 3 . Wind power cost variation with change in scheduled wind power

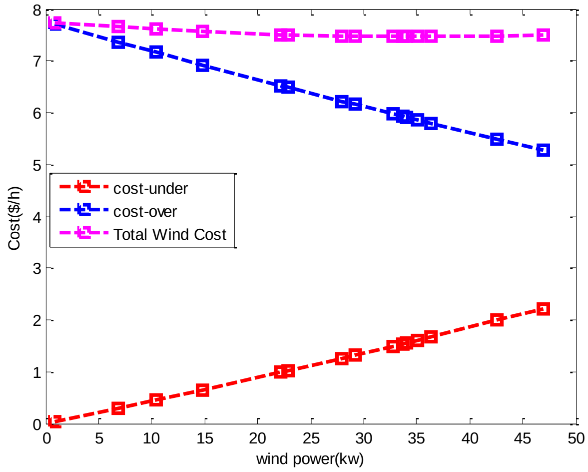

Fig 4 Wind power cost variation with scheduled wind power for minimum emission scheduling (169 kW load)

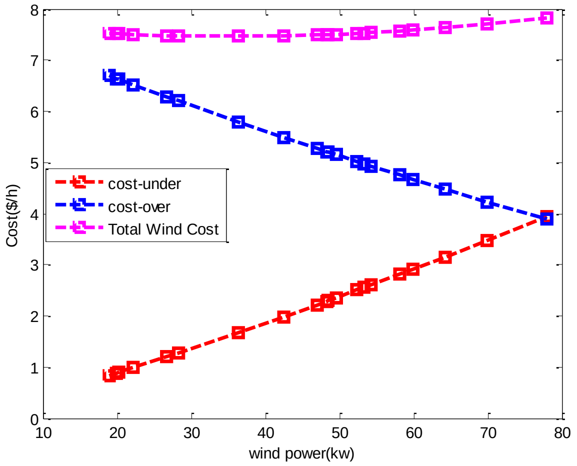

Fig 6 Wind power cost variation with scheduled wind power for minimum cost scheduling (169 kW load)

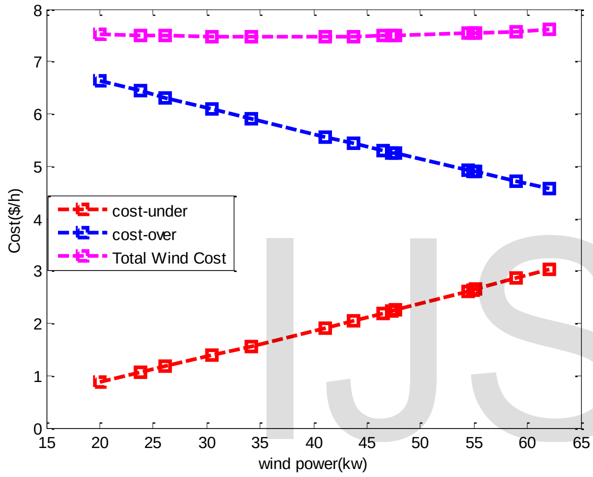

Fig 5 Wind power cost variation with scheduled wind power for minimum loss scheduling (169 kW load)

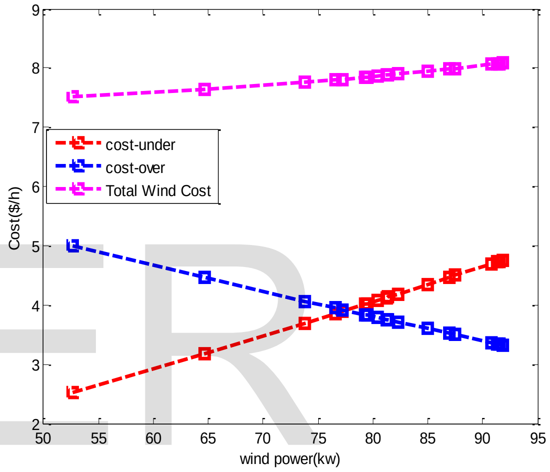

Fig. 7 Variation of objective function with scheduled wind power for multi-objective scheduling (169 kW load

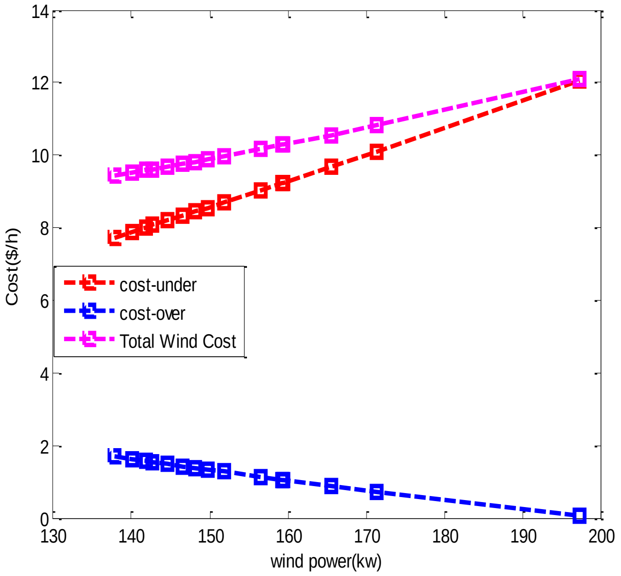

Fig 8 Variation of objective function with scheduled wind power for multi-objective scheduling (248 kW load)

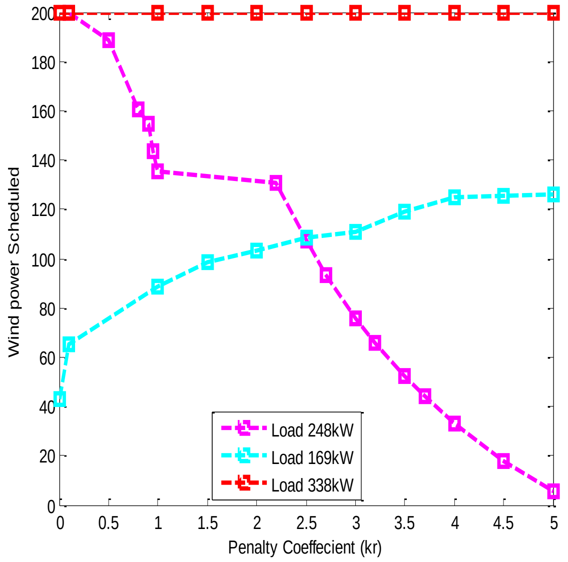

Fig 9 Variation of scheduled wind power with penalty coefficient

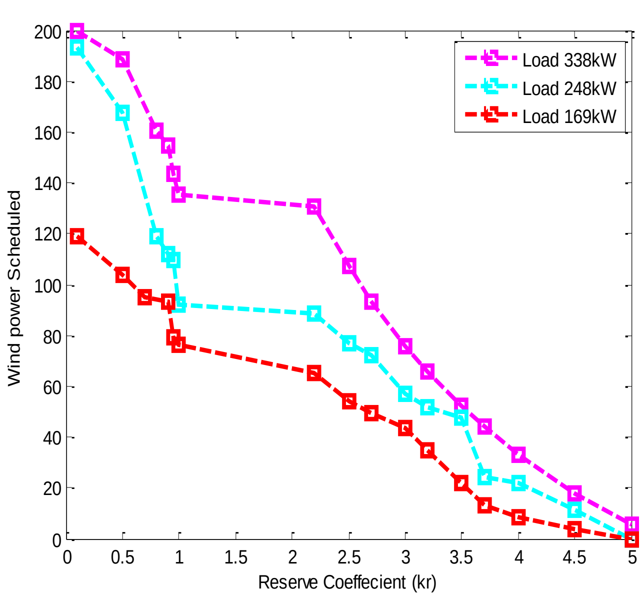

Fig. 10 Effect of reserve coefficient (kr) on wind power scheduling (Multi-objective)

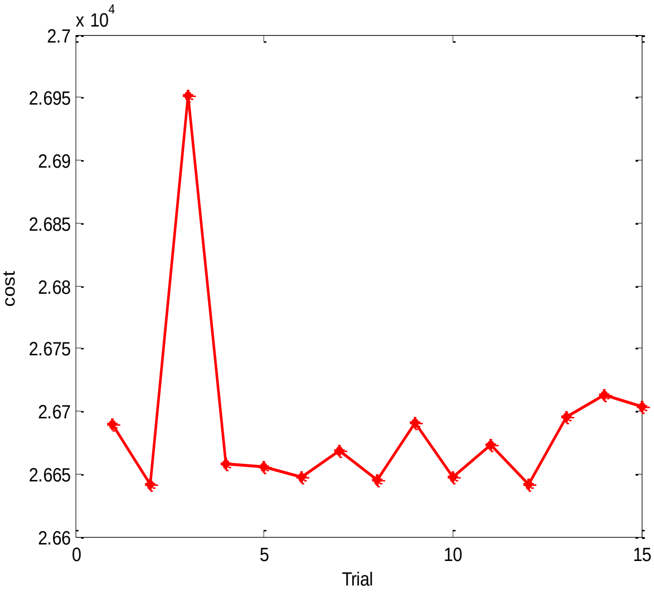

Fig 11 Consistency Analysis of results (MOO case-4 obj)169MW

The selection of reserve and penalty coefficients (kr & kp) play a very important role in optimal scheduling of micro grid when wind generators are present. The increase in the value of kr means that a higher cost will be is imposed if the wind power is over estimated, i.e if the available wind power comes out to be less than the scheduled value. Therefore, the optimization routine tends to schedule a lesser value of wind power as kr is increased. Fig. 9 shows the variation/reduction in scheduled wind power with increase in kr for three different loading conditions. For higher load, more wind power is scheduled to get best performance in terms of the four objectives. Fig. 11 shows the variation/reduction in scheduled wind power with increase in kp for three different loading conditions. For higher load, more wind power is scheduled to get best performance in terms of the four objectives.Figure 11 shows that the cost vary very consistently with the number of trials except one instant.

Two-objective optimization: All possible combinations of the four objectives were taken, which resulted in six cases: Cost-Emission, Cost-Loss, Cost-Heat, Emission-Loss, Emission-Heat and Heat-Loss. Pareto fronts were plotted in Figure 12 to 16 for all the six combinations to get a large number of trade off solutions in a wide range.

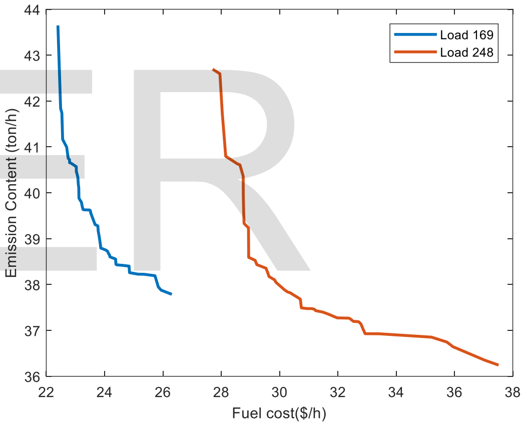

Fig.12 Pareto front for Cost-Emission Optimization

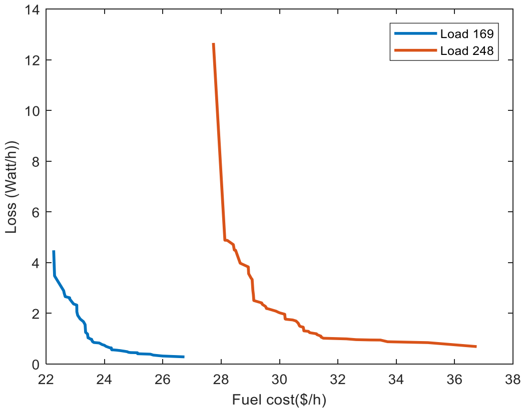

Fig 13 Pareto front for Cost-Loss Optimization

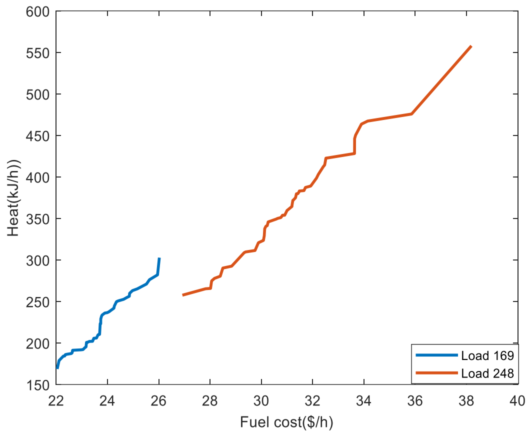

Fig 14 Pareto front for Cost-Heat Optimization

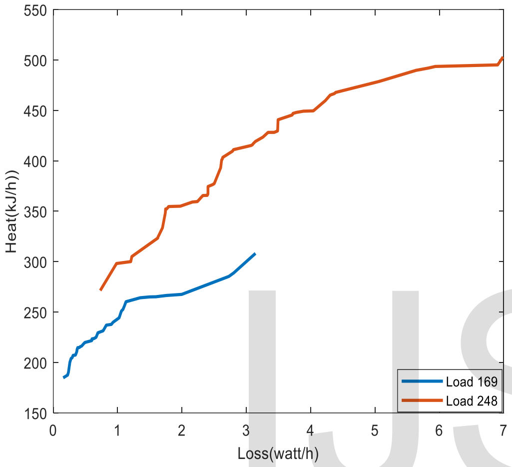

Fig 15 Pareto front for Loss-Heat Optimization

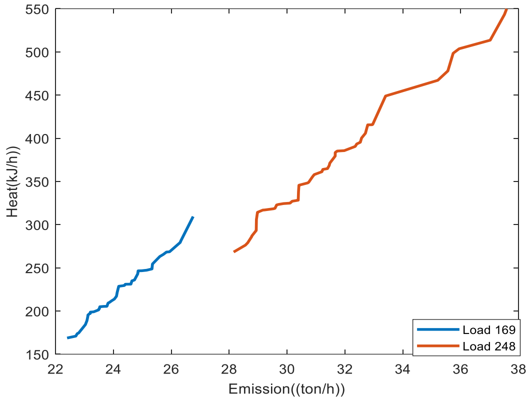

Fig 16 Pareto front for Emission-Heat Optimization

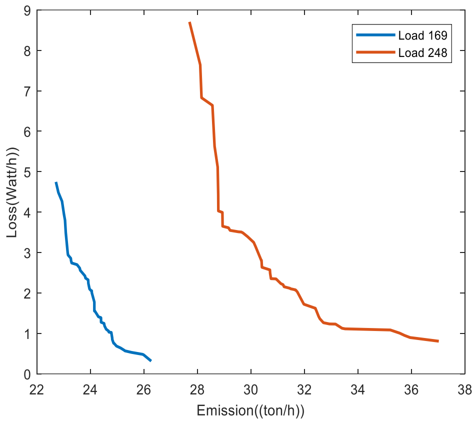

Fig 17 Pareto front for Emission-Heat Optimization

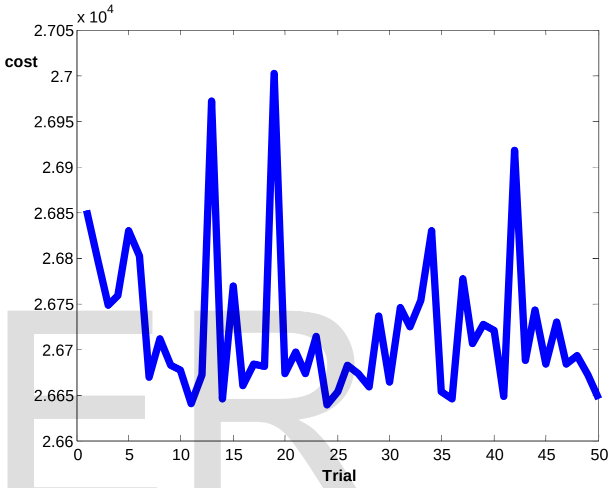

Fig 18 Variation of cost for different loading condition with trials.

Conclusion:-

Multi objective fuzzy index based optimal scheduling may help the power system operator to choose the better option for preferred atmospheric condition for the optimum allocation of the different energy resources. A fuzzy logic based method is suggested for a MG consisting of CHP units and micro turbines for finding the optimal dispatch solutions with real-time optimization of cost, emission, loss & heat. The TVDE method is creating a well-proportioned pareto front with large number of trade off solutions fairly consistent.

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