Journal of Advanced Research in Technology and Management Sciences
Volume: 01 Issue: 03 ISSN: 2582-3078 November 2019
Available online at: http://www.jartms.org

Economic Load Dispatch of Distributed Generation – An analysis of Thermal units with and without integration of PV units.

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Abstract—The means of distributing the ever-changing load by properly scheduling the available units, both thermal and solar photovoltaic(PV) units of distributed generation so as to obtain the most economic operating cost, reducing the valve point loading effects, minimizing the emissions and making the maintenance of the units simpler is proposed in this paper. The analysis carried out on 6,15,31Thermal units without and with integration of solar PV units distributed at uniform geographical locations in the state of Telangana, India. The unique cost -per -hour characteristics of thermal generating units(TG), their emissions, valve point loading effects, ramp rate limits, prohibited operating zones and capacity constraints make the cost equation more complex also the cost of operation of thermal units is more.To supply for reliable, sustainable,ever increasing load requirements in most economical way, solar power plants have to be installed and integrated them to the grid evenly across various geographical locations in addition to the already existing ones. The allocation of the load i.e the Load Dispatch to the generating units both Solar PV and TG considering their various parameters which effect their cost of operation are evaluated for different load demands to obtain the most economical operating costs using the 3 algorithms, viz., Non-linear Generalized reduced gradient (GRG) algorithm, Evolutionary algorithm(EA) and Moth flame optimization algorithm (MFA) and the results are compared.

While calculating ELD,the various parameters such as the fuel cost coefficients, valve point loading effects, penalty due to emissions, transmission losses, minimum and maximum capacities, ramp rate limits and prohibited operating zones of thermal power units and the parameters such as the minimum, maximum and average power capacities of a solar PV units placed at that particular location,which in turn depend on the solar irradiance values for the peak solar hours in any day of the year at that location and a factor of overestimation, underestimation of available solar power of PV units are considered.

By integrating PV units with Thermal units, the transmission line losses, the cost incurred due to valve point loading effects, the penalties due to emissions, and mainly cost of load dispatch which is associated to all the aboveare greatly reduced more so in case of systems having lager number of units and with greater power demand.Even the maintenance of TG units becomes simpler as the loads are distributed to PV units.

Non-Linear GRG and Evolutionary algorithm are simpler and can be evaluated in Solver an add-in ofMicrosoft Excel inMSOffice2010 version and above systems and consume less time and needs only a minimum coding knowledge.Also,the results obtained from MFA are more economical compared to Evolutionary algorithm and GRG algorithm andthe time taken for convergence to arrive at Global optima is also very less.

Key words—Cost of dispatch,Evolutionary algorithm, GRG Algorithm, Load demand,Moth flame algorithm, Photo-voltaic.

I. Introduction

Globally the rate of increase of load demand is 2.1% per annum due to the increasing digitalization and adopting energy efficiency methods in all sectors. The power consumption in the state of Telangana, India is increasing rapidly more so in the agrisector which has seen a steep rise of 62% since 2013and the peak demand has crossed 13,500 MW. The installed capacity of Thermal power is 6682.5MW from various units belonging to Kakatiya TPP(1100MW),KothagudemTPP(2460MW), Ramagundam(62.5MW & 2600MW),Singereni (1200MW) and 7780 MW is under construction. The installed capacity of solar PV plants is 173 MW distributed at Palwal village (**Lat, Lon: 17.55, 77.45**) near Gadwal(12+12 MW)from Telangana –I & II Solar power plants(SPP), Dharmaraopet SPP (143MW) near Kamareddy**(Lat, Lon: 18.45, 78.25**), Ramagundam (**Lat, Lon: 18.75, 79.45**)SPP(10MW), Jalar SPP(1MW)[1][2].

For the conventional methods of power generation like Thermal power plants, which is the major source (almost 80%)of power globally, Coal is the raw material.It is fast depleting and may not be able to supply for the power demands in the coming future, the various units of TPP have dissimilar input-output characteristics which makes the cost equation quadratic, as the scheduled load on the units vary, the valves for steam injection on the turbines have to be adjusted which effects its speed resulting in the rippling effects also called Valve point Loading effects. The emissions like Cox, NOx, SOx etc., emanating out of TPP pollute the atmosphere and need to bear the penalties, they have to be operated within their capacity limits and also the ramp up or ramp down limits have to be taken care of. .In some operating

Zones, the efficiency of the machine falls below the acceptable level, so the units are not put into operation in those ranges or zones called Prohibited operating zones. All the above effects increase the cost of load dispatch. Hence there is a dire necessity for the Power sector to think of a better alternative. To start with, the integration of TPPs with other non-conventional sources like solar, wind, bio-mass etc minimizes the utility of coal, preserves them for future generations, reduces pollutionand mainly the cost of Load dispatch. The integration of Solar PV units with Thermal units is one of the intelligent alternatives because solar energy is freely available as many parts of India receive high solar irradiance for almost 300 days in any year.Hence installation of various solar power plants(SPP) of 12MW/ 15MW capacity in addition to the already existing ones are to be proposed and placed mainly in all the district headquarters in Telangana. Interestingly Hyderabad is highest power consuming city in India next to Mumbai with greater than 20000MU since 2018.From the solar irradiance data obtained fromhttps://pvwatts.nrel.gov/pvwatts.php,[3]the maximum, minimum and average output power at a particular location for the designed SPP is calculated considering only the peak sun hours in a day (though the solar radiation is from 7.00am to 05.00pm on any average day).For solar PV units, the transmission line losses are not considered as they are placed at the distribution end. All the PV units of SPP are of Modular, standard, fixed (open rack) type with arrays tilted by 20^0 and with an azimuth angle of 180^0. System losses are estimated to be 14.08% due to soiling, shading, mismatch of modules, wiring, light induced degradation etc.,For integrating the number of units of TPP and SPP,the most important task is to interconnect all generating units in parallel, synchronize them with the grid then properly schedule them to meet the load demand in the most economical way by considering all their constraints. For this an optimized and timely switching of generating units are to be made possible. Hence in this paper, the parameters of TPP are taken from standard test systems used by researches such as IEEE -6-unit ELDtest system consisting of 6 thermal units and IEEE-15unit ELD test system consisting of 15 thermal units and 30 thermal units for the load demand of 1263 MW, 2630 MW and 6000MW respectively [4].

The cost of Load dispatch is evaluated without and with a load sharing of 25%, 50%,75% by Solar PV units. In TPPs, the input output characteristic curves of all the generators connected in parallel are not similar or identical to each other, as they belong to different brands and have varied efficiencies, hence the load cannot be divided symmetrically on all of them. Also fuel cost curves at differ at different power outputs.The total cost of dispatch is the sum of fixed costs and variable costs (which depend of the scheduled power), of both TP units and SP units. The objective of ELD is to schedule the power output of all the units within the designed limits of each individual unit and to meet load demand with optimal fuel and operating cost.

The Load demand profiles are very complex and irregular in nature which makes the objective function i.e., the total cost/ hr of load dispatch still more complex. Hence A number of optimizing techniques,computational techniques, stochastic methods based on Modern BIA (Biologically Inspired Algorithms), MATLAB programming methods, Lambda iteration mathematical programming methods are employed to solve Economic Load Dispatch problem[5].

The Modern BIA (Biologically Inspired Algorithms) are classified as Evolutionary based, Ecology based, Swarm based algorithms find their applications to solve ELD[6].

The **Evolutionary based algorithms** aim at solving the problem based on the collective phenomena in adaptive populations comprising growth, development, reproduction, selection, and survival. EAs are nature inspired, classical, non-deterministic cost-based optimization algorithms and mimic the strategies of living organisms to interact with each other performing with best-to-survive criteria. A family of EAs comprises of genetic algorithm (GA), genetic programming (GP), Differential Evolution, evolutionary strategy (ES) and Paddy Field Algorithm. The EA are all population-based stochastic search algorithms. They commence by creating an initial population of feasible solutions and evolve iteratively from generation to generation towards a best solution. In successive iterations of the algorithm, fitness-based selection takes place within the population. Better solutions are selected to fit into the next generation of iterations.

The **Ecology based Algorithms** are also bio inspired algorithms in which the living organisms interact with abiotic environment such as air, soil, water etc. The interactions can be among the species of ecosystem which can occur between the species or within the species and can be cooperative or competitive. These are PS2O, Invasive weed colony Algorithm (IWCA), Biogeography based Optimization (BBO).

Another type of bio inspired algorithms **Swarm based Algorithms** which are an extension of EC. While EAs are based on **genetic adaptation** of organisms, Swarm Intelligence (**SI**) is based on collective **social behavior** of organisms**. SI** implements the collective intelligence of groups of simple agents based on the behavior of real-world insect swarms, as a problem-solving tool. The family of SI which can solve ELD problem comprises of Particle swarm optimization(PSO), Ant colony optimization(ACO),Artificial Bee colony optimization(ABC), Fish Swarm optimization(FSO), Intelligent Water Drops optimization(IWDO), Bat Algorithm(BA), Krill -Herd Algorithm(KHA), Bacterial Foraging Optimization Algorithm(BFOA), Firefly Algorithm (FFA), Artificial Immune system Algorithm(AISA), Group research Algorithm(GRA), Shuffled Frog Leap Algorithm(SFLA), Moth flame Algorithm(MFA)etc

The Non-linear GRG algorithm works by considering the reduced gradient to find either the minimum or maximum of the objective function.Solver an **add**-in has found its application in what-if analysis and to find an optimal (maximum or minimum) value for a formula in the objective cell in Excel — subjected to constraints, or limits, on the values of other formula cells in any worksheet.The Non-linear Generalized Reduced Gradient (GRG) Algorithm present in the Solver tool in the additional settings in Data menu of Microsoft Excel Add-ins is the most popular method of optimization used to solve problems with active inequalities. The GRG Nonlinear Solving Method uses the Generalized Reduced Gradient (GRG2) code for solving nonlinear optimization problems.The variables are separated into a set of dependent variables and independent variables. Then, the reduced gradient is computed in order to find the optimum value in the search direction. This process is repeated until the convergence is obtained.

It is easy to install run and execute solver in any system having MSOffice and the time taken for execution is also very less compared to various methods of solving ELD. The personal working in Load dispatch centres can work on this for effectively scheduling the load instantly and economically and need not have any programming knowledge. Setting the parameters by defining the changing variables as the loads on units subjected to the constraints of the units to obtain the global minima of the formulated objective function by selecting a method or algorithm gives the solution.

Similarly,ELD can be solved by using Evolution Algorithm which is a built-in algorithm in Solver of Excel using similar steps. It uses Genetic algorithm for solving optimization problems. It gives better results than Non-linear GRG algorithm, but takes longer time comparatively.

Moth flame Optimization Algorithm is also a population-basedBio inspired algorithm which works on swarm intelligence techniques, i.e., the behaviour of moths around lights. It is superior over lambda iteration method, Particle swarm optimization (PSO) and Sine-Cosine algorithm (SCA)in the aspect of time taken for iterationsto arrive at complete convergence. It gives better performance than than SCA in view of various parameters viz. Exploration, local optima avoidance, exploitation and convergence. Though Grey wolf optimization (GWO) algorithm has a good balance between exploration and exploitation, resulting in high local optima avoidance, the computational time taken is more when applied to economic dispatch problem of medium and large-scale power system. Moreover, the convergence of MFO is very swift in comparison to the Lambda Iteration Method, Genetic algorithm (GA), Particle Swarm Optimization (PSO) algorithm for the small-scale power systems. Owing to all the above, MFO has the capability to congregate to a superior quality near optimum solution &has superior convergence qualities compared to the other algorithms[9].

Hence in this paper, ELD is computed on6,15,31thermal units without and with integration of PV units for various load demandsusing GRG algorithm, Evolutionary algorithm and Moth flame Optimization algorithm and the results are compared with respect to efficiency and economy.

2. PROBLEM FORMULATION

Economic Load Dispatch of Thermal power interconnected with Solar power:

Economic load dispatch is calculated to find out the operating cost of power system through the strategic scheduling of power to be generated by various units both TP and Solar PV taking into account the fuel costs, valve-point loading effects, penalty due to emissions, transmission losses while considering the minimum and maximum capacities, prohibited operating zones, ramp-rates limits of all the thermal units and the operating costs, the reserve cost factor, the penalty cost factor for overestimation and underestimation of available solar power by considering the minimum, maximum and average capacities for PV units there by fulfilling the load demand. Transmission losses are negligible for PV as they are to be placed near the load end.In general, only real power generated is considered for solving ELD.

2.1.Parameters of Thermal Power Units:

2.1.1.Operating Cost equation considering fuel cost coefficients :

The cost per hour of thermal power generation is the summation of the fixed costs which are independent of the amount of power generated and variable costs which depend on the scheduled power to be generated by each unit.

The cost function is given as:

$$\boldsymbol{Cost_{gen.Tp}} = \sum_{i=1}^{n} \boldsymbol{a_i P_i^2} + \boldsymbol{b_i P_i} + \boldsymbol{c_i} \ldots(1)$$

For ‘n’ number of units

Where $\boldsymbol{Cost_{gen.Tp}}$ is the fuel cost of generating Pi amount of output power in Rs./Hr.

ai, bi and ci are the fuel cost coefficients for Pi.

a_i= coefficient to measure of losses in the ith generator given in \$/MW^2Hr.

b_i = coefficient which represents the fuel cost in the ith generator in \$/ MW.Hr

c_i = constant coefficient includes salary, wages, interest and depreciation of the ith generator and is independent of the amount of power generated in \$/Hr.

2.1.2.Effects due to Valve point Loading

The cost per hour of thermal power generation also depends on the valve point loading effects, which are caused due to the changes in steam admission through various nozzles as the scheduled power to be generated by a particular unit(P_i)changes. This gives rise to rippling effects due to variation in speed of the turbine.

Journal of Advanced Research in Technology and Management Sciences
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$$Cost_{gen.Tp} = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i + |d_i \sin(e_i(p_i^{min} - p_i)) | \quad ...(2)$$

Where d_i and e_i are the co-efficients reflecting valve point loading of ith generator in $/Hr.

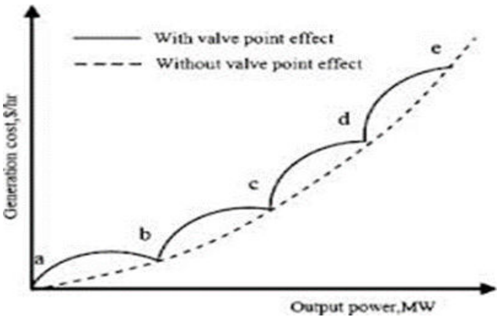

Fig.2: Operating cost curve considering valve point loading effects.

2.1.3.Transmission Losses:
The losses in the transmission network can be calculated using the formula

$$P_{loss} = \sum_{i}^{n}\sum_{j}^{n} P_i B_{ij} P_j + \sum_{i}^{n} B_{0i} P_i + B_{00} \quad .....(3)$$

Where B_{ij}, B_{0i}, and $B_{00}$are the loss coefficientmatrices.

The total Real power to be generated is the sum of load demand P_D and losses due to transmission, considering only real power losses P_{loss} and is given by

$$P_{T\ total} = \sum_{i=1}^{N_g} P_i = P_D + P_{loss} \quad ......(4)$$

For efficient operation of the units,their scheduled power generation must lie within their minimum and maximum capacities.
The inequality constraint considering the generation limits is given by Eq.(5)

$$P_{imin} \le P_I \le P_{imax} \quad ....(5)$$

Where *Pimin*is the minimum generation capacity limit and *Pimax*is the maximum capacity limit of i[th] generator.

2.1.4Cost incurred due to Emissions:
When the thermal power units are put into operation, it give rise to the emissions in the form of CO_X, SO_2, NO_Xetc.,while the coal is burnt. These emissions pollute the atmosphere and are subjected to penalty. To minimize the emissions, ash free coal or refined coal is used. As the % of usage of refined coal increases, emissions decrease, thereby reducing the penalties to be paid for emissions.

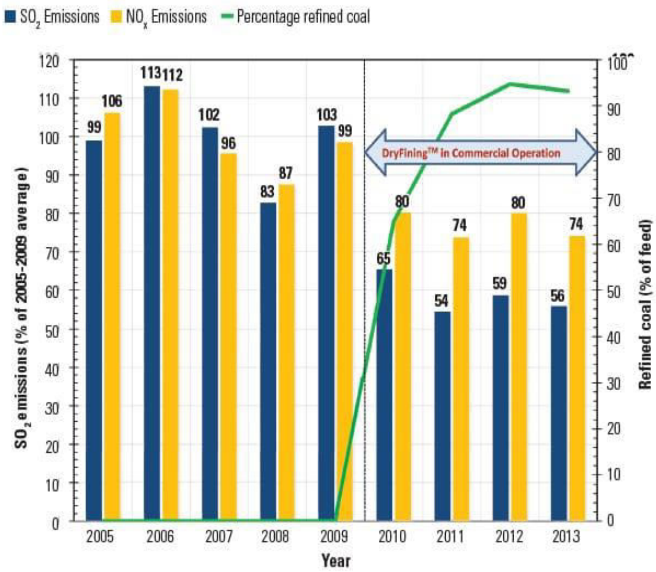

Fig.3: Emissions over a period of time

Further the emissions mostly depend upon the amount of power generated. The Economic load dispatch involves generation of required power for serving the system load with minimum emissions so as to reduce the penalty costs. The emission cost per hour for a particular power generation is given by a function

$$Emission\ cost = \sum_{i=1}^{n} \alpha_i P_i^2 + \beta_i P_i + \gamma_i \quad .....(6)$$

Where αi, βi, γi are emission coefficients of the ith generating unit given in $/MW^2Hr., $/MW.Hr and $/Hr respectively.
The Operating cost of Thermal power unit considering valve point loading and emission is given as

$$Cost_{gen.Tp} = \sum_{i=1}^{n}((a_i P_i^2 + b_i P_i + c_i) + |d_i \sin(e_i(p_i^{min} - p_i))| + h_i(\alpha_i P_i^2 + \beta_i P_i + \gamma_i)) \quad ......(7)$$

Where $h_i = \frac{a_i P_{imax}^2 + b_i P_{imax} + c_i}{\alpha_i P_{imax}^2 + \beta_i P_{imax} + \gamma_i}$ .....(8)

Where P_{imax} is the maximum capacity of generation i[th] generator
h_i is the price penalty factor of emissions for i[th]generator.
'*h*'for a particular load demand is obtained by calculating the value of h_i for each generating unit, arranging these values *of* h_i in assending order along with the corresponding P_{max} of the units,writing down the cumulative values of maximum power generation. The value of '*h*' for a particular load demand is the value of h_i corresponding to the cumulative P_{max}.

2.1.5.Ramp rate limits:
For balancing the net load, providing flexibility, reliability and economy of operation, the difference in power generated by a particular generator (P_i) in a certain interval and that of in the previous interval P_{i0} must not exceed by more than a certain amount called

the up-ramp rate limit URi and must not decrease by less than certain amount called the down-ramp rate limit DRi of that generator.
These constraints are given as
As generation increases Pi–Pi0 ≤ URi
As generation decreases Pi0–Pi≤ DRi and
max (Pi min,Pi0 -DRi) ≤ Pi ≤ min(Pi max, Pi0+ URi)….(9)

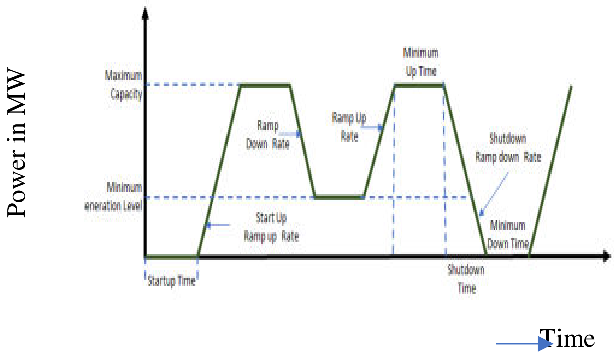

Fig.4.Ramp Rate Limits

2.1.6 Prohibited Operating Zones:
In some operating Zones, the vibrations in the shaft bearings will be very high due to which the efficiency of the machine falls below the acceptable level, so the units are not put into operation in those ranges or zones. These zones are called Prohibited operating zones.There can be multiple such zones for any machine, which makes the problem of ELD still more complex. For unit 'i'with 'j' POZs, the feasible operating zones can be described as follows:

Pi min <=Pi<= Pl i,1
P u i,j-1 <= Pi <= P l i,j j=2,3,…….ni
P l i,ni<= Pi <= Pi max …………… (10)

Where
j is the number of prohibited operating zone of unit i.
Pli,j is the lower limit of jth prohibited operating zone and
Pui,j-1 is the upper limit of (j-1)th prohibited operating zone of ith unit.
ni is the total number of POZs of ith unit.

2.2.The operating cost Solar PV units is given by
The power generated by solar PV units at a particular location is obtained from the solar irradiance values during various seasons as given by NREL data. Solar irradiance is not constant throughout any hour in a day, all the days in any month, all the months in a year. So the average Solar irradiance / day is calculated for an year by considering the peak sun hours in a day over an year.
The minimum, average and maximum PV Watt values per hour are calculated from the solar irradiance values obtained from the data.

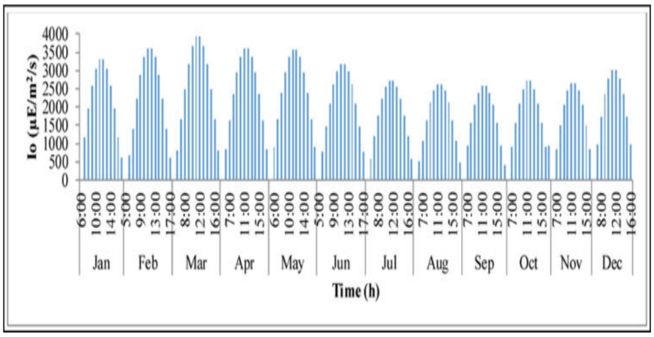

Fig.5. Solar Irradiance Profile of Hyderabadin the year 2021.

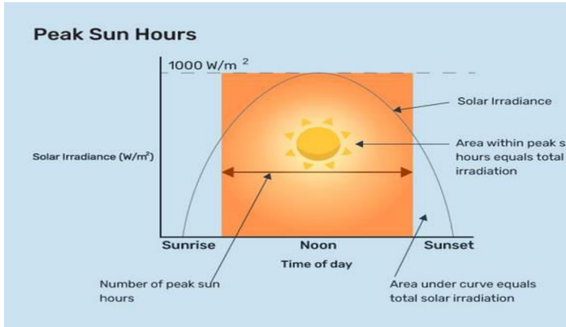

Fig.6. Peak Sun hours

The total cost solar power of ith unit is given by

$$Cost_{gen.PV} = \sum_{j=0}^{p} \sum_{i=0}^{m} ((\mathbf{C\ pvi\ (\ pv\ ij)} + \mathbf{Cp.pvi\ (\ PVi.av - pvij\ )} + \mathbf{C\ rpvi\ (\ pv\ ij - PVav\ )\ )}....(11)$$

Where $C_{pvi}$is the cost coefficient of the generated output solar power which is the scheduled power,$C_{p,pvi}$is the penalty cost coefficient for under estimation i.e., for not using all the available PV generated power and $C_{r,pvi}$is the reserve cost coefficient for over estimation of PV power i.e the reserves which is due to that the actual solar power generated is less than the scheduled power,*pvij*is the power committed by *ith*PV unit during *jth* hour. *PVi,av*is the available amount of energy of *ith*PV unit, adding the factor of overestimation and underestimation of available solar power.
The tariff paid by DISCOMs to the solar PV companies varies from state to state. As per the Power purchase agreement (PPA) of Telangana state, the cost of each unit is Rs.6.49 with a penalty of Rs.0.50 per unit if the deviations are > 15% but <=25%, For deviations > 25%, Rs.0.50 per unit upto 25% and Rs.1.0 per unit for deviations >25% and <=35%. For deviations > 35%,Rs.0.50 per unit upto 25%,Rs.1.0 per unit from 25%to 35% and Rs.1.50 per unit for deviations are > 35% in 15minute duration.[5]

The total operating cost is calculated by summing Eq. (1) and eq. (11),

Cost $_{\text{total}}$ **=** $\boldsymbol{Cost_{gen.Tp}} +$ **Costgen . PV** **……………(12)**

C:The Objective Function

The objective function of this study is to strategically distribute the load among the units so as to minimize the cost of Load dispatch of power system when PV units are used along with Thermal units satisfying all the constraints.

$$F_T = \mathrm{Min}(\mathrm{Cost}_{\text{total}}) = Min\left(Cost_{gen.Tp} + Cost_{gen.PV}\right) \quad \text{……………(13)}$$

Equation (13) is evaluated by considering all the concerned parameters mentioned above for thermal units and Solar PV units.

3.METHODOLOGY

To find the Most economical total operational cost of the Load dispatch

- without integration of PV units and
- with integration of 2,4,6,10, 31 PV units separately on
- 6 thermal units 15 thermal units and 31 thermal units for different Load demands,
- comparing the results and thereby proposing the best combination of units for the distributed generation

the following methods are implemented.

- Nonlinear GRG Algorithm
- Evolutionary Algorithm
- Moth Flame Algorithm

3.1.A Non- Linear Generalized Reduced Gradient Algorithm:

GRG non- linear Algorithm is applicable for non-smooth and most difficult type of optimization problems where best decision is needed. GRG Nonlinear and Evolutionary are best for nonlinear problems, while Simplex LP is limited only to linear problems.Of the two nonlinear solving methods, GRG Nonlinear is the fastest. In this method the gradient or slope of the objective function is taken as the decision variables (input values) and are then are separated as basic variables which are dependent variables and non - basic variables which are independent variables.

As the input values (or decision variables) change, it determines that it has reached an optimum solution when the partial derivatives of the objective function is equal zero. The solution obtained with this algorithm is highly dependent on the initial conditions and may not be the global optimum solution.Figuratively, this means that Solver has found a “peak” (if maximizing) or “valley” (if minimizing). The solver will most likely stop at the local optimum value nearest to the initial conditions, giving a solution that may or may not be optimized globally.The GRG Nonlinear Algorithm in solver is used to solve ELD and arrives at a locally optimal solution and also globally optimal solution.

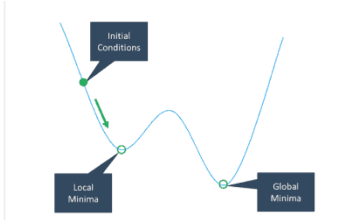

Fig.7. Graph of GRG algorithm

In this work, it is used to evaluate the most economical value(minimum) of cost function satisfying all the conditions and constraints of TP units and SPPV units to meet the load demand in accordance with the scheduled load. This is computed in the solver tool which is an add-in in Excel in advanced options of MSOffice10 or above versions. **Excel Solver** is a What-if Analysis Tool used in a number of engineering and business models for the purpose of simulation and optimization. The algorithms used in Excel solver are **GRG non-linear Algorithm**, Simplex LP and Evolutionary Algorithms. Simplex LP is used for linear problems and hence is not applicable to find ELD.

The various parameters like cost coefficients, emission coefficients, different load demands, transmission losses and the constraints like minimum, maximum values, limits of ramp rate for either increase or decrease in the scheduled generation, prohibited operating zones of thermal power plants for TP units and the minimum, average and maximum capacities for SPPV units are placed in a spread sheet. The cost/hr is calculated using the formula of cost function by choosing random initial values satisfying all the conditions. The optimum(minimum) value of the total cost/hrof load dispatch is set as objective function of the system, the load scheduling for various units will be the changing variable cells which in turn is equal to the sum of allocated load demand and transmission losses at a particular load. The various conditions and constraints of the units are to be defined in the algorithm. In order to obtain optimum value, the reduced gradient is computed in the search direction till it reaches convergence. The population size is taken as 100 and the number of iterations as 100. It gives the solution at a very fast rate. GRG solver results in better solutions, escaping locally optimal solutions in favour of globally optimal ones.

3.2 .Evolutionary Algorithm:

The Evolutionary algorithm is more robust than GRG Nonlinear because it is more likely to find a globally optimum solution.The Evolutionary method uses genetic algorithms to find its solutions and is applicable for non-smooth problems. The Evolutionary method is based on the Theory of Natural Selection and looks at randomness, population, mutation, crossover and selection to solve the problem. In simple terms, the solver starts with a random “population” of sets of input values. These sets of input values are plugged into the model and the results are evaluated relative to the target value.The sets of input values that result in a solution that's closest to the target value are selected to create a second population of "offspring". The offspring are a "mutation" of that best set of input values from the first population.The second population is then evaluated and a winner is chosen to create the third population. This goes on until there is very little change in the objective function from one population to the next.This process so time-consuming because each member of the population must be evaluated individually. Also, subsequent "generations" are populated randomly to find the next best set of values, instead of using derivatives or the slope of the objective function as in non-Linear GRG algorithm.

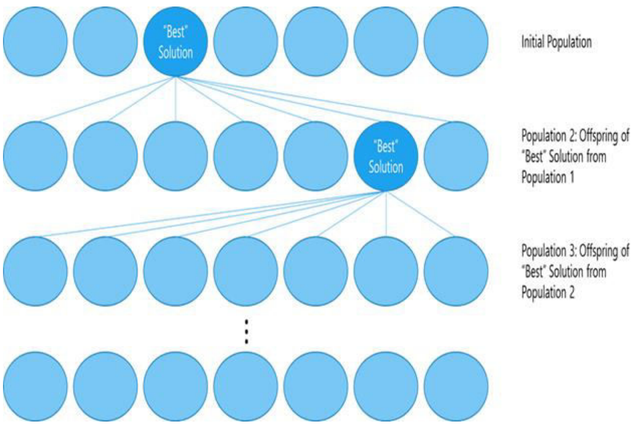

Fig.8 : Working of Evolutionary Algorithm

Excel application in MSOffice gives some control over the algorithm through the Solver Add-in options window. The Mutation Rate and Population Size can be chosen to potentially shorten the time taken for the solution.Here population size of 100, mutation rate of 0.75, convergence at 0.00001for 100 iterations are taken to solve ELD problem.Similar to GRG algorithm, the values of all the parameters effecting the cost function and their various constraints are placed in different columns in a spread sheet.The cost / hr is calculated using the formula, by considering a initial set of values of scheduled load for each unit. The optimum (minimum) value of the total cost /hr of load dispatch is set as an objective by changing the load schedule of all the units as variables and defining all the constraints, the evolutionary algorithm is run/ executed. With population size of 100, mutation rate of 0.75, convergence at 0.00001for 100 iterations, the algorithm processes by starting multiple times from different initial conditions, and finds a solution which is the global optimum.It gives a feasible solution satisfying all the conditions and constraints.

3.3 Moth Flame Algorithm

MFA is a population based evolutionary algorithm which finds its application in solving ELD problem.

This optimization Algorithm has the capability to arrive at a superior quality near optimum solution and convergence attributes compared to other methods like PSO, SCA, WFA etc. It uses better exploration and exploitation techniques thus avoiding local optima.It requires a fitness function to measure the 'quality' of a solution instead of complex mathematical operation like gradient or matrix inversion. This reduces the computational complexity

Moths are fancy insects, similar to the butterfly families. Their two main milestones in their lifetime are larvae and adult. Cocoons convert larvae to moth.They have been evolved to fly in night using the moon light. The most interesting fact about moths is their special navigation methods in nights called transverse orientation.In this method, a moth flies by maintaining a fixed angle with respect to the moon, a very effective mechanism for travelling long distances in a straight path. Since the moon is far away from the moth, this mechanism guarantees flying in straight line. When moths see an artificial light, they try to maintain a similar angle with the light,since such a light is extremely close compared to the moon, maintaining a similar angle to the light source causes a spiral fly path for moth and it eventually converges toward the light. The mathematical model of this behaviour can be proposed as an algorithm called Moth-Flame Optimization (MFO) algorithm

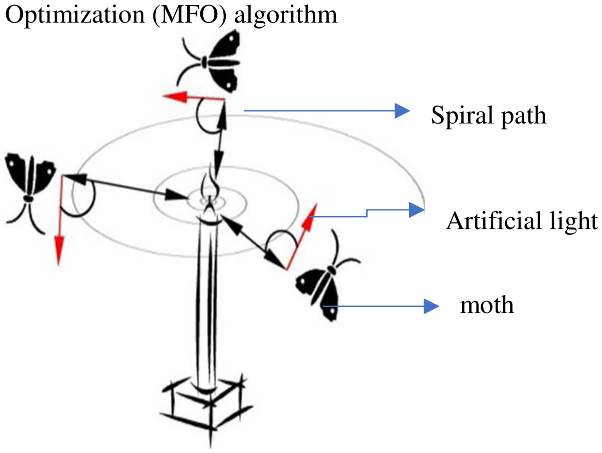

Fig.9: Spiral movement of moth towards flame

In this algorithm, the flame is taken as the best solution i.e., the most economical Load dispatch, while the position of moth with reference to flame is taken as the solution at a given time. The population of moths represents all possible solutions from which one best optimal solution is found. MFA is the best algorithm for exploring the search space.This is because of the individual searching of moth around the flame which leads to avoidance of local stagnation. Initially a random set of solutions are generated, Each of these solutions is considered as a candidate solution for a given problem, assessed by the objective function, and assigned an objective value. The algorithm then updates the candidate solutions based on their fitness values with a hope to improve them. The created solutions are again assessed by the objective function and assigned their relevant fitness values. This process continuedtill the end condition is satisfied. At the end of this process, the best solution obtained is reported as the best approximation for the global optimum.

For economic load dispatch problem, we assume that the cost/hr of load dispatch values of units are moths and the load scheduling of the units as the position of moths in the space.where d is the number of variables (i.e. population or dimension) and n is the number of moths (i.e. generating units).

[which implies: the cost/hr of the generating unit1 i.e., moth m1 for a particular scheduled load(i.e., at a particular position d1 to the flame) d1 is m11, of m1 for load d2 is m12….for load d is m1d, similarly, the cost of generating unit2 i.e., moth 2 for load (position of moth) d1 is m21….and so on…so that the set of moths or cost/hr for 'n' Gen.units/moths for loads 1 to d is written in matrix form as

$$M = \begin{bmatrix} m11\ m12\ m13\ldots\ldots m1d \\ m21\ m22\ m33\ldots\ldots m2d \\ . \\ . \\ mn1\ mn2\ mn3\ldots\ldots mnd \end{bmatrix}$$

The corresponding fitness values (i.e. optimal cost) for all moths for a particular load 'd' can be stored in a array as represented below:

$$OM= \begin{bmatrix} OM1 \\ OM2 \\ . \\ . \\ OMn \end{bmatrix}$$

Similar to moths, the set of flames can be represented in a matrix as:

$$F = \begin{bmatrix} f11\ f12\ f13\ldots\ldots f1d \\ f21\ f22\ f33\ldots\ldots f2d \\ . \\ . \\ fn1\ fn2\ fn3\ldots\ldots fnd \end{bmatrix}$$

where d is the number of variables (i.e. population or dimension) and n is the number of flames.The corresponding fitness values for all flames can be stored in an array as represented below:

$$OF = \begin{bmatrix} OF1 \\ OF2 \\ . \\ . \\ OFn \end{bmatrix}$$

The moth fame optimization algorithm is three tuple that approximates the global optimal of optimization problem and can be represented as: MFA = f{I,P,T}

where I, P and T are three functions.

The function **I** generates a random population of moths (cost/hr of load dispatch of units) and corresponding fitness values (optimum cost/hr) and mathematically can be represented as: I=Φ= {M,OM}

The function P moves the moths around the search space. It receives the matrix M and returns its updated one eventually i.e the original M matrix is updated based on the costs near to the optimum value and hence the updated matrix M contains the cost/hr of load dispatch of the units better than original M, and is mathematical represented as:P: $M \rightarrow M$

Like this a number of iterations take place till the function T returns true(i.e.,the termination criterion is satisfied : which corresponds to the global optima) and return false if the termination criterion is not satisfied and hence further iterations take place and mathematically can be represented as:

$T : M \rightarrow \{True, False\}$

The function **I** is used generate initial generation schedule and to calculate fuel cost value. The random generation used in function I can be implemented using algorithm mentioned below:

The framework of MFO algorithm with I, P and T can be updated as: MFO = (I, P, T),

$I : = \{M, OM\}$; $P : M \rightarrow M$; $T : M \rightarrow \{True, False\}$

After the initialization, the function P is iteratively run until the function T returns true. The P function is the main function that moves the moths around the search space. In order to mathematically model the transverse orientation, we update the position of each moth with respect to a flame (optimum value) using the following equation:

$Mi = S (Mi, Fj)$..(14)

where, S indicates the spiral function, Fj indicates the jth flame and Mi indicates the ith moth. By selecting logarithmic spiral as the main mechanism of moths, MFO algorithm can be represented as:

$S(Mi , Sj) = Di .e^{bt}. \cos(2\pi t) + F$..(15)

where Di indicates the distance of ith moth from jth flame (which indicates the difference between the optimum cost/hr of dispatch and the obtained cost/hr of dispatch corresponding to the scheduling of units as per the load demand), b is a constant for defining the shape of the logarithmic spiral and t is a random number in [−1,1]. Di can be calculated as:

$Di = | Fj - Mi |$…(16)

The position updating moths with respect to n different locations in search space may degrade the exploitation of the best promising solutions. To resolve this issue, following mathematical mechanism is adopted (Fig. 2):

$flameNo. = round (N - l * (N - 1)/ T)$…(17)

The code for MFA is written in JAVA programming language.It is executed and the results obtained are summarized in table:6.

4.RESULTS AND DISCUSSIONS

The Analysis is carried out on 6 ,15,31thermal power generating units, the values of the parameters effecting their cost function are taken from the standard IEEE-6 unit ELD test system and IEEE-15 unit ELDtest system and IEEE – 30 unit ELD test system respectively considering their fuel costs, penalty due to emissions, valve point loading effects, power capacity constraints, ramp rate limits, prohibited operating zones, and transmission losses with out and with integrating them with uniformly distributed PV units at various loads while sharing a load of 25%, 50% and 75% and the results are compared.

4.1 Consolidated results on using Non-Linear GRG Algorithm:

The parameters of the Tp units and PV units are placed in a spreadsheet, the emission penalty constant is calculated for various loads, Tr.losses, cost due to VPL effects, Cost /hr. of each unit both Tp& PV by using their cost functions and total cost/hr. are evaluated by considering a random initial values. Then in Solver Add-in, an application in Data tab of Excel, solver parameters such as total cost / hr. in Rupees is set as an objective function, the loads on various generating units are set as the changing variables, Optimization to find the minimum of the objective function is carried out by stating all the constraints like minimum and maximum capacities, Ramp rate limits, POZs, total power to be generated etc for Tp units and min, max, conditions for PV units. The solution is obtained by applying the inbuilt Non-linear GRG algorithm by setting a population size of 100 and convergence rate of 0.0001.The solution so obtained i.e., the load to be scheduled on each unit so as to arrive at the most economical load dispatchis updated automatically in the spread sheet. It also gives the values of Transmission losses and cost due to VPL based on the updated load dispatch of the units. Table:1 shows the results of IEEE-6-unit ELD test system on 1260MW load. For a load share of 25% , 50% and 75% by PV, 4 PV units, 8 PV units and 11PV units are placed at uniformly distributed locations respectively and are integrated to the grid connected to TPunits. It is found that with nearly 25% load taken up by PV units, the cost/ hrof dispatch is reduced by 41.37%, cost due to VPL effects are reduced by 19.75% and Transmission losses by 1.35%. Similarly with 50% & 75% load scheduling to PV,the cost/hrof dispatch is reduced by 67.86 %&77.81%, cost due to VPL effects are reduced by 57.83% &100% and Transmission losses by 66.3%&90.88% respectively. Interestingly, when the TPP units are loaded with their minimum capacities, the cost due to VPL is nil.So, 100% reduction in cost due to VPL. The % reduction in cost /Hr. of dispatch, VPL and Tr. Losses areshown in Fig.12.

Table 1: Results of IEEE-6 unit ELD test system on 1260MW load

GRG Consolidated for 6Tp with a load of 1260MW				
Gen. Units	100%Tp	75%Tp + 25%PV	50%Tp+ 50%PV	25%Tp + 75%PV
Cost in RS./Hr	3613103.93	2118484.75	1161193.774	801696.28
VPLin Rs./Hr.	355.780121	285.491641	150.0098647	0
Tr.Losses in MW	13.11226	8.31294225	4.419365157	1.196296

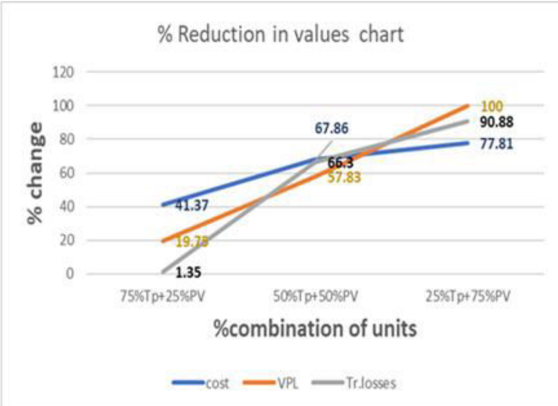

Fig.10: % Reduction in cost/hr.,VPL, Tr.losses

Table:2 shows the results of IEEE-15 unit ELD test system on 2640MW load. For a load share of 25% , 50% and 75% by PV, 8 PV units, 16 PV units and 24PV units are placed at uniformly distributed locations respectively and are integrated to the grid connected to TP units. It is found that with nearly 25% load taken up by PV units, the cost/ hr is reduced by 34.53%, cost due to VPL effects are reduced by 0.75% and Transmission losses by 39.35%. Similarly with 50% & 75% load scheduling to PV,the cost/ hr is reduced by 55.21 % &61.04%, cost due to VPL effects are reduced by 53.94% & 100% and Transmission losses by 80.49% & 86.15% respectively as shown in fig.13. Interestingly, when the TP units are loaded with their minimum capacities, the cost due to VPL is nil even in this case, when using Non-linear GRG algorithm with a population size of 100 and convergence rate of 0.0001.

Table 2: Results of IEEE-15 unit ELD test system on 2630MW load

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GRG Consolidated for 15Tpp with a load of 2630MW				
Gen. Units	100%Tpp	75%Tp+25%PV	50%Tp+50%PV	25%Tp+75%PV
Cost in Rs./Hr.	6354657.544	4159787.157	2846083.169	2475773.965
VPLin Rs./Hr.	1592.583	1604.751	733.46	0
Tr.Losses in MW	12.37	7.5	2.4	1.713315

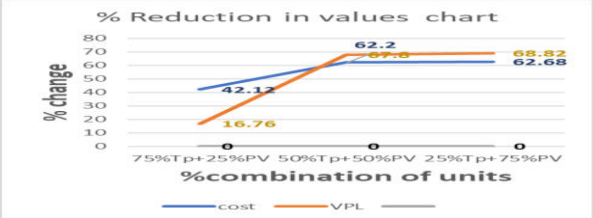

Fig.11: % Reduction in cost/hr.,VPL, Tr.losses

Table:3 shows the results of IEEE-30 unit ELD test system on 3450MW load. For a load share of 25% , 50% and 75% by PV, 11 PV units, 21 PV units and 31PV units are placed at uniformly distributed locations respectively and are integrated to the grid connected to TP units. It is observed that with nearly 25%,50% & 75% load share by PV units, the cost/ hr is reduced by 42%,62.2% and 62.58% respectively and cost due to VPL effects are reduced by 16.76% ,67.8% and 6.82% respectively as shown in fig.14. when using Non-linear GRG algorithm with a population size of 100 and convergence rate of 0.0001.

Table 3: Results of IEEE-30 unit ELD test system on 3650MW load

GRG Consolidated for 31Tp with a load of 3450MW				
Gen. Units	100%Tpp	75%Tp + 25%PV	50%Tp + 50%PV	Tp+75 %PV
Cost/ hr	14202489.88	8220191.897	5364576.995	5314629.083
VPL	3482.665253	2900.164717	1120.281476	1085.758301

Fig.14: %

Table 4: GRG Consolidated: Cost/ Hr. of Load Dispatch table

GRG Consolidated: Cost/ Hr. of Load Dispatch table				
Load/Gen .units	100% Tp	75%Tp+ 25%PV	50%Tp+ 50%PV	25%Tp+ 75%PV
1260MW Load	3613104	2118485	1161194	801696.3
2630MW load	6354658	4159787	2846083	2475774
3450MW Load	14202490	8220192	5364577	5314629
6000MW Load	70632310	68254886	10087227	8645808

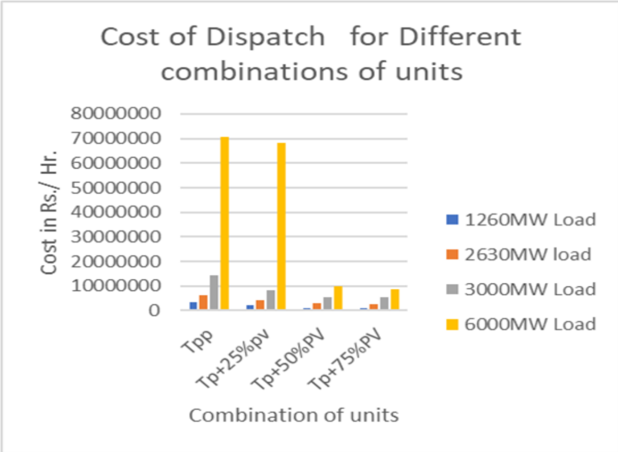

Fig.12: Consolidated result from GRG

4.2Results fromEvolutionary Algorithm:

Similar to Non-linear GRG algorithm, The parameters of the Tp units and PV units are placed in a spread sheet and the emission penalty constant is calculated for various loads, Tr. losses, cost due to VPL effects, Cost /hr. of each unit both Tp& PV by using their cost functions and total cost/hr. are evaluated by considering a random initial values. Then inSolver Add-in, an application in Data tab of Excel, solver parameters such as total cost / hr. in Rupees is set as an objective function, the loads on various generating units are set as the changing variables, Optimization to find the minimum of the objective function is carried out by stating all the constraints like minimum and maximum capacities, Ramp rate limits, POZs, total power to be generated etc for Tp units and min, max, conditions for PV units. The solution is obtained by applying the inbuilt Evolutionary algorithm by setting a population size of 100, mutation rate of 0.75, convergence at 0.00001for 100 iterations, the algorithm processes by starting multiple times from different initial conditions, and finds a solution which is the global optimum. The solution so obtained i.e., the load to be scheduled on each unit so as to arrive at the most economical load dispatch is updated automatically in the spread sheet. It also gives the values of Transmission losses and cost due to VPL based on the updated load dispatch of the units.

Table:5 shows the results of IEEE-6-unit ELD test system on 1260MW load. For a load share of 25% , 50% and 75% by PV, 4 PV units, 8 PV units and 11PV units are placed at uniformly distributed locations respectively and are integrated to the grid connected to TP units. It is found that with nearly 25% load taken up by PV units,

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the cost/ hr of dispatch is reduced by 39.37%, Transmission losses by 1.26% and cost due to VPL effects are increased by 39.43%. Similarly with 50% & 75% load scheduling to PV,the cost/ hr of dispatch is reduced by 60.43 % & 77.81%, cost due to VPL effects are reduced by 57.83% & 100% and Transmission losses by 61.78% &90.88% respectively. Interestingly, when the TPP units are loaded with their minimum capacities, the cost due to VPL is nil.. The cost/hr of load dispatch are better than GRG, but time taken for convergence is more. The results of IEEE- 15unit ELD test system and IEEE-30 unit ELD test system are given in Table. 6 and Table .7 respectively. It is found that in all the cases, the cost / hr and transmission losses decreases with an increased integration of PV with Tp units.

Table5: Result of IEEE-6 unit ELD system with integration of PV units for a load of 1260MWfrom Evolutionary Algorithm

EVO Consolidated for 6Tp with a load of 1260MW				
Gen.Units	100 %Tp	75%Tp+ 25%PV	50%Tp+5 0%PV	25%Tp+7 5%PV
Cost in Rs./hr.	3611 900.0 6	2182379 .54	1429083. 068	801774.4 339
Cost due to VPL in Rs./hr.	354.4 5020 2	494.203 119	953.6503 87	0
Tr.Losses in MW	13.10 8952 3	8.63290 984	5.009657 875	1.196296

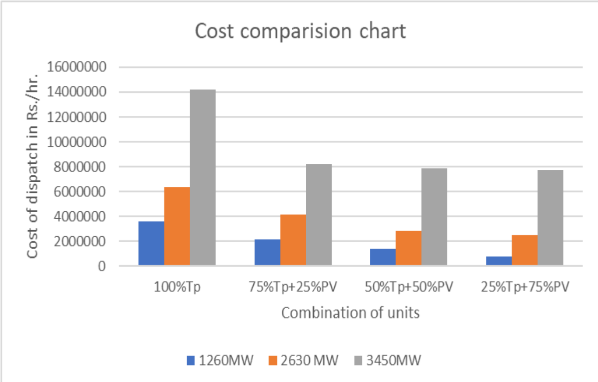
Table6: Result of IEEE-15 unit ELD system with integration of PV units for a load of 2640MW from Evolutionary Algorithm

EVO Consolidated for 15Tpp with a load of 2630MW				
Gen.Units	100 %Tp p	75%Tp +25%P V	50%Tp+5 0%PV	25%Tp+7 5%PV
Cost in Rs./hr.	6354 657.5 44	415978 5.653	2846083.1 69	2475773. 965
Cost due to VPL in Rs./hr.	1592. 583	1604.75 5	733.46	0
Tr.Losses in MW	12.37 1375 46	7.50318 8388	2.4132220 4	1.713315

Table7: Result of IEEE-30 unit ELD system with integration of PV units for a load of 3450 MW from Evolutionary Algorithm

EVO Consolidated for 31Tp with a load of 3450MW				
Gen.Units	100 %Tp p	75%Tp +25%pv	50%Tp+5 0%PV	25%Tp+7 5%PV
Gen.Uni ts/load	100% Tp	75%Tp+2 5%PV	50%Tp+5 0%PV	25%Tp+7 5%PV
1260M W	36119 00.06	2182379. 54	1429083. 07	801774.4 339
2630 MW	63546 57.54	4159785. 65	2846083. 17	2475773. 965
3450M W	14202 489.9	8220191. 9	7855212. 87	7737986. 345
Cost in Rs./hr.	1420 2489. 88	822019 1.897	7855212.8 7	7737986. 345
Cost due VPL in Rs./hr.	3482. 6652 53	2900.16 4717	3727.4243 78	2367.840 972

Table8: Consolidated Cost of Dispatch values in Rs./hr.from Evolutionary Algorithm



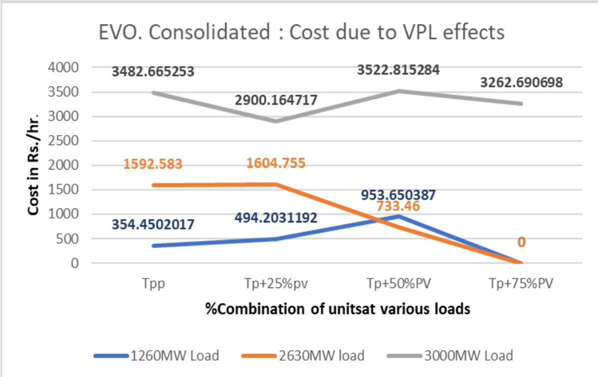
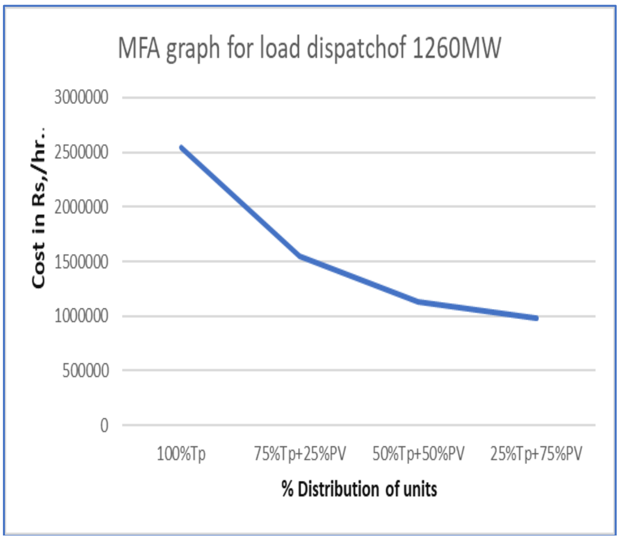


Fig.19: Cost of Dispatch from EA at various loads.Fig.20: Cost due to VPLeffects from EA at various loads

4.3. Results from Moth Flame Optimization Algorithm: The code for MFOA is developedin JAVA programming language in Intel(R) Core(TM) i5-processor with 8.00GB RAM,64 bit O.S. The optimizer reads the data of all the parameters and constraints of Tp units (6/15/30) and also PV units and then compiles it as per the code in the algorithm and when the Program is run with the given command gives the result .

Table 9: Results from MFA for load dispatch of 1260MW

MFA : IEEE-6 unit ELD test system with a Load demand 1260 MW : summary				
units	100% Tp	75%Tp+ 25%PV	50%Tp+ 50%PV	25%Tp+ 75%PV
Cost in Rs./hr	2546 472	1548050	1126271	977097
%reduc tion in cost		39.208049 4	55.771318 12	61.62938371
VPL in Rs./Hr	612.1 1	663.647	862	783.81
TL in MW	20.08	6.69	2.73	2.74



From the above table, it is noticed that as the number of PV units increase or with the % increase in PV integration increases, the cost of load dispatch and Transmission losses decrease.

Table 10: Results from MFA for load dispatch of 2630MW

MFA : IEEE-15 unit ELD test system with % distribution of loads to PV units on a Load demand 2630 MW				
Gen. units	100 %Tp	75%Tp+2 5%PV	50%Tp+5 0%PV	25%Tp+7 5%PV
Cost in Rs./hr.	7920 731	4941357	4123359	2587873
%reducti on in cost		37.61488 681	47.94219 119	67.32785 143
VPL in Rs./Hr.	1879	2000	2008	2020.88
TL in MW	285	95	31.66	23.8

Table 11: Results from MFA for load dispatch of 3450MW

MFA : : IEEE-30 unit ELD test system with % distribution of loads to PV units on a Load demand 3450 MW				
units	31Tp	31Tp+PV (25%)	31Tp+PV (50%)	31Tp+PV (75%)
Cost in Rs./hr.	3439 439	2099775	1550591	1041283
%reducti on in cost		38.95007 3	54.91732 809	69.72520 809
VPL in Rs./Hr.	612. 11	663.647	862	783.81

Table 12: Results for load dispatch of 1260MW

Consolidated result on IEEE- 6unit ELD test system			
method/ units	GRG	EVO	MFA
100%Tp	3613104	**3611900.1**	2546472
75%Tp+25%PV	2118485	2182380	1548050
50%Tp+50%PV	1161194	1429083	1126271
25%Tp+75%PV	801696.3	801774.4	977097

Fig.22: Cost of Load dispatch for various % distribution of units

Table4: Consolidated result.from GRG Algorithm, Evolutionary Algorithm and MFA for various loads

Consolidated results of Cost of Load dispatch in Rs./hr.												
Algorithm	GRG				EVO				MFA			
Gen. Units /load	100 %Tp	75%Tp+25%PV	50%Tp+50%PV	25%Tp+75%PV	100%Tp	75%Tp+25%PV	50%Tp+50%PV	25%Tp+75%PV	100%Tp	75%Tp+25%PV	50%Tp+50%PV	25%Tp+75%PV
1260 MW	**3613104**	**2118485**	**1161194**	**801696.3**	**3611900.1**	**2182379.5**	**1429083.1**	**801774.43**	**2546472**	**1548050**	**1126271**	**977097**
2630 MW	6354658	4159787	2846083	2475774	**6354657.**	**4159785.7**	**2846083.2**	**2475774**	**7920731**	**4941357**	**4123359**	**2587873**

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					5							
3450MW	14202490	8220192	5364576.995	5314629.083	14202490	8220191.9	4529604	4271204	3439439	3161306	1550591	1041283

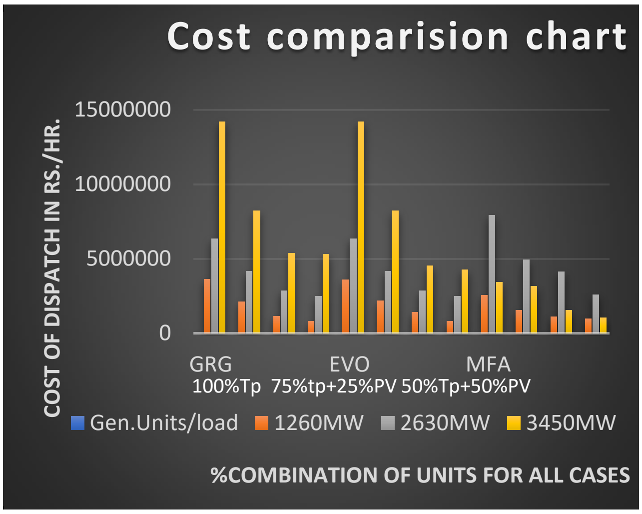

Fig23: Consolidated result.from GRG Algorithm, Evolutionary Algorithm and MFA for various loads

V: CONCLUSIONS

By the distributing the generation by uniformly placing PV at various geographical locations and interconnecting them to the grid near distribution ends, the transmission losses and the cost of dispatch is greatly reduced as the % integration of PV increases as compared to the ones without PV units. We also observe that the % total cost and the transmission losses are reduced more so in the case of IEEE-30-unit ELD test system compared to IEEE-15unit ELD test system and IEEE – 6unit ELD test system in that order. Hence it is proposed to place a greater number of PV units i.e., schedule greater % load dispatch by PV units at uniform locations. Further it is noticed that MFA gives better results and is more cost effective compared to Evolutionary algorithm and Non-linear GRG algorithm.

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