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Optimal Economic Dispatch Considering Load Uncertainty

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***Abstract*—Economic Dispatch Plays a crucial role in planning the generation of the generating units to fulfill the specified load demand at any point of time at a minimum operating cost.The output power of every generating unit is decided by load forecasting satisfying unit and system constraints.Load form a major source of uncertainty in power system.Load vary from time to time because of unsure demands of the customers and time of use of high wattage appliances that is subjected to high uncertainty.This paper presents a prbabilistic approach to resolve economic dispatch drawback considering uncertainty in load demand.The load demand is recognised as a random variable with given probability distribution function.A case study is employed to demonstrate the relevance of planned methodology.Results show that the planned approach will offer additional correct data on load demand to the power system operators and/or planners during a specified time period and therefore enable them in better decision making, control and management within the power system network.**

Keywords—Economic Dispatch, Load Uncertainty, Normal Distribution function, Forecasting error

I. INTRODUCTION

Due to rapid economic development,there is an increase in the consumption of energy and thus an increase in the energy demand all over the globe. In this regard,the Economic Dispatch (ED) problem plays a significant role in the schedule of committed power generation units outputs to fulfill the specified load demand at any given purpose of your time at a minimum operating cost while satisfying both the equality and the inequality constraints of all the generation units and the power system.Economic Dispatch(ED) problem of an interconnected power system can also be defined as the process of finding net real and reactive power schedule of every generating unit so as to minimize the operating cost as much as possible.This tells us that generating unit's real and reactive power is permitted to vary within certain limits so that it will satisfy the load demand at a minimum fuel cost value.This can be called as the optimal power flow.The optimal power flow is most widely used to optimize power flow solution of a large power system.This can be done by minimizing chosen objective functions while maintaining acceptable performance of the system in terms of electrical generators capability limits and output of real and reactive power compensating devices.The other objectives of the economic dispatch includes maintaining the power system stability and security constraints and minimization of the emissions i.e.,reduction within the production of unwanted gases that causes hurt to sourroundings such as SO2, NOx, CO and CO2 from the thermal power plants.Economic Dispatch also aims in the maximization of profit obtained by reducing total operating cost.Economic Dispatch(ED) benefits consumers in a number of ways.It typically results in more efficient and economic electric power generation that can lead to lower fuel usage,better fuel utilization and reduced air emissions.Additional value savings will be obtained from pooled operating reserves that permits an area to fulfill load demand reliability using minimum total generation capacity than that may be required otherwise.This requires power system operators to keep a watch on the system conditions so as to maintain secure power grid operation and therefore maximimizing the generating unit's operational reliability while not increasing the prices.Economic Dispatch(ED) also can be versatile enough to incorporate policy goals like respecting load demand as well as supply resources and promoting fuel diversity.In the course of future,it attracts and encourages new investment in generation as well as in further transmission system expansion and upgrades that may improve both the dependability and cost savings.

However, the power demands are inherently unsure and are not fixed.The load varies from time to time because of unsure demands of the customers and the time during which high power electric appliances are used.So the generation from the generation units cannot be constant throughout the scheduled time period and the power output of the thermal generators cannot be increased or decreased beyond their generation limits.Thus, the upkeep of balance between generation and real time load demand has become more complicated as both the generation sources and load demand are now currently variable. Power System planners and operators need new higher cognitive process tools to attain power system reliabily and stability under load uncertainty within the power system network.

There are several optimisation techniques that has been developed to balance the generation and load demand. These Optimisation techniques are classified into three classes particularly hybrid,heuristics and classical approaches.The conventional approaches applied to solve the economic dispatch drawback are lambda iteration method(LIM), linear programming(LP), dynamic progrmming(DP), quadratic programming(QP), lagrange relaxation algorithm(LRA),weighted mini-max.These standard approaches need incremental cost curves which monotonically increases or piecewise linear in nature. However typically input-output of modern generating units are non-linear because of ramp-rate limit,valve point effect etc.Thus economic dispatch problem is highly discontinuous and highly non-linear. Because of non-linearity different non-linear optimization techniques has been developed ParticleSwarmOptimization(PSO),genetic algorithm, artificial neural networks,non dominated sorting,evolutionary optimisation. The above techniques are well developed and really difficult to establish their merits and demerits over each other.The selection of the non-linear optimisation method to resolve economic load dispatch drawback is essentally a choice by the user or the investigator.

Uncertainty in load will extremely be reduced by correct load forecasts. This is often achieved by the utilization of modelled data and onsite monitoring.The simplest way to account for uncertainty in load demand are to think about load as probabilistic in nature.In order to take this into consideration,the consumer demand will be calculable employing a probabilistic distribution function.In this paper a discrete probabilistic distribution function is employed to model the dynamic nature of load demand.Load demand is modelled using the normal Probabilistic Distribution Function(PDF).The probabilistic distribution functions are incorporated in economic load dispatch problem considering solely representative values obtained from individual probabilistic distribution functions.The results that we tend to get from the planned approach is presented as probability distribution and single values can be obtained from resultant probability distribution and a risk level parameter will be hooked up to its value.This inturn provides elaborated data on power system planning and operation to power system planners and operators and enable them in better decision making in power system control and network management.

II. LOAD UNCERTAINTY MODELLING

Since the power demands are inherently unsure and varies time to time with respect to uncertain demands of the consumer and time of use of high wattage devices, the uncertainty in load is modelled using probabilistic distribution functions.The load demand is modelled as normal PDFs in this paper.

A. Normal Distribution for uncertainty in load demand

The electrical load demand exhibits a pattern that is influenced by varied factors like time of the day,day of week,temperature,weather conditions,cloud cover etc.The uncertainty in load demand is often modelled by using the normal distribution for short term scheduling and therefore it's employed in this paper.The normal distribution function for load demand uncertainty is represented as follows:

$$F_l(x) = \frac{1}{\sigma_l \sqrt{2\Pi}} e^{\frac{-(x-\mu_l)^2}{2\sigma_l^2}} \qquad (1)$$

Where x is load demand

(μ_l) is the mean load demand

(σ_l) is the standard deviation of the load demand

B. Scenario Generation

The electric load demand L_{hr} depends on discrete probability distribution functions with finite sample space.During first step,a predetermined class R is selected for load demand.Then for this class,economic dispatch problem is solved using the dispatch program.Assuming that the vector of these random variables are:

($P_{Lhr}(1)$,$P_{Lhr}(2)$,....,$P_{Lhr}(R)$),

with probability given by:

($p_{Lhr}(1)$,$p_{Lhr}(2)$,....,$p_{Lhr}(R)$), respectively.

Where 'hr' is hour under consideration.

As per definition,Scenario selection based on iterative procedure.The class (r) represents a given scenario composed of two different values i.e., mean and standard deviation value of load demand.The probability of each scenario p_{Lhr} indicates possibility of future occurence of respective scenario and this is got from respective original PDF of parameter under consideration.

Consider a determined level of uncertainty of net load demand(φ_L), the interval, [μ_l-φ_L, μ_l+φ_L] is swept with a determined step (sampling increment), $\Delta\varphi_L$, obtaining R scenario values.This can be formulated by Eq. (2)

$$\varphi_L = \{\varphi_i \in [\mu_l - \varphi_L , \mu_l + \varphi_L], i=1,2,....,R \qquad (2)$$

Here, the load demand classes are defined in the interval {$\Delta\varphi_L$ =0.1 MW} according to PDF of load demand.This method permits resultant PDF of output power for all electric power generation units to be obtained.

The main advantage of using this method is that when $\varphi_L = (\mu_l - \varphi_L)$, the low PDFs conditions and values are considered.On the contrary, when $\varphi_L = (\mu_l + \varphi_L)$, the high PDFs conditions and values are considered.Thus, this inturn permits the thought of utmost conditions of PDFs(the low as well as high values) under consideration.

A significant thing to consider is that probability of occurence of each individual scenario do not sum upto a value of 1.This is due to the fact that not all possible combinations are taken into account.To consider this problem, corresponding combined probability (Pr{.}) is replaced by normalized probability (NPr{.}) in Eq(3) for which sum is 1 for any number of scenarios.

$$N\,\Pr\{.\} = \frac{\prod_{r=1}^{R} \Pr(r)\{.\})}{\sum_{S=1}^{R}(\prod_{r=1}^{R}(\Pr(r)\{.\}))} \qquad (3)$$

Where (Pr{.}) is the combined probability which is given by product of probabilities of combined scenarios, i.e,

$$\Pr(r)\{.\} = \Pr(S)\{.\} = p_{Lhr}(r) \qquad (4)$$

Where S =1, 2, 3, ..., (R); r is the scenario number for the load demand

III. PROBABILISTIC GENERATION SCHEDULING FORMULATION

Economic Dispatch (ED) problem plays a significant role withinin the schedule of committed power generation units outputs to fulfill the specified load demand at any given point of your time at a minimum operating cost while satisfying both the equality and the inequality constraints of all the generation units and the power system.The output power of every generating unit is determined by load forecasting satisfying unit and system constraints.To do Economic Dispatch planning,the network grid controller ceaselessly receives and stores data relating to the load demand.At each scenario,load demand differs from one another and power generated from thermal generation units is subjected to vary in every scenario so as to balance between power generation and load demand.Therefore in each scenario,new generation set points for thermal generation units is calculated.

A. Constraints

1) Load balance:The total power generated by the thermal generation units should be equal to load demand at any given point of your time.

$$\sum_{k=1}^{K} P_{Gk}(k,r) = P_l(r) \quad \forall r \tag{5}$$

where k=1,2,3,....K represents the index of thermal generation units

$P_{Gk}(k,r)$ represents power output of thermal generation unit Gk in scenario 'r'.

$P_l(r)$ represents load demand in scenario 'r'.

2) Generation Limits :The thermal power generation should be in between the maximum and minimum power generation capability.

$$P^{\min}{}_{Gk} \le P_{Gk}(s) \le P^{\max}{}_{Gk} \quad \forall k = 1,2,..,K \tag{6}$$

Where $P^{min}{}_{Gk}$ represents the minimum value of the generation of the thermal unit Gk.

$P^{max}{}_{Gk}$ represents the minimum value of the generation of the thermal unit Gk.

B. Objective Function

The Expected Cost(F(P_{Gk})) of power generation for a given hour is the objective function to be minimized.If the forecasting error(ε) is included,the optimization problem can be modelled as shown below:

$$F(P_{Gk}) = \min\left(\sum_{k=1}^{K} C_G^S(k,s)\right)$$

$$= \min(\Pr(s)\{.\} \times \sum_{k=1}^{K} C_G^S(k,s))\forall s \tag{7}$$

subject to : Constraints (5) and (6)

$$\Pr\left\{\sum_{k=1}^{K} P_{Gk}(k,r) = P_l(r)\right\} \ge (1-\varepsilon)\forall r \tag{8}$$

where $C^S{}_G(k,s)$ represents hourly fuel cost of thermal generation unit Gk in scenario 's'.

Pr(s){.} represents probability of combined scenario in scenario 's'.

$P_{Gk}(k,r)$ represents power output of thermal generation unit Gk in scenario 'r'.

$P_l(r)$ represents load demand in scenario 'r'.

ε is the forecasting error

The expected cost of power generation is multiplied by probablility of combined scenario Pr(s){.}in a particular given hour to reflect the likelihood of each combined scenario in scheduling result.

The thermal power generation unit fuel cost is usually represented as a quadratic polynomial and is given as follows:

$$C_{Gk}(k,t) = a_k + b_k P_{Gk}(k,t) + c_k P_{Gk}^2(k,t)$$

Where $C_{Gk}(k, t)$ is the thermal power generation unit fuel cost.

$P_{Gk}(k, t)$ represents power output of thermal generation unit G_k in the period t.

a_k, b_k, c_k represent fuel cost value coefficients of the thermal generation unit Gk.

The planned methodology is enforced as follows:

- Step 1:Initialize offered system data.
- Step 2:Generate PDF of system load demand using normal distribution.
- Step 3:Using PDFs generated in Step 2 randomly choose inputs from probablility distributions according to predetermined class in Eq.2 for the distribution.
- Step 4:Calculate the combined probability for corresponding combined scenario.
- Step 5:For every selected inputs,use deterministic optimal economic dispatch to determine best solution employing a dispatch program.
- Step 6:Repeat (3) and (5) to solve all possible combinations of load demand scenarios.
- Step 7:Save Results

IV. CASE STUDY AND ANALYSIS

The planned technique was applied to a modified IEEE 3-bus system network given in Fig. 1.

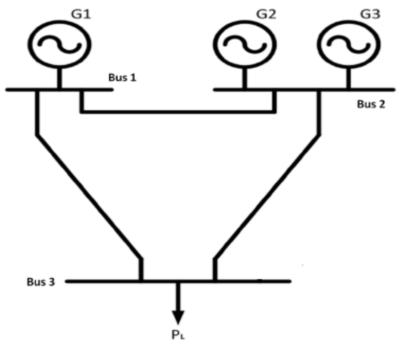

Fig. 1. Single line diagram of the 3-bus sample network

This system consist of three thermal generation units and one load demand. Transmission line constraints are not included in the analysis. The cost coefficients are tabulated in Table. 1. In this paper we assume the forecasting error ε =5%.

TABLE I:
FUEL COST COEFFICIENTS OF 3 GENERATOR SYSTEM

Unit no.	ai	bi	ci	pimin	pimax
1	0.004	5.3	500	0	70
2	0.006	5.5	400	0	70
3	0.009	5.8	200	0	70

We have considered the load demand for 24 hours in a day to calculate the mean(μ_l) and standard deviation(σ_l) of the load demand.The uncertainties in load demand is modelled using discretized normal distribution as given in equation (1). The loads were randomly selected and a class was considered according to the Probability Density Function(PDF) of the system load demand.A dispatch program was then used to solve economic dispatch for the class.

V. RESULTS

The load demand was assumed to be normal distribution with parameters μ_l=112.958 , σ_l=42.276. The table II shows the generation result of 3 generators considering uncertainty in load for each hour in a day. Figure 1 represents Normal Distribution Value (PDF) with respect to the load demand for 24 hours in a day and figures 2 - 4 represents corresponding power generation results of units 1,2 and 3 with respect to time.

TABLE II:
NORMAL DISTRIBUTION VALUE[P(X)] OF CORRESPONDING LOAD(X) ALONG WITH OPTIMAL GENERATION RESULT FOR 3 GENERATORS CONSIDERING LOAD UNCERTAINTY FOR 24 HOURS ON A DAY

HOUR	X(MW)	P(X)	P1(MW)	P2(MW)	P3(MW)
1	50	0.003113	44.7368	13.1579	0
2	60	0.004305	49.4737	16.3158	0
3	70	0.005631	54.2105	19.4737	0
4	72	0.005901	55.1579	20.1053	0
5	90	0.008142	63.6842	25.7895	0.5263
6	100	0.009003	68.4211	28.9474	2.6315
7	120	0.009306	70	40	9.9999
8	110	0.009413	70	33.9999	5.9999
9	80	0.006963	58.9474	22.6316	0
10	65	0.004958	51.8421	17.8947	0
11	70	0.005631	54.2105	19.4737	0
12	80	0.006963	58.9474	22.6316	0
13	85	0.007583	61.3158	24.2105	0
14	150	0.006428	70	58	22
15	140	0.007690	70	52	18
16	120	0.009306	70	40	9.99998
17	160	0.005081	70	64	26
18	180	0.002683	70	70	39.9999
19	175	0.003214	70	70	34.9999
20	176	0.003104	70	70	35.9999
21	167	0.004168	70	68.1999	28.8
22	153	0.006025	70	59.8	23.2
23	148	0.00669	70	56.8	21.2
24	90	0.008142	63.6842	25.7895	0.5263

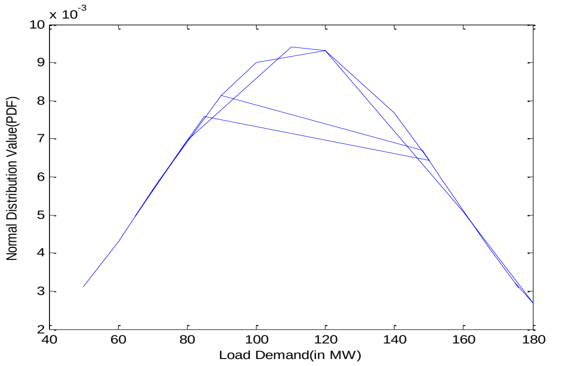

Fig 1. Normal Distribution Function(PDF) value vs the load demand

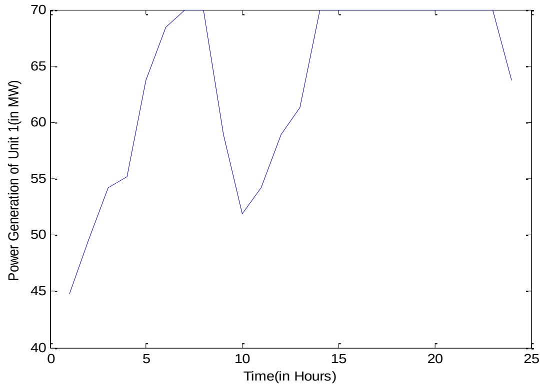

Fig 2 Power Generation of Unit 1 vs Time

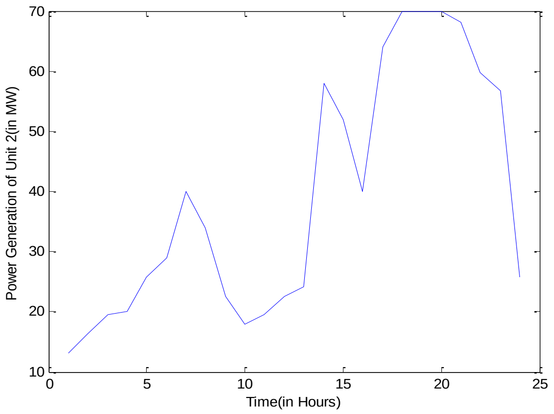

Fig 3 Power Generation of Unit 2 vs Time

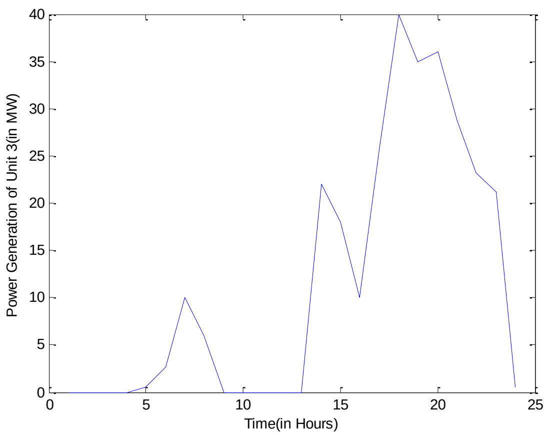

Fig 4 Power Generation of Unit 3 vs Time

From the figures 2 -4 and from the table II,it has been discovered that higher power generation capability is achieved in thermal generation unit 1 followed by thermal generation unit 2 and lastly thermal generation unit 3.In other words, the cost of generating electrical power is cheaper for thermal generation unit 1 and thus it is first used to supply the load demand.Thermal power generation 2 has generation less than unit 1 in most cases since it costs more compared to thermal generation unit 1.The thermal generation unit 3 is least used since it is the most expensive.The net load demand PDF have an influence on every thermal generation unit.

The high values of load demand PDF will increase probability of commitment of every thermal generation unit with thermal generation unit 3 commited at last.It has conjointly been found that Expected Cost(EC) is reduced for prime uncertainty values compared to low uncertainty values.This tells us that the low uncertainty values of economic dispatch,overestimate price of the expected value.The minimum Expected Cost(EC) is possible and feasible once all thermal generation units are operating at their minimum output power.The maximum expected cost(EC) is obtained once system load demand is at a maximum.Also high uncertainty in system load demand values can provide a broad variation of total Expected Cost(EC) values.These aspects are important in understanding load uncertainty in power system management.

V. CONCLUSION

This paper proposes a probabilistic approach to resolve economic dispatch to research the result of uncertainty in load demand.The uncertainties in load demand is modelled using discretized normal distribution.The use of Probability Density Functions(PDFs) permits the consideration of utmost conditions(high and low values) along with its corresponding probability.The loads were at randomly selected and a class was considered according to the Probability Density Function(PDF) of the system load demand.A dispatch program was then accustomed to solve economic dispatch for the class.The results show that there is a rise within the total generation cost value of the thermal power system with increase within the uncertainty of the system load demand.This approach conjointly provides additional purposeful and helpful data relating to power system management under uncertainty.The power system operators and planners will use this purposeful data to make decisions along with the knowledge of risk levels associated with those decisions.The additional development of the work lies in increasing this technique to a time horizon(e.g.week or year)and calculation of risk levels at each time span.

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