Optimal Dispatch of Energy/Reserve in Restructured Electricity Market with Demand Variations

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***Abstract*—**The electrical power system plays a crucial role in the development of a country. The power systems are being restructured all over the world to improve efficiency and enhance performance by encouraging competition among various agencies involved in the generation, transmission and distribution of electrical power. Operating reserve plays a significant role in maintaining reliability and security of power supply under constant demand variations. The optimal energy and reserve dispatch routine allocates energy and reserve to different players in such a manner that total cost is minimized and all system constraints are satisfied. In traditional vertically integrated electricity markets reserve is dispatched after completing the energy dispatch but in the competitive market a simultaneous dispatch of energy/reserve is carried out. For this, separate price bids are submitted by power companies for energy and reserve. In this paper a constrained optimization solver 'fmincon' using the MATLAB optimization tool box is employed for computing the optimal energy/reserve dispatch schedules under dynamic conditions with power balance constraint, generation and reserve min/max capacity constraints, ramp-up/down limits, and energy- reserve-coupling constraints. The proposed algorithm is tested on 17 generating unit, IEEE 57 bus system. Three different test cases are simulated and the proposed method is found to produce feasible results with full satisfaction of complex equality/inequality constraints.

***Keywords*—** Dynamic energy and reserve dispatch (DERD), inelastic load, MATLAB optimization toolbox, ramp rate limits, sectional price characteristics

I. Introduction

Deregulation of the power sector has changed the operational strategies by introducing competition which has resulted in improving the economy. In this new environment, ancillary services such as spinning reserve plays a pivotal role in maintaining acceptable level of security and reliability. The balance between generated power and demand is to be maintained in real time. The reserve market makes sure that in case of a contingency the demand is met. The policy adopted all over the globe for energy and reserve dispatch is to minimize the cost

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without jeopardizing system security. Spinning reserve (SR) is a designated generation capacity which can be scheduled to meet the demand immediately. SR is a kind of back-up power capacity which can be brought into service for transmitting loads within ten minutes' notice and which will remain available for operation continuously for at least two hours once it is dispatched into service online.
Non-spinning reserve is the power capacity which is can be brought online within 10 minutes if offline and which can be disconnected within 10 minutes if it is online. The non-spinning reserve has the capacity to be either operated or interrupted for minimum two hours. Normally SR is obtained from hydroelectric or combustion turbines Reserve generator turbines are usually kept running without generating any electricity so that it can be brought online whenever needed.

Many European and American, Australian and New-Zealand electricity markets permit separate bidding of energy
and ancillary services. It is the duty of the independent system operator (ISO) to optimally assign energy and reserve to individual generation companies/units in such a manner that reliability and security are maintained [1] and certain market rules are followed. The guidelines specify the amount of SR as the largest on-line thermal generator, or sometimes as a given percentage (5-15%) of peak load demand. Different rules are applicable for different ISOs.

Many comprehensive studies can be found on energy and reserve formulation in competitive electricity market. Some of them are based on multi-objective approach for improving system security [2], probability based analysis [3], reliability criterion [4]. A recurrent neural network is applied for including generating unit reliability during the scheduling where units having lower forced outage probabilities are rewarded [4]. Reserve costs are separately included in the cost function and the objective is to reduce overall costs.

The static optimal dispatch finds an optimal dispatch schedule to satisfy the load at a specific time interval. The static dispatch does not model the inter-relation between different time intervals arising due to the operational ramp up/down constraints of generating units. The dynamic optimal dispatch takes into account the coupling effect of power generators at different time moments. These practical constraints limit the generators to increase/decrease their outputs beyond a specified value called as the climbing rate of a generator. Therefore the modeling of dynamic energy and reserve dispatch is much more complex than the static optimal energy/reserve dispatch. However, the computation results obtained with dynamic formulation are more near to the actual practical requirements. In [5] an extensive review of energy and reserve markets focusing on different kinds of reserves, dispatching methods and different modeling approaches is presented**.**

In conventional electricity markets, energy and reserve are dispatched separately; one after the other, i.e reserve is dispatched only after the energy market is cleared. This method suffers from many problems and does not produce a comprehensive picture. The joint dispatch is much more complicated as it has to address many new issues and constraints. It requires new planning strategies and modified formulation with some changes such as, i) price bids submitted by utilities replace cost curves of generating units ii) Cost of supplying reserve is also included separately based on the reserve bids iii) Instead of sequential dispatch of energy and reserve, a simultaneous dispatch is carried out iv) mutual coupling between energy and reserve capacity also needs to be considered v) reserve capacity limits vi) generator contingencies and vii) ramp rate limits. The generating companies can change their price bids for maximizing profit.

References [2] – [28] present a joint dispatch of energy and reserve to remove the difficulties associated with traditional sequential dispatch. The joint dispatch problem is solved using an LP-based approach [6]. A flexible real- time static dispatch option for the joint dispatch of energy and reserve is presented in [7].The coupling of energy/reserve has been effectively formulated in [8]. Joint reserve and energy dispatch to cater to demand-supply discrepancy has been modeled with flexible approach in [9]. A static model for joint energy/reserve dispatch can be found in [10] with non convexities existing due to the fixed costs and capacity constraints of generation. A cost-effective dispatching strategy for emergency reserve is floated in [11] with detailed representation of supply and demand side options. Mixed integer non-linear programming based approach is presented in [12] for minimizing two objectives, payment and cost for simultaneous dispatching of energy/ reserve. Reserve requirements with contingency-constraints are determined in [13] using a unit commitment programme with embedded security-constraints.

Grid reliability is being ascertained along with increased spot market efficiency by the application of distributed generation and associated demand response programs [14]. Nature inspired (NI) optimization methods [15] such as genetic algorithm (GA) [16], particle swarm optimization [17], differential evolution (DE) [18], memetic algorithm (MA) [19] and harmony search (HS) [20] have also proved to be effective for joint dispatch of energy and reserve. Modified NI methods have also been applied for this problem. In [21] a recurring DE has been used and in [22] time varying version of DE has been applied.

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With growing penetration of renewable energy sources (RES) such as wind and solar power stations, the need for allocation of sufficient reserve has grown tremendously. The uncertain nature of RES coupled with the forecast inaccuracies needs sufficient spinning reserve to preserve system stability in the event of sudden loss of generator or sudden increase in demand. Therefore a joint dispatch of energy and reserve becomes most essential [23-27]. Some papers have presented the joint energy/reserve dispatch problem for multi-zone power systems with transmission constraints [27,28].

The interior point algorithm using matlab optimization tool was effectively applied in [29] for the joint dynamic dispatch of energy and reserve.

This paper presents the solution of the optimal dynamic energy and reserve dispatch the practical power market environment using interior point algorithm formulated in MATLAB environment. The total market cost is minimized subject to the above constraints by employing sectional cost characteristics. The performance is tested on three test cases of IEEE 57 bus system having 17 generating units. The algorithm is found to converge for all the simulated dynamic conditions with load changes. Feasible results for all tested cases are produced after including practical generator constraints such as ramp rate limits. The effect of generator outages on the operating cost and reserve is also illustrated.

II. Problem Formulation for Joint Dynamic Energy/ Reserve Dispatch

Generally the optimal energy and reserve dispatch is carried out under static conditions for a fixed energy and reserve demand. In such static economic dispatch (SED) the demand is distributed economically among the committed generators assuming load to be constant for a period of time. This creates inaccuracies in the practical systems where demand is varying continuously and the generator power output has to be adjusted constantly. To overcome this issue, dynamic economic dispatch (DED) is conducted to allocate the online generator outputs with the forecast load demands over a certain period of time.

In DED the costs involved in changing generation from one level to the other are also included. During this change, the operators need to keep gradients for temperature and pressure inside the boiler and turbine within their safe limits in order to avoid the damage to the equipment. This operational limitation is modeled as a constraint on the rate of increase or decrease of the generator power output, known as ramp limit.

The DED solution is normally computed by dividing the total dispatch period into a number of small sub intervals and implementing a SED for each interval. This paper formulates the dynamic energy and reserve dispatch (DERD) for one day period consisting of 24 intervals, each of one hour duration.

A. Optimization Goal

The objective of DERD is to minimize total market cost consisting of the sum of energy and reserve cost for a given period of time. The total cost for N number of generating units, for the dispatch period consisting of 'T' number of intervals can be stated as,

$$Cost = \sum_{t=1}^{T} \sum_{i=1}^{N} \left[F(P_i\ (t)) + G(R_i\ (t)) \right] \tag{1}$$

Here Pi(t)and Ri(t) are respectively the generation and reserve of i^{th} unit at t^{th} interval; $F(P_i(t))$ and $G(R_i(t))$are the energy and reserve bid prices of the i^{th} generating unit at t^{th} time interval respectively.

Following are the constraints for the DERD problem dispatch:

B. Power and Reserve Balance Constraints

1) Power balance constraint for interval 't' are given as:

$$\sum_{i=1}^{N} P_i\ (t) = P_D(t) + P_L(t) \tag{2}$$

Demand and power loss for interval't' is given by $P_{D(t)}$ and $P_{L(t)}$ respectively.

2) Spinning reserve constraint for interval 't' is given as

$$\sum_{i=1}^{N} R_i\ (t) = R_D(t) \tag{3}$$

The reserve demand for interval't' is $R_{D\,(t)}$.

C. Inequality Constraints

1) Unit energy capacity constraints

$$P_i^{\min} \le P_i(t) \le P_i^{\max} \tag{4}$$

2) Unit reserve capacity constraints ;

$$\mathbf{0 \le R_i(t) \le R_i^{max}} \tag{5}$$

;

Here, $P_i^{\min}$, $P_i^{\max}$ and $R_i^{\max}$ are limits of generating units

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3) Unit energy and reserve coupling constraints

$$P_i(t) + R_i(t) \leq P_i^{\max}$$

(6)

4) Unit ramp-rate constraints given by:

$$-DR_i \leq (P_i(t) - P_i(t-1)) \leq UR_i$$

(7)

The down and up ramp limits of the i[th] unit are represented by DRi and Uri respectively. The objective of the DERD problem is to minimize the total cost of energy and reserve given by (1) subject to the equality and inequality constraints specified by (2)-(7).

In place of the conventional linear/quadratic or non-convex cost characteristics, here a block/sectional energy/reserve offering price characteristics [17][20] as shown in Fig. 1 is used for computing the cost/price.

The price offers/bids of the i[th] generator for energy and spinning reserve in the k[th] power block are ρ_{Gik} and ρ_{Rik} respectively. The variables P_{Gik} and R_{Rik} represent the energy and reserve values for the kth price band. For the ith generator supplying energy Pi and reserve R the energy and reserve costs $F_{(Pi)}$ and $G_{(Ri)}$ are given as [19][21].

$$F(P_i) = \begin{cases} \rho_{Gi(k-1)} \times P_i .....if....P_i \leq P_{Gi(k-1)} \\ \rho_{Gi(k-1)} \times P_{Gi(k-1)} + (P_i - P_{Gi(k-1)}) \times \rho_{Gik} ;if.....P_{Gi(k-1)} < P_i \leq P_{Gik} \\ \rho_{Gi(k-1)} \times P_{Gi(k-1)} + (P_{Gik} - P_{Gi(k-1)}) \times \rho_{Gik} + (P_i - P_{Gik}) \times \rho_{Gi(k+1)} ....if....P_{Gik} < P_i \end{cases}$$

(8)

$$G(R_i) = \begin{cases} \rho_{Ri(k-1)} \times R_i .....if....P_i \leq P_{Gi(k-1)} \\ \rho_{Ri(k-1)} \times R_{Ri(k-1)} + (R_i - R_{Ri(k-1)}) \times \rho_{Rik} ....if.....P_{Gi(k-1)} < P_i \leq P_{GRik} \\ \rho_{Ri(k-1)} \times R_{Ri(k-1)} + (R_{Rik} - R_{Ri(k-1)}) \times \rho_{Rik} + (R_i - R_{Rik}) \times \rho_{Gi(k+1)} ....if....P_{Gik} < P_i \end{cases}$$

III. Matlab Based Implementation of Energy/Reserve Joint Optimization

The interior point method was invented using the homogeneous linear system which was later popularized by Karmarkar's algorithm, [30] for linear programming. This method makes use of a barrier function for encoding a convex solution set and converges to an optimal solution by searching the feasible region.

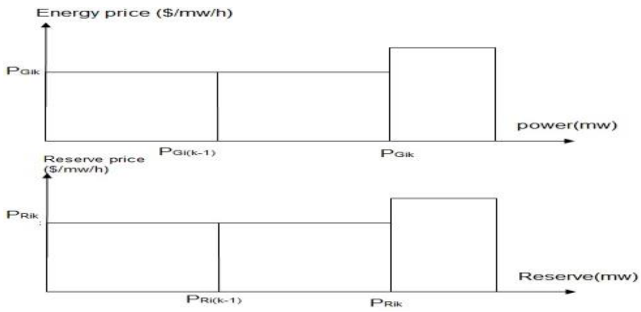

Fig 1. Block price bids submitted by utilities for energy and reserve

A sequence of points x (0) , x (1), x (k),… is generated in decreasing order of the objective function. The function g(x) is expressed as

$$g(x) = \sum \ln\left(\frac{i(x)}{x_j}\right) + k \quad (k \text{ is constant})$$

(10)

The interior-point methods are very effective in solving the special conic programming problems (including linear and semi-definite programming) and general programming including convex programming. Interior-point approaches can solve general convex programming problems of the form:

$$\min_x \; f(x) \;\; s.t. \;\; g_i(x) \leq 0, \qquad i = 1,2.....m$$

(11)

(where f and g_i, i = 1; 2; : : :;m, are convex functions defined for m number of variables)

D. Implementation of 'fmincon' routine using Interior point algorithm inoptimization toolbox

Matlab platform provides a very simple implementation of different non linear optimization algorithms. Constraint mapping and problem definition is provided in a very user friendly way using the powerful 'fmincon' function which finds the constrained minimum of a function defined over several variables for problems of the following form:

$$\min_x \; f(x) \;\; s.t: \; A * X \leq B, \; A_{eq} * X = B_{eq}$$

(12)

$$c(x) \leq 0, c_{eq}(x) = 0 \;\; (Nonlinear \;\; constraints)$$

(13)

$$LB \leq x \leq UB \;\; (Bounds)$$

(14)

E. The different solver options

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The function ‘fmincon’ implements four different algorithms; i) Interior point ii) Sequential quadratic programming (SQP) iii) Active set and iv) Trust region reflective which can be selected the ‘options’ function.

Then the options set above are passed on to ‘*fmincon’* for implementation of the interior point algorithm. Here, ‘fun’ represents the objective function to be minimized, x0 is the initial value of variables, ‘A, b, Aeq, beq’ are the matrices of coefficients of linear equality and inequality constraints. The lower and upper limits on variables are defined by matrices ‘lb’ and ‘ub’. The non linear equality and inequality constraints are computed by the ‘nonlcon’ function. The Hessian matrix is the Hessian of the Lagrangian values and is given by

$$L = f + \sum_i \lambda_i c_i + \sum_j \lambda_j ceq_j \quad (15)$$

In ‘interior-point algorithm’ the Hessian matrix of the lagrangian function uses lagrangian multipliers and non linear constraint function. Fmincon uses Hessian which is the second derivative of the Lagrangian given as:

$$\Delta^2_{xx} L(x,\lambda) = \nabla^2 f(x) + \sum \lambda_i \nabla^2 c_i(x) + \sum \lambda_i \nabla^2 ceq_i(x) \quad (16)$$

F. Setting the termination creteria using iteration count/function tolerance/ number of function evaluations

It is important to stop any optimization algorithm at the right time. The proposed fmincon based approach can be stop by three methods. 1) By specifying the number of maximum iteration (itermax) 2) By specifying the tolerance limit (tolmax) 3) By specifying the number of function evolutions (maxfun). In matlab the above three option for stopping the optimization algorithms are implemented by setting the options by user.

VI. Testing and Validation

The combined energy and reserve dispatch problem formulated in Section II is tested on IEEE 57 bus 17 Generating unit system. Cost and reserve bids are taken from [3]. The load and reserve demand for 24-hours,the reserve and energy limits, the cost characteristics and ramp rate limits can be found in [15]. In this paper the values of maxfun, Iterrmax and tolmax are taken as 50000, 1000 and 10-6 respectively.

A. Case 1: Optimal dynamic dispatch for operating cost

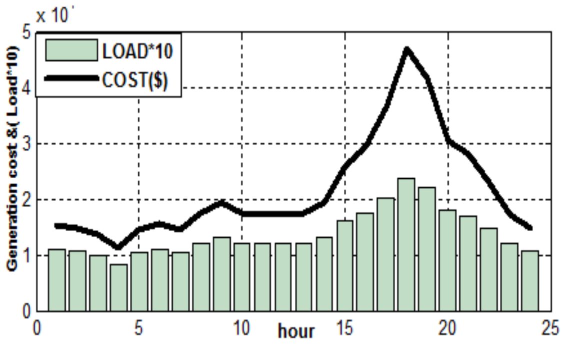

Fig 2. Variation of optimal cost with hourly demand

First economic dispatch is carried out with cost optimization only using the sectional cost characteristic [13]. Ramp rate limits are included to compute the twenty four hour optimal schedule with cost optimization only. Fig.2. Show the variation of optimal operating cost with load against time .The fluctuation of optimal cost with load shows that the proposed method is capable of tracing the complex relationship between these two quantities quiet accurately.

B. Case 2: Dynamic dispatch with cost and spinning reserve.

The practical combined dynamic dispatch is computed using the interior point algorithm on MATLAB and optimal values of generation and reserve are listed in Table I. Fig.3 shows the variation of optimal generation cost and reserve cost against the hourly demand. The variation of the optimal and reserve cost shows that method is capable to trace the complex relation between the two quantities.

Table II present the solution of joint dispatch for demand variation .as shown in table II .The hourly load variation pattern is changed as shown in the table and the optimal dispatch was carried out. The result in table II show that the convergence is achieved is all cases along with satisfaction of unit ramp rate limits.

TABLE 1.OPTIMAL GENERATION AND RESERVE COST FOR 24 HOURS BASE LOAD

H	Load (Pd) MW	Reserve (RD) MW	Generation cost ($) $\sum_{i=1}^{17} F(P_i)$	Reserve cost($) $\sum_{i=1}^{17} G(R_i)$	Total cost ($)	iterations
1	1083	284	15327.84	5580.26	20908.1	305
2	1056	211	14823.84	3814.26	18638.1	431
3	986	139	13653.2	2243.299	15896.5	204
4	833	122	11145.62	1936.26	13081.88	157
5	1028	178	14355.01	3045.3	17400.31	229
6	1097	227	15512.64	5405.26	20917.9	266

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7	1042	278	14588.64	5430.26	20018.9	299
8	1208	267	17432.27	7836.259	25268.53	267
9	1319	367	19462.77	7836.253	27299.02	187
10	1208	406	17418.07	8928.259	26346.33	403
11	1194	406	17173.06	8928.259	26101.32	681
12	1194	411	17173.3	9069.294	26242.59	200
13	1208	411	17418.3	9069.294	26487.6	190
14	1319	411	19462.77	9068.253	28531.02	202
15	1611	411	26064.76	9068.251	35133.01	203
16	1750	431	29313.75	9640.249	38954	152
17	2014	300	36365.19	5980.286	42345.48	122
18	2361	500	46910.4	11730	58640.4	44
19	2194	495	41547.64	11570.43	53118.06	89
20	1791	486	30382.13	11282.24	41664.37	164
21	1694	472	27940.36	10851.24	38791.6	187
22	1472	411	22720.07	9068.253	31788.32	161
23	1194	400	17346.88	8760.26	26107.14	161
24	1055	361	14807.04	7668.26	22475.3	405
Cost US $/Day			518345.6	183810.2	702155.8	

TABLE 2. RESULTS OF OPTIMAL ENERGY /RESERVE DISPATCH WITH DEMAND VARIATIONS (WITHOUT OUTAGE CASE)

H	Load (Pd) MW	Reserve (RD) MW	Generation cost ($) $\sum_{i=1}^{17} F(P_i)$	Reserve cost($) $\sum_{i=1}^{17} G(R_i)$	Total c ($)
1	836	122	11598.04	2398.24	13996.
2	912	172	12857.67	3598.24	16455.
3	950	222	13493.04	4834.24	18327.
4	980	275	13997.2	6301.201	20298
5	1048	322	15145.04	7616.24	22761.
6	1120	378	16399.06	9230.238	25629
7	1350	420	21504.48	10531.12	32035
8	1434	440	23390.21	11210.09	34600
9	1590	470	27636.1	12200.08	39836.
10	1645	480	29214.47	12530	41744.
11	1796	490	29112.5	12200.08	41312.
12	1820	495	28925.5	12035.08	40960.
13	1950	498	28738.5	11870.08	40608.
14	2170	498	35910.37	9740.224	45650.
15	2220	500	35756.11	9890.206	45646.
16	2357	450	35816.2	11540.08	47356.
17	2213	409	35345.97	10178.21	45524.
18	2170	354	35036.14	8526.047	43562.
19	2050	310	40412.08	7280.321	47692
20	1920	250	36476.26	5600.236	42076
21	1810	210	33336.8	4530.236	37867.
22	1776	162	32378	3358.239	35736.
23	1654	142	29024.59	2878.234	31902.
24	1574	128	26885.63	2542.225	29427.

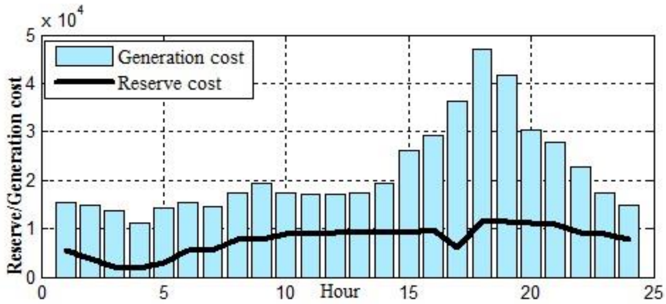

Fig 3. Variation of optimal reserve/generation cost with hourly demand

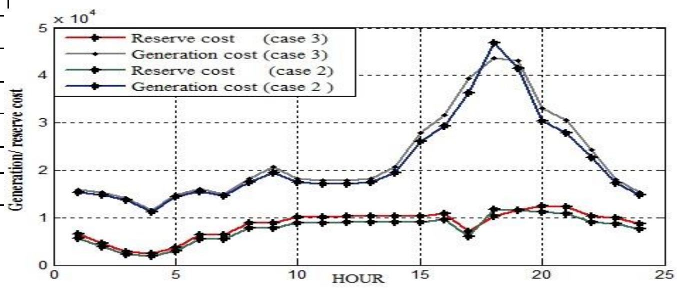

Fig. 4 Generation/reserve cost for generator outage case 2 and case 3

Table III shows the comparison of results for hour 19 by using interior point algorithm and RDE [15]. The validity of the interior point algorithm is established with reference to the RDE method.

TABLE 3. RESULT COMPARISON WITH RDE FOR HOUR 19(BASE CASE)

Unit	*Energy MW*	*Reserve MW*	*Energy[RDE]MW*	*Reserve[RDE]MW*
1	249.9978	79.9986	160.13	80
2	227.968	69.9982	207.87	70
3	102.9959	49.9985	88	50
4	102.9916	19.9984	103	20
5	160	29.9964	204	30
6	160	19.9977	226	20
7	79.04043	14.9541	76	15
8	60.07716	0.06566	95	0
9	273.9927	0	274	0
10	175.9923	99.9966	134	100
11	81.99474	0.00308	82	0
12	100	29.9970	103.99	30
13	80.0085	29.9984	84	30
14	80	29.9981	96	30
15	99.99231	0	100	0
16	97.98291	19.9988	98	20
17	61.9733	0	62	0
Cost($)/H	41547.64	11570.4	42772.85	11569.99
Iterations	89		1000	

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C. *Case 3: Optimal dispatch with generator outage*

The practical combined dynamic dispatch is computed using the interior point algorithm on Matlab platform and optimal values of generation/reserve for generator outage contingency are presented in Table.IV and Table V

The optimal energy reserve dispatch was also carried out for generator outage with load variation . it was seen that for hour 11 to hour 18 the algorithm did not converge for load variation case . this was because of the ramp rate constrained of generation limits which reduced the available power capacity . to get convergence with generator outage the load and reserve demand for hour 11 to 18 was changed as show in table V.

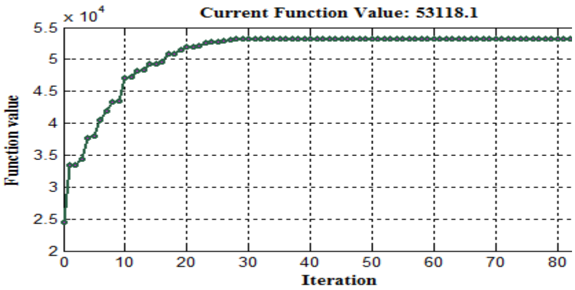

Fig. 5 Convergence characterstics of energy/ reserve dispatch (Case 2)

Table VI compares the interior-point algorithm with active-set and it if found that the latter method requires larger time to obtain minima. Fig. 4 compares the generation/reserve costs for two cases. Fig. 5 shows the convergence behavior, Fig. 6 and Fig.7 plot the iterative variation of function evaluation count and step size.

The detailed and complete dispatch solution showing the energy and reserve allocation of individual unit of ieee 57 bus 17 unit test system is shown in table VII and table VIII for load variation cases. Similarly, table IX and table X shown that the variation of result in contingency case. The result show that all limits and constrained are followed and the algorithm is capable of producing feasible hourly schedules for reserve and energy under varying load condition for practical power system.

TABLE 4. RESULTS OF OPTIMAL ENERGY /RESERVE DISPATCH WITH DEMAND VARIATIONS (OUTAGE CASE)

H	Load (Pd) MW	Reserve (RD) MW	Generation cost ($) $\sum_{i=1}^{17} F(P_i)$	Reserve cost($) $\sum_{i=1}^{17} G(R_i)$	Total cost ($)	iter
1	836	122	11598.04	2398.24	13996.28	242
2	912	172	12857.67	3598.24	16455.91	354
3	950	222	13493.04	4834.24	18327.28	382
4	980	275	13997.2	6301.201	20298.4	251
5	1048	322	15145.04	7616.24	22761.28	258
6	1120	378	16399.06	9230.238	25629.3	333
7	1350	420	21504.48	10531.12	32035.6	169
8	1434	440	23390.21	11210.09	34600.3	257
9	1590	470	27636.1	12200.08	39836.18	176
10	1645	480	29214.47	12530	41744.47	199
11	1796	490	29112.5	12200.08	41312.58	162
12	1820	495	28925.5	12035.08	40960.58	139
13	1950	498	28738.5	11870.08	40608.58	138
14	2170	498	35910.37	9740.224	45650.59	126
15	2220	500	35756.11	9890.206	45646.32	127
16	2357	450	35816.2	11540.08	47356.28	105
17	2213	409	35345.97	10178.21	45524.18	123
18	2170	354	35036.14	8526.047	43562.19	198
19	2050	310	40412.08	7280.321	47692.4	71
20	1920	250	36476.26	5600.236	42076.5	112
21	1810	210	33336.8	4530.236	37867.04	132
22	1776	162	32378	3358.239	35736.24	127
23	1654	142	29024.59	2878.234	31902.82	194
24	1574	128	26885.63	2542.225	29427.86	211

VII. Conclusions

The paper presents a combined energy and reserve dispatch model for deregulated electricity market using interior point algorithm. The findings are compared with previous results and active-set method. The proposed method is found to be more accurate and faster as compared to the existing methods with efficient and simple constraint handling with stable convergence behavior.

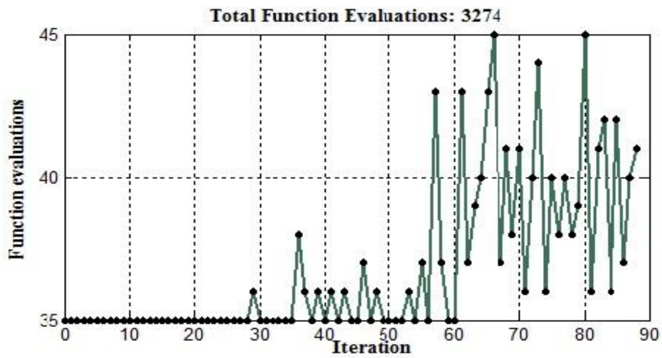

Fig 6. Variation of function evaluations(counts) with the progress of the algorithm

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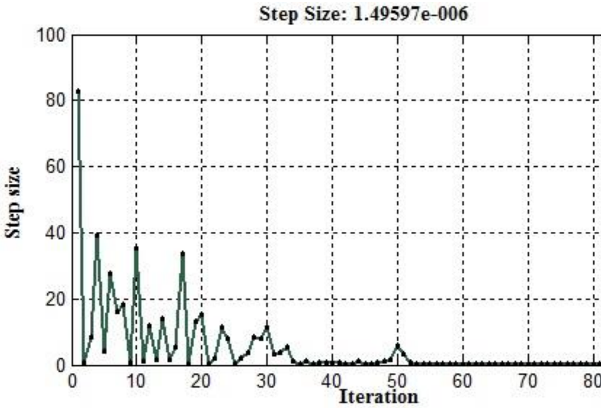

Fig. 7 Variation of step size with the progress of the algorithm

TABLE 5. OPTIMAL DISPATCH SOLUTION FOR GENERATOR OUTAGE

	HOUR18		HOUR 19	
UNITS (i)	*ENERGY MW*	*RESERVE MW*	*ENERGY MW*	*RE*
1	0	0	0	
2	228.003	69.9998	228.0027	6
3	104.0092	49.99108	104.0664	4
4	103.005	19.99523	103.0631	1
5	204.8011	29.1992	204.0086	2
6	226.0037	19.1992	226.1061	1
7	90.97074	0.02953	66.13427	2
8	85.00195	9.99831	94.99983	(
9	274	0	274	
10	176.2769	99.72335	194.2954	8
11	81.97961	0.02064	42.01591	3
12	129.0102	29.9904	129.1096	2
13	84.0155	29.98467	84.08166	2
14	86.01779	29.98246	96.0035	2
15	100	0	100	
16	98.0065	19.9937	98.00086	1
17	62	0	62	
COST (\$)/H	43579.08	10221.34	43131.45	1
Iterations	789		1000	

TABLE 6. COMPARISON OF INTERIOR POINT WITH ACTIVE SET METHOD

Method	Interior-point	Iterations	Line search	Iterations
H-1	20908.1	305	20907.8000	235
H-2	18638.1	431	18637.8005	239
H-3	15896.5	204	15895.0028	388
H-4	13081.88	157	13082.6004	223
H-5	17400.31	229	17398.6001	205
H-6	20917.9	266	20917.6003	301

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