Chapter 5

Environmental Dispatch

5.1 Introduction

Ever increasing demand of energy has necessited installation of larger and larger generating capacities year after year. The major share of these capacities come from coal fired, oil, and gas based plants. The share of nuclear power plants is negligible at present. For Indian coal based power stations, coal is found to contain larger portion of ash and sulphur. All these power stations produce undesirable particulate material such as ash, gaseous pollutant such as carbon oxides and oxides of sulphur and nitrogen. The heat energy dissipated in cooling water raises environmental temperature and is considered as pollutant [55, 56]. Nuclear power plants produce hazardous radiation emission. To cope up with ever increasing energy demand, the number of such plants are likely to increase, resulting in increased pollutants proportionately. These pollutants are hazardous not only to life but also to other life forms and materials. Excessive emission also causes global warming. All the above effects are viewed as social burden and are encashed in terms of penalty from resources. The U.S. Government has already passed clean air act 1990 [49], which mandates that utilities take the rate of SOx and NOx (oxides of Sulphur and Nitrogen) emission of their generating units into consideration while dispatching them. Having realized hazardous impacts of pollutants, power generation industries are incorporating means of reducing the same. Emission may be reduced through following means.

(1) By installation of electrostatic precipitators and SOx emission can be reduced by installing stack gas scrubber.

(2) By switching over from high sulphur content fuel to low sulphur content fuel.

(3) By dispatching power from generators to minimize emission as supplement to economic dispatch.

IEEE working group report (1981)(2) defines environmental dispatch in the following way.

" Environmental dispatch is the allocation of the power resources, which are connected to the system at a particular time to meet the system load at that time in a manner which minimizes the adverse impact on the environment or limit it to an acceptable level". Environmental dispatch should take into account the following aspects.

- Generating unit incremental environmental impact characteristics which include the effects of power station auxiliaries.

- Incremental changes in system transmission losses resulting from changes in generators outputs.

- Effects of station apparatus which contribute to or reduce the environmental impact.

Environmental dispatch strategy includes following methods

- Minimum emission dispatch.
- Controlled emission dispatch.
- Controlled and minimum dispatch.

Initially attempts were made to minimize emission only. The problem was handled exactly like economic dispatch. Minimum emission dispatch was an interesting and useful method, however in comparison with economic dispatch,the following observations are made.

- It is possible to reduce emission by applying minimum emission dispatch (MED)

- MED results in higher cost.

- Loss in economy, which amounts to few percent, may be a valuable investment in clean air.

So far many attempts are made for environmental dispatch. Gent and Laman [39] reported minimum emission dispatch by conventional λ method and has concluded that MED results in higher cost. Controlled emission dispatch is reported by Delson [40]. He attempted to shift generation from one station to another so as to maintain proper NOx level at station site. The method depends on the use of monetary conversion factors, in which for each set of environmental objectives and each system load level, minimum operating costs are achieved. Heslir and hobbs[45] have presented a method for evaluating the cost and employment impact of effluent dispatching and fuel switching as a means of reducing emissions from power plant. In their method, the problem is modelled as large range planning taking into account cost effectiveness of emission dispatching versus other options for emission reduction. Kermanshahi, et.al.[46] dealt with a decision making methodology to determine the optimal generation dispatch and environmental marginal cost with conflicting objectives, using goal programming. J. Nanda, et al [43] have attempted the problem of economic emission load dispatch using goal programming. One more attempt is made by Nanda [130] for environmental dispatch.

In their attempt, they have solved the problem by adjusting the compromise factor to minimize fuel cost and emission cost. Kothari and Nanda [54] have viewed the problem as emission minimization problem and have applied Box method. Observing the Indian conditions, it is realized that power stations are sparsely located and surrounding of a power station may be different as compared to other. Secondly, units at a plant may not emit the same proportion of pollutants. Hence, it is necessary to view the problem which will take into account local environment level and individual characteristics of every unit at plant. The important point which should be taken into account is that the maximum limit of generation at a plant may get reduced due to emission level, which may further result in the shifting of generation from one plant to other. Hence, in this work following objectives are considered and accordingly for each objectives, solution is sought.

(1) Emission minimization

(2) Combined economic and emission dispatch.

(3) Estimation of maximum generation limit at a plant due to maximum emission level.

For the first objective of minimization of emission for a given load, dynamic programming technique is employed. For the second objective, the problem is viewed as a multi-objective problem and applying weighting factors, the problem is reduced to a single objective problem. The third objective is self explanatory. Due to imposed emission level, the reduced maximum generation level is estimated. Finally, attempt is made to solve combined economic and environment dispatch for a system consisting of several plants and each plant having number of units. The solution of the problem is sought taking

into account all the above mentioned objectives using Dynamic Programming (DP).

5.2 Minimum Emission Dispatch (MED)

The MED is viewed as similar to economic dispatch. Using recursive technique of dynamic programming, minimization can be achieved. Similar to economic dispatch, NOx functions are taken as quadratic function and using the set of equations (2.21-2.29), minimum NOx can be estimated.

5.2.1 Problem Formulation

NOx emission function is estimated as

$$F_i(p_i) = e_i P_i^2 + f_i P_i + g_i \qquad Kg/MW/hr \qquad ; \qquad i = 1, n \tag{5.1}$$

For D MW, the balancing equation is

$$\sum_{i=1}^{n} P_i = D \tag{5.2}$$

with usual inequality bounds, $P_{min_i} \leq P_i \leq P_{max_i}$

5.2.2 Method of Solution

Looking to the above formula, it can be realized that the problem is similar to conventional dispatch problem and NOx can be minimized using the technique of dynamic programming developed in Chapter 2 and applying set of equations (2.21-2.29).

5.3 Economic and Environmental Dispatch

As reported earlier, minimization of NOx or SOx leads to higher cost of generation. Moreover, at any load, minimized emission level may be lesser than the level declared at the power station by pollution control agencies. Hence, economic and environment dispatch is treated as multi-objective problem so as to minimize cost of generation and simultaneously, satisfying the emission constraint. Usual method adopted to convert multi-objective function to single objective function is to apply weights to emission function. The methodology developed is iterative in nature and at the end of iteration, weights are adjusted. The method is useful for an on-ine application and can be extended to optimal load dispatch integrating unit commitment. However, the problem is considered as a local problem, i.e. generation allocation of all units at a plant are calculated with emission level satisfied.

5.3.1 Method of Solution

The problem of NOx emission dispatch is viewed as a localized problem and maximum level is specified at a plant with due consideration to type of fuel, type of plant, age of plant and subsequently surrounding of power station sight. For example, a power station situated far away from industrial zone may have higher level of emission as compared to highly polluted industrial zone. Hence NOx level or otherwise SOx level may differ from plant to plant. Hence solution of the problem is sought with following assumptions.

(1) Generation level is estimated at a plant is availed from dispatch calculation of the system.

(2) Cost functions and emission are quadratic.

Let

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \qquad Rs/MW/hr \tag{5.3}$$

and

$$NOx_i = e_i P_i^2 + f_i P_i + g_i \qquad Kg/MW/hr \tag{5.4}$$

where,

a_i, b_i, c_i have usual meaning,

e_i, f_i, g_i are emission constants, and

i is the index for generating units.

To minimize system operating cost with NOx constraint, an augmented cost function is defined with h as weight due to emission, as follows.

$$F_{A_i}(P_i) = F_i(P_i) + h * (NOx_i(P_i)) \tag{5.5}$$

Hence, the problem can be defined as

$$Min[F_{A_i}(P_i)] = Min[F_i(P_i) + h * (NOx_i(P_i))] \qquad i = 1, n \tag{5.6}$$

subject to the constraints such as equality, inequality and maximum NOx level at a unique load. The aim is to estimate the value of h at a given load to get minimum cost of generation satisfying all constraints. From equation (5.4), it can be easily verified that NOx value decreases with increase in value of h. The value of h can be estimated at the end of every iteration, using following linear relation of NOx and h as shown in figure (5.1)

$$\frac{[(NOx)_{j-2} - (NOx)_{j-1}]}{[(NOx)_{j-1} - NOXD]} = \frac{[h_{j-1} - h_{j-2}]}{h_j - h_{j-1}} \tag{5.7}$$

or

$$h_j = h_{j-1} + \frac{[NOXD - (NOx)_{j-1}]}{[(NOx_{j-1} - (NOx_{j-2}]} * (h_{j-1} - h_{j-2}) \tag{5.8}$$

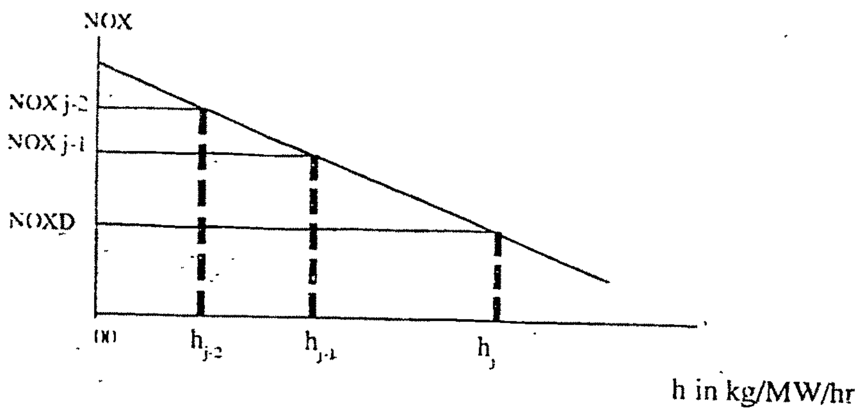

Figure 5.1: Relation Between NOx and h

The figure (5.1) and equation (5.6) reveal that new estimation of h depends on two consecutive values of h and NOx. The method is naturally iterative and after few iterations, specified NOx level can be achieved with minimum cost and satisfaction of other constraints. In each iteration, having found recent value of h, augmented cost function can be formed and using dynamic programming, generation allocation on each can be calculated. The method can be implemented in following steps.

(1) Initialize the problem by selecting the proper number of units, their cost function and NOx function as per unit commitment.

(2) Select the value of h as shown below.

$$h_i = \frac{\frac{df_i(P_i)}{dP_i}}{\frac{dNOx_i(P_i)}{dP_i}} \tag{5.9}$$

where P_i is generation on i^{th} unit calculated from economic dispatch.

Arrange h in ascending order and select first two values of h.

(1) Selecting these values of h, form the augmented cost function and calculate generation allocations and estimate two values of NOx.

(2) Using equation (5.6), estimate new value of h and calculate generation allocation and NOx along with usual constraints, and check NOx with desired NOx.

(3) If desired NOx is obtained, stop; otherwise, go to step 4 and repeat the procedure until desired convergence is obtained. For verification of proposed method, two systems [53, 54] are tested for 1100 and 900 MW and results are tabulated.

5.4 Estimation of Maximum Generation Level due to Emission Constraint

This estimation is necessary to find shift in generation from plant to plant while performing combined economic and environmental dispatch. The maximum generation level is the indication for maximum emission level. Hence this maximum generation level may be less than the generation capacity of plant. This level can be obtained as follows.

Assuming full capacity on each unit, total emission is first calculated, if NOx level is greater than the desired NOx level. With definite step size, generation level is reduced and minimum NOx level of the plant is calculated. The procedure is repeated till minimum NOx, corresponding to reduced generation level, is less than that specified. Next, with assumed two step sizes generation level is increased and NOx is calculated and compared with specified value. If necessary, using interpolation method, step size is estimated and the procedure is repeated till estimated generation level provides minimized NOx sufficiently near to the specified NOx level.

5.5 Combined Economic and Environmental Dispatch

Having developed the technique of estimation of maximum generation capacity due to environmental constraint as well as technique of tradeoff between cost and emission level, a generalized approach is attempted for a system consisting of number of plants each having its own NOx level as dictated by emission control agencies. The aim of the problem is to dispatch all units of all plants satisfying usual constraints and maintaining NOx level at all plants. For this dispatch, it may be necessary for a particular system load to reduce the generation at a plant and balance to be shifted to other plants. Hence all possibilities are to be explored at a plant for this dispatch, that is , whether it is necessary to minimize NOx, maximum generation level is already reached or it is necessary to perform tradeoff.

5.5.1 Problem Formulation

The problem can be formulated in an conventional manner as

$$Min\,[F_t] = min\,[F_{ij}] \tag{5.10}$$

subject to

$$\sum_{i=1}^{N}\sum_{j=1}^{m_i} P_{ij} = D + pl \tag{5.11}$$

$P_{min_{ij}} \leq P_{ij} \leq P_{max_{ij}}$

where,

F_t is total cost of generation F_{ij} is cost of generation of j^{th} unit at i_{th} plant,

$P_{min_{ij}}$ is the minimum generation level,
$P_{max_{ij}}$ is the maximum generation level,
i is the index of plant,
j is the index of unit,
$NOxd_i$ is the desired NOx level at a plant i,
D is the system demand,
pl is transmission losses, and
m_i is number of units at i^{th} plant.

5.5.2 Method of Solution

For a system consisting of number of plants, the following assumptions are made.

(1) Units are availed as per unit commitment order.

(2) For an available fuel at each plant, maximum generating capacity is already estimated.

(3) A set of B-coefficients are available to include transmission losses.

Assumption 2 is optional in the sense that while performing dispatch calculation, algorithm for estimating maximum generation capacity may or may not be included. If however, the same is included, the capacity calculation is unnecessarily repeated in every iteration. The problem solution can be initiated for given load by first estimating dispatch excluding emission constraint at each plant. Having known the value of plant generation, unit allocation can be finalized with following options.

(1) Calculate generation on each unit and calculate NOx of plant. If NOx of the plant is less than or equal to the desired NOx , there is no need to make any correction.

(2) If on the other hand NOx is greater than specified NOx, then two alternatives are adopted. First, calculate generation scheduling so as to minimize NOx. If NOx so calculated is less than specified limit of NOx, then go for second alternative; otherwise, finalize unit generation. Second alternative is to adjust generation by tradeoff algorithm developed in section 5.3 .

(3) If generation at a plant is crossing the bounds dictated by emission constraints, fix the generation at this plant and repeat the dispatch algorithm till the desired convergence is obtained. The method is summarized into an algorithm comprising

following steps.

(a) Read system data and form plant cost functions from the available units at each plant.

(b) For a given load, calculate plant generation including transmission losses. Set iteration count to 1.

(c) Calculate unit allocation at each plant. Calculate generation cost and estimate NOx level at each plant.

(d) (i) If generation at a plant is crossing the maximum bound, set generation at the plant at a maximum value.

(ii) Compare NOx level with desired NOx (NOxd) level. If NOx is less than NOxd, no correction is necessary.

(iii) If NOx is greater than NOxd, recalculate generation of each unit to minimize NOx. If minimized NOx is equal to NOxd go to step 5; otherwise, adjust the generation using trade off algorithm (5.3)

(e) If any plant has crossed the fixed bound, advance iteration by one and repeat the procedure from step 3, till convergence is obtained.

5.6 System Studies and Results

An attempt is made in this chapter to compartively study economic, environmental and combind economic & environmental dispatch. First, a set of units is selected along with their cost and emission coefficients. A program is run for a particular load to evaluate economic, environmental and emission constrained dispatch. Two eaxmples are solved on these aspects. For the first example, units' details are given in Tables 5.1 and 5.2. Cost coefficients and bounds are given in Table 5.1. Emission coefficients are given in Table 5.2. A generation scheduling program is run for the following three aspects.

(1) Economic dispatch

(2) Environmental dispatch

Table 5.1: Economic and Environmental Dispatch, Example 1:Input Data No 1

Unit No.	Cost Coefficients			Bounds	
	a_j	b_j	c_j	P_{min_j} MW	P_{max_j} MW
1	.009030	2.28251	44.82131	27.0	99.0
2	.0062700	2.73377	23.72967	27.0	99.0
3	.0016800	2.39248	62.18597	37.0	226.0
4	.0021000	2.26864	73.64796	37.0	222.0
5	.0012500	2.15151	98.22856	144.0	344.0
6	.0010600	2.26656	80.34796	144.0	344.0

(3) Economic and environmental dispatch.

Table 5.3 is the result of above three aspects. First part of the Table is the economic dispatch, second part is the environmental dispatch, whereas third part is the emission constrained dispatch. Load assumed is $1100MW$. From the Table 5.3, it can be observed that cost due to economic and environmental dispatch is more than that due to economic dispatch but it is less than that due to environmental dispatch. Another example is solved for the same aspects. Table 5.4 and Table 5.5 are input data and Table 5.6 is the result for 900 MW. This technique is further extended for a multiplant system. Table 5.7 shows plantwise number of units. Input data comprising cost coefficients and bounds are given in Table 5.8. Table 5.9 provides emission coefficients. B-coefficients matrix is given in Table 5.10. Plantwise specified emission level is shown in Table 5.11. For some selected load, economic dispatch program is run and the results are shown in Table 5.12. Table 5.13 shows the result of environment or emission constrained economic dispatch. From Table 5.13, it can be observed that maximum generation capacity due to emission constraint is reduced. This particular aspect can be observed at Plant No 1 which achieves this limit at 1030.85 MW.

Table 5.2: Economic and Environmental Dispatch, Example 1:Input DataNo 2

Unit No.	Emission Coefficients		
	e_j	f_j	g_j
1	.009390	.73398	31.04487
2	.009390	.73398	31.044870
3	.015300	-1.22195	90.197840
4	.015300	-1.22195	90.197840
5	.010330	-1.14499	96.085990
6	.010330	-1.14499	96.085990

Table 5.3: Economic and Environmental Dispatch for 1100 MW Load

Unit No.	Economic Dispatch			Emission Dispatch			Economic and Emission Dispatch		
	P_j	Cost	NOx	P_j	Cost	NOx	P_j	Cost	NOx
1	39.44	148.90	74.60	99.00	359.29	195.74	79.32	282.72	148.36
2	27.00	102.11	57.70	99.00	355.83	195.74	78.61	277.38	146.77
3	179.28	545.13	362.92	183.27	557.10	380.16	183.69	558.37	382.02
4	172.91	528.72	336.37	183.27	559.97	380.16	181.54	554.71	372.60
5	337.35	966.30	885.43	267.72	763.84	529.96	288.71	823.59	626.57
6	344.00	985.48	924.62	267.72	763.14	529.96	288.10	821.35	623.66
Cost Rs. 3276.65 Total NOx kg/hr 2641.66				Cost Rs. 3359.74 Total NOx kg/hr 2211.74			Cost Rs. 3318.11 Total NOx kg/hr 2300.00		

Table 5.4: Economic and Environmental Dispatch, Example 2:Input Data No 1

Unit No.	Cost Coefficients			Bounds	
	a_j	b_j	c_j	P_{min_j} MW	P_{max_j} MW
1	.15247	38.53973	756.7989	10.00	125.000
2	.10587	46.15916	451.3251	10.00	150.000
3	.02803	40.39655	1049.9980	35.00	225.000
4	.03546	38.30553	1243.531	35.00	210.000
5	.02111	36.32782	1658.5700	130.00	325.000
6	.01799	38.27041	1356.6590	125.00	315.000

Table 5.5: Economic and Environmental Dispatch, Example 2:Input DataNo 2

Unit No.	Emission Coefficients		
	e_j	f_j	g_j
1	.00419	.32767	13.85932
2	.00419	.32767	13.85932
3	.00683	-.54551	40.2669
4	.00683	-.54551	40.2669
5	.00461	-.51116	42.89553
6	.00461	-.51116	42.89553

Table 5.6: Economic and Environmental Dispatch for 900.0 MW Load

Unit No.	Economic Dispatch			Emission Dispatch			Economic and Emission Dispatch		
	P_j	Cost	NOx	P_j	Cost	NOx	P_j	Cost	NOx
1	32.49	2170.24	28.93	116.99	7352.57	109.54	59.25	3576.03	42.99
2	10.81	962.97	17.89	116.99	7300.69	109.54	52.34	3157.34	42.48
3	143.64	7431.18	102.83	135.69	7047.68	92.00	151.97	7836.67	115.11
4	143.03	7447.88	101.97	135.69	7094.28	92.00	151.21	7846.67	113.95
5	287.103	13828.50	276.13	197.31	9648.40	121.51	244.1419	11785.98	192.88
6	282.905	13623.40	267.24	197.31	9608.32	121.51	241.0696	11627.97	187.57
	Cost Rs. 45464.16 Total NOx kg/hr 795.16			Cost Rs. 48051.92 Total NOx kg/hr 646.1285			Cost Rs. 45830.68 Total NOx kg/hr 700.0025		

Table 5.7: Economic and Emission Dispatch Multi-Unit System

Plant	1	2	3	4	5
Units	5	5	5	5	5

Table 5.8: Economic and Emission Dispatch Multi Unit System

Plant No.	Unit No.	Cost Coefficients			Bounds	
		a_{ij}	b_{ij}	c_{ij}	$P_{min_{ij}}$	$P_{max_{ij}}$
1	1	.00903	2.28251	44.82131	27.0	99.00
	2	.00168	2.39248	62.18597	37.0	226.00
	3	.00210	2.26864	73.64796	37.0	222.00
	4	.00125	2.15151	98.22856	144.0	344.00
	5	.00106	2.26656	80.34791	144.0	344.00
2	1	.00607	2.73377	23.72967	27.0	99.0
	2	.00168	2.39248	62.18597	37.0	226.0
	3	.00210	2.26864	73.64796	37.0	222.0
	4	.00125	2.15151	98.22586	144.0	344.0
	5	.00106	2.26656	80.34796	144.0	344.0
3	1	.00903	2.28251	44.82131	27.0	99.0
	2	.00627	2.73377	23.72961	27.0	99.0
	3	.00210	2.26864	73.64796	37.0	226.0
	4	.00125	2.15151	98.22856	144.0	344.0
	5	.00106	2.26656	80.34796	144.0	344.0
4	1	.00903	2.28251	44.82131	27.0	99.0
	2	.00627	2.73377	23.72961	27.0	99.0
	3	.00168	2.39248	62.18597	37.0	226.0
	4	.00125	2.15151	98.22856	144.0	344.0
	5	.00106	2.26656	80.34796	144.0	344.0
5	1	.00903	2.28251	44.82131	27.0	99.0
	2	.00627	2.73377	23.72961	27.0	99.0
	3	.00168	2.39248	62.18597	37.0	226.0
	4	.00210	2.26864	73.64796	37.0	222.0
	5	.00106	2.26656	80.34796	144.0	344.0

Table 5.9: Economic and Emission Dispatch Multi-Unit System

Plant No.	Unit No.	Emission Coefficients		
		e_{ij}	f_{ij}	g_{ij}
1	1	.00939	.73398	31.04487
	2	.015300	-1.22195	90.19784
	3	.015300	-1.22195	90.19784
	4	.010330	-1.14499	96.08599
	5	.009390	.73388	32.04467
2	1	.00939	.73388	32.04467
	2	.01530	-1.22195	90.19764
	3	.01530	-1.22195	90.19764
	4	.01033	-1.14499	96.08599
	5	.01033	-1.14499	96.08599
3	1	.00939	.73398	31.04487
	2	.00939	.73398	31.04487
	3	.01530	-1.22195	90.19784
	4	.01033	-1.14499	96.08599
	5	.01033	-1.14499	96.08599
4	1	.00939	.73398	31.04487
	2	.00939	.73398	31.04487
	3	.01530	-1.22195	90.19784
	4	.01033	-1.14499	96.08599
	5	.01033	-1.14499	96.08599
5	1	.00939	.73398	31.04487
	2	.00939	.73398	31.04487
	3	.01530	-1.22195	90.19784
	4	.01530	-1.22195	90.19764
	5	.01033	-1.14499	96.08599

Table 5.10: Loss Coefficients

.00001	.000007	.000004	.000003	.000009
.000007	.00004	.000006	.000007	.000008
.000004	.000006	.00002	.000009	.000005
.000003	.000007	.000009	.00005	.000007
.000009	.000008	.000005	.000007	.00003

Table 5.11: Plantwise NOx Constraints

Plant No.	1	2	3	4	5
NOx Specified	2500	2100	2300	2230	2300

5.7 Conclusion

An attempt is made to solve a problem of sensitive nature that is emission constrained generation scheduling. A simple approach is proposed for economic and environmental dispatch using basic dispatch algorithm. Algorithm incorporates 'tradeoff' so as to maintain a specified emission level at minimum cost. The algorithm solves this problem in three steps.

(1) Economic Dispatch

(2) Environmental Dispatch

(3) Economic and Environmental Dispatch.

The algorithm gives expected results in Table 5.3 and 5.6. Unlike reports of other researchers, the problem of emission constrained dispatch is treated as localized problem and for every plant, a specified NOx level is assigned. The developed algorithm for any load restricts generation of a plant as dictated by specified NOx level and this also takes care of any plant if necessary to maintain NOx level applying trade off strategy (Tables 5.12 and 5.13). The solution of these examples revel the following points are worth noting.

(1) The method developed is simple and gives satisfactory results. Referring Table 5.3, it can be confirmed that for a load of 1100 MW, economic dispatch cost is least and NOx level is higher than the expected value. Environmental dispatch costs more but NOx level is lower than the specified level. Hence, trade off technique is applied and as expected NOx level is maintained at cost lesser than the latter. This is also found to be true for a load of 900 MW for second example (Table 5.6).

Table 5.12: Economic Dispatch

Sr.No	Demand MW	Plant No.	Plant Load MW	Plant Cost Rs	Plant Actual NOx	Plant Specified NOx	Total Cost
1	3500.0	1	958.0297	2839.45	2489.1290	2500.00	
		2	724.7913	2160.89	1158.5460	2100.00	
		3	761.2676	2268.80	1536.7970	2300.00	
		4	621.0737	1869.90	1013.1200	2230.00	
		5	572.3358	1754.84	974.1920	2300.00	10893.89
2	4380.00	1	1215.4310	3636.50	3637.35	2500.00	
		2	908.8105	2680.19	1843.8350	2100.00	
		3	961.4507	2861.33	2460.9940	2300.00	
		4	779.4188	2314.90	1601.54	2230.00	
		5	734.2626	2222.54	1608.3580	2300.00	13715.46
3	4500.00	1	1235.00	3700.52	3684.50	2500.00	
		2	935.810	2759.49	1962.139	2100.00	
		3	1000.01	2977.17	2594.120	2300.00	
		4	805.119	2388.69	1711.3350	2230.00	
		5	756.547	2292.09	1726.4130	2300.00	4078.40
4	4700.00	1	1235.00	3700.52	3684.5050	2500.00	
		2	994.96	2932.66	2237.2040	2100.00	
		3	1063.66	3194.94	2721.8690	2300.00	
		4	854.20	2531.81	1937.5420	2230.00	
		5	810.06	2454.25	1956.1450	2300.00	14753.77

Table 5.13: Economic Disaptch With NOx Constraint Plants

Sr.No	Demand	Plant No.	Plant Load MW	Plant Cost Rs	Plant NOx	Plant Specified NOx	Total Cost
1	3500.00	1	958.0297	2839.45	2489.1290	2500.00	
		2	724.7913	2160.89	1158.5460	2100.00	
		3	761.2676	2268.80	1536.7970	2300.00	
		4	621.0737	1869.90	1013.1200	2230.00	
		5	572.3358	1754.84	974.1920	2300.00	10829.89
2	4380.00	1	1030.85	3099.38	2500.00	2500.00	
		2	960.53	2831.58	2074.21	2100.00	
		3	1015.01	3089.49	2300.04	2300.00	
		4	822.07	2438.18	1787.84	2230.00	
		5	780.22	2362.79	1826.56	2300.00	13821.40
3	4500.00	1	1030.854	3099.38	2500.0000	2500.00	
		2	1010.391	3005.81	2100.121	2100.00	
		3	1015.014	3089.51	2300.005	2300.00	
		4	864.415	2561.82	1986.7390	2230.00	
		5	824.779	2499.66	2018.2190	2300.00	14256.19
4	4700.00	1	1030.85	3099.38	2500.00	2500.000	
		2	1019.67	3052.18	2100.00	2100.000	
		3	1015.01	3089.48	2300.04	2300.000	
		4	970.43	2904.74	2230.059	2230.000	
		5	938.43	2883.30	2299.99	2300.000	15029.08

(2) It is possible that a particular plant may emit NOx higher than the specified level above a critical load. Hence, the capacity of the plant must be reduced to the critical load. This aspect can be observed in Table 5.12 and Table 5.13. Table 5.12 is the result of economic dispatch without NOx constraint. For a load of 4500 MW and above, plant 1 reaches its maximum capacity and is emitting NOx more than the specified value. Also it may be noted that total generation of first, second and third plant for a load of 4700 MW is 3293.62 MW. Hence, it is necessary to reduce the capacity of plant 1 to an appropriate level. On running the proposed algorithm, generation of plants 1, 2 and 3 is reduced to an appropriate level and total generation of these plants is reduced to 3065.53 MW. Hence, necessary balance load is now shared by plants 4 and 5. Even due to sharing of this balance load, plants 4 and 5 undergo trade off to maintain specified level.

In short, the proposed algorithm is useful for a plant system having different NOx levels.