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Optimized Power Generation Using Dynamic Programming

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Abstract – *The modern complex power system has conflicting requirements. With heavy load demands and distributed generation, cost of generation becomes the primary casualty with its attendant pollution hazards and increased losses contributing for an inefficient system. The whole generation becomes economical and environmental friendly if coordination is brought between cost, emission and loss. The earlier long iterative procedures are laborious in nature for this pareto-optimal problem. This paper discusses a new Dynamic Programming technique with a novel recursive approach for realizing production cost minimization, with an emission constrained and loss reduced condition. Multi-objective solution is provided by a performance comparison table. The results for the test systems portray the computational efficiency and accuracy of the solution.*

Keywords – Economic dispatch, emission dispatch, Emission Constrained Economic Dispatch (ECED), Self Adaptive Dynamic Programming (SADP).

1. INTRODUCTION

In the power driven world, energy demand is predicted to increase 50% by the year 2030, and most of that demand is expected to be met by fossil fuels. Out of 4,055 billion kWh of electricity produced in the entire world during the year 2005, about 2015.335 billion kWh of electricity were obtained through conventional coal fired thermal power generating stations[1]. This generation has to be realized considerably in a most economical, viable and environmental friendly manner.

Any power system at the initial stages of its inception must have a proper planning after due consideration for the load demand, the transmission circuit, the capacity of generators, the cost of generation and the environmental pollution. In the past three decades, detailed surveys show that conventional methodologies [2]-[4] and optimization techniques using various soft computing methods have been held as the prime solution procedures.

Over the years, several authors have suggested various optimization techniques [5]. These techniques either help in minimizing cost or emission or aid in obtaining a pareto-optimal solution for this multi-objective problem. Reference [6] presents a summary of several techniques intended to reduce emissions into the atmosphere due to electric power generation. A combined handling of economic and minimum emission dispatch by introducing a price penalty factor has been discussed in [7]. Similarly, a fuzzy logic approach for environmental/economic dispatch has been dealt in [8]. Reference [9], [10] demonstrated the usage of neural network method to economic-emission dispatch problems.

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Sequential quadratic programming was used as a tool to solve economic emission load dispatch [11]. Reference [12] presented genetic algorithm based solution for emission controlled economic generation dispatch problem. Non-inferior solution for this multi-objective decision making problem has also been attempted [13]. Reference [14] presented a new evolutionary algorithm for environmental/economic power dispatch.

Dynamic Programming (DP), because of its non-analytic approach was not given due weight all these days. A well-defined analytic approach is possible with DP and this establishes the aptness of our choice. This fine analytical expression can provide a preliminary footing for the various case studies at the initial stages of planning. If need be, refined and rigorous optimization techniques can be attempted in these systems during operation after the installation of these plants.

2. OPTIMIZED POWER GENERATION

In the initial stages of planning for a given demand, the approximate capacity or rating of the plant can be fixed. They can be planned on optimum generation condition, so that excessive rating of the generators can be avoided. A study involving simple optimization technique is undertaken in this article for fixing up plant capacity. Towards this end, a pareto-optimal solution format is explored for this multi-variable, multi-constraint problem involving cost, emission and loss.

Initial scheduling methods in power system were based on cost criterion. The cost minimum approach relied on equal lambda condition for which analytical methods exist. However, as the system became very large with heavy demands, transmission losses were experienced on a large scale. The coordination equations were developed which solely depended on long iterative techniques. With increased power generation in large thermal power stations, environmental pollution occurred and a cleaner power generation became the casualty. Remedial measures in the form of emission regulations became stringent and the prime requirement was hygiene. This gave way to a scenario where emphasis is given for all the three factors namely cost, emission and loss. This article presents a novel recursive approach in DP, which considers all the relevant factors for power system generation planning.

In thermal stations, sudden changes in loads cannot be matched by sudden fixing of new optimal generation conditions for the individual generators. The problem considered assumes a longer duration for load continuity. Optimization of power generation for a specific period, even for a day, cannot be considered as a single problem because of variation in power demand from hour to hour. So finding an optimum solution for a day includes finding an optimum allocation for each hour.

Dynamic Programming is a mathematical technique dealing with the optimization of multistage decision process [15]-[16]. The word 'programming' has been used in the mathematical sense of selecting an optimum allocation of resources and it is 'dynamic' as it is particularly useful for problems where decisions are taken at several distinct stages. Discrete, continuous, deterministic as well as probabilistic models can be solved by this method**.**

In contrast to linear programming, there does not exist a standard mathematical formulation for the DP. Therefore, problem solving is in two stages: in developing the functional equations for the problem and in solving functional equations for determining the optimal solution. Increase in the number of states at each stage is the curse of dimensionality in the literature of DP. The result is spectacular in computational savings, if the state variables are three or less. Against this background, it has been established that the format developed in this paper can even be extended to higher number of state variables with well-defined mathematical approach. Hence, it has been aptly called Self Adaptive Dynamic Programming (SADP) approach. This paper presents the above technique eliminating common Lambda approach. The analytical nature ensures high accuracy and the same is nicely demonstrated by the results.

Unlike the DP search technique, the SADP approach presented here does not search through the solution space. The optimum allocation can be obtained directly by substitution of cost, emission coefficients in the equations.

3. DYNAMIC PROGRAMMING

A system in its initial state, described by a vector s_N, finally reaches the state s_0 as a result of certain decisions denoted by the vector 'd'. The transformation T_N can be functionally explained as $s_0 = T_N(s_N, d)$. Let a real valued function $\psi_N(s_N, d)$ called the objective or the return function be associated with the transformation (T_N) which measures the effectiveness of the decisions made and the output that results from these decisions. The objective is to determine a given input s_N to optimize (minimize or maximize) ψ_N subject to the constraint $s_0 = T_N(s_N, d)$.

This multistage problem is decomposed into 'j' stages, where $1 \le j \le N$, and s_j represents the input at the j[th] stage. Starting from the initial state s_N, the system is considered to pass through successive states $s_{N-1}, s_{N-2}, s_{N-3}, \ldots s_2, s_1$ before reaching the final state s_0. Thus each state s_{j-1} is the function of the input state s_j and the decision vector d_j, i.e. $s_{j-1} = T_j(s_j, d_j)$. There results a stage return function $f_j(s_j, d_j)$. In addition, the return function ψ_N is a function of stage returns, i.e $\psi_N = \psi_N(f_N, f_{N-1}, \ldots f_2, f_1)$. From the above discussion, it would seem to suggest that if ψ_N is of the form $\psi_N = f_N o\, f_{N-1} \ldots f_2 o\, f_1$ where "o" represents a composition operator indicating either addition or multiplication, then $\psi_N = f_N\, o\, \psi_{N-1}$, where $\psi_{N-1} = f_{N-1} o\, f_{N-2} \ldots f_2 o\, f_1$. It is possible to separate all $\psi_N, \psi_{N-1}, \ldots \psi_2$ successively in this order, and thus the recursive equation may now be proposed as:

$$F_j(s_j) = \min_{d_j} [f_j\, o\, F_{j-1}(s_{j-1})],\ 2 \le j \le N \quad (1)$$

with $F_1(s_1) = \min_{d_1} f_1$ subject to

$$s_{j-1} = T_j(s_j, d_j),\ 2 \le j \le N \quad (2)$$

This type of approach is called the backward recursion. This backward recursion can be conveniently used only when optimization with respect to a specific input s_N is needed, because in such case the output s_0 is not taken into account.

To optimize the system with respect to a prescribed output s_0, it would naturally be convenient to reverse the direction. Treat s_j as the function of s_{j-1} and d_j, and substitute $s_j = T_j(s_{j-1}, d_j), 1 \le j \le N$. Also express stage returns as functions of stage output and then proceed from stage N to stage 1. Such a procedure is called the forward recursive approach which is adopted in this work.

4. FORMULATION OF OPTIMIZED POWER GENERATION PROBLEM

This article visualizes the generation planning problem as five different cases involving cost, emission independently and also with loss, in different combinations as presented in Table 1. Each case can be modelled as a mathematical equation involving its own parameters.

Case A:

In general, an economic dispatch problem starts with a mathematical cost equation, modelled to represent each individual generator in terms of generation and cost coefficients.

$$F_i(P_i) = \sum_{i=1}^{n} \left(a_i P_i^2 + b_i P_i + c_i\right) \$/\text{hr} \quad (3)$$

where P_i is the individual generation from unit 'i'; a_i, b_i and c_i are its cost coefficients.

Table 1. Coordination chart

Cases	Cost	Emission	Loss
A	✓	×	×
B	×	✓	×
C	✓	✓	×
D	✓	×	✓
E	✓	✓	✓

✓	Included	×	Not included

Case B:

An emission dispatch problem involves an emission equation, modelled to represent each individual generator in terms of generation and emission coefficients.

$$E_i(P_i) = \sum_{i=1}^{n} \left(d_i P_i^2 + e_i P_i + f_i \right) \text{Kg/hr} \quad (4)$$

where P_i is the individual generation from unit 'i' and d_i, e_i and f_i are its emission coefficients.

Case C:

An emission constrained economic dispatch problem starts with mathematical cost equation (3), modelled to represent each individual generator in terms of generation and cost coefficients and mathematical emission equation (4), formulated to relate the emission coefficients with the individual generation.

An appreciable increase in the volume or weight of emission is governed by the magnitude of generation which in turn governs the cost and hence the economical operation of the system. These costs are coordinated with the actual fuel costs by a price factor called the penalty cost of emission (h).

$$h_i = \frac{F_i}{E_i} \quad (5)$$

where, F_i and E_i are the cost and emission corresponding to i^{th} generator for specific conditions of generation including the limits of generation and the average costs of generation as given below:

ie. $h_{i\max} = F_{i\max} / E_{i\max}$; $h_{i\min} = F_{i\min} / E_{i\min}$

$$h_{i\,ave} = \left(h_{i\max} + h_{i\min} \right) / 2 \; ; \; h_{i\,com} = \sum_{i=1}^{n} h_{i\,ave} \Big/ n$$

The emission constrained cost equation for the system can now be formulated as:

$$f_t = \sum_{i=1}^{n} \left(\left(a_i P_i^2 + b_i P_i + c_i \right) + h_i \left(d_i P_i^2 + e_i P_i + f_i \right) \right) \quad \$/\text{hr} \quad (6)$$

Case D:

In economic dispatch problem under loss-included case, transmission losses are given by P_L, where $P_L = P' B P$ where P and B are in the form of matrices representing generation power and transmission loss coefficients. Also P' is the transpose of P.

The cost of transmission losses in between the plants are accounted with the actual fuel costs by a price factor (g).

$$g_i = \frac{F_i}{P_i} \quad (7)$$

where, F_i and P_i are in turn the cost and generation corresponding to i^{th} generator for specific conditions of generation including the limits of generation and the average costs of generation as given below :

$$g_{i\max} = F_{i\max} / P_{i\max} ; \; g_{i\min} = F_{i\min} / P_{i\min}$$

$$g_{i\,ave} = \left(g_{i\max} + g_{i\min} \right) / 2 \; ; \; g_{i\,com} = \sum_{i=1}^{n} g_{i\,ave} \Big/ n$$

Now the loss-included cost equation is:

$$f_t = \sum_{i=1}^{n} \sum_{j=1}^{n} \left(\left(a_i P_i^2 + b_i P_i + c_i \right) + g_i \left(P_i' B_{ij} P_j \right) \right) \$/\text{hr} \quad (8)$$

Case E:

In emission constrained economic dispatch problem under loss-included case, modified form of cost equation is:

$$f_t = \sum_{i=1}^{n} \sum_{j=1}^{n} \left((a_i + h_i d_i) P_i^2 + (b_i + h_i e_i) P_i + (c_i + h_i f_i) + g_i \left(P_i' B_{ij} P_j \right) \right) \$/\text{hr}$$

$$f_t = \sum_{i=1}^{n} \sum_{j=1}^{n} \left(a_i' P_i^2 + b_i' P_i + c_i' + g_i \left(P_i' B_{ij} P_j \right) \right) \$/\text{hr} \quad (9)$$

where $a_i' = (a_i + h_i d_i)$, $b_i' = (b_i + h_i e_i)$ and $c_i' = (c_i + h_i f_i)$

A load balance equation will impose constraint over generation as:

$$\sum_{i=1}^{n} P_i - P_L - P_d = 0 \quad (10)$$

where P_d is the total system load demand and P_L is the transmission loss.

A generation limit will also be a constraint over the operating range of individual generators

$$P_{i\min} \le P_i \le P_{i\max} \quad (11)$$

Now the loss formula for the first generator can be modified as:

$$P_L = P_1 B_{1i} P_i = P_1 B_{11} P_1 + P_1^2 B_{12} \frac{P_2}{P_1} + P_1^2 B_{13} \frac{P_3}{P_1}$$
$$= P_1^2 B_{11} \left(\alpha_{11} + \alpha_{12} + \alpha_{13} \right)$$
$$= P_1^2 B_{11}' \quad (12)$$

where B_{11}' is the modified form of self-coefficient.

Using this, cost equation for the first generator can be rewritten as:

$$f_1 = \left(a_1' P_1^2 + b_1' P_1 + c_1' + g_1 \left(P_1^2 B_{11}' \right) \right)$$
$$= \left(\left(a_1' + g_1 B_{11}' \right) P_1^2 + b_1' P_1 + c_1' \right) \ \$/\text{hr}$$

Now substituting, $a_1'' = a_1' + g_1 B_{11}'$ we get the cost equation for the first generator as:

$$f_1 = \left(a_1'' P_1^2 + b_1' P_1 + c_1' \right) \$/\text{hr} \quad (13)$$

Similar cost equations can be arrived for second and third generators.

This whole formulation has turned out to be purely analytic in nature with high possibility for accurate solutions. A best choice was chosen for penalty cost of emission and price factor of loss.

A penalty cost of emission and a price factor for transmission loss have helped the suggested recursive technique to achieve this simple analytical form. A triangularization has been adopted for the loss coefficient matrix, which has made the discussed DP approach also suitable for loss-included condition.

Since the procedures of applying SADP to these situations are similar in nature, Case E which involves all the three objectives has been considered in this paper. The methodology and the cases undertaken are figuratively presented in Figure 1.

5. IMPLEMENTATION OF RECURSIVE APPROACH

Let s_i be the output from the i^{th} stage of this multistage problem. For a generation planning problem involving three generators, s_3 is the output from the 3rd stage and it equals $P_1 + P_2 + P_3$. Outputs from earlier stages are $s_2 = P_1 + P_2 = s_3 - P_3$ (for the second stage) and $s_1 = P_1 = s_2 - P_2$ (for the first stage).

Now

$$f_1(s_1) = \min_{0<P_1<s_1} \left(a_1^{''} P_1^2 + b_1^{'} P_1 + c_1^{'}\right) \text{\$/hr} \quad (14)$$

Since $c_1^{'}$, $c_2^{'}$ and $c_3^{'}$ are constants, they are removed from the respective equations and their sum can be added to the cost equation at the end.

$$f_2(s_2) = \min_{0<P_2<s_2} \left(a_2^{''} P_2^2 + b_2^{'} P_2 + f_1(s_1)\right) \text{\$/hr}$$
$$= \min_{0<P_2<s_2} \left(a_2^{''} P_2^2 + b_2^{'} P_2 + f_1(s_2 - P_2)\right) \text{\$/hr}$$
$$= \min_{0<P_2<s_2} \left(a_2^{''} P_2^2 + b_2^{'} P_2 + a_1^{''}(s_2 - P_2)^2 + b_1^{'}(s_2 - P_2)\right) \text{\$/hr} \quad (15)$$

For the second generator, minimum is attained when the above equation (15) is differentiated with respect to P_2 and equated to 0. This gives the value of P_2 in terms of s_2 and constant,

$$\text{i.e., } P_2 = A_2 s_2 + B_2 \quad (16)$$

where, $A_2 = 2a_1^{''} / \left(2a_1^{''} + 2a_2^{''}\right)$ and $B_2 = \left(b_1^{'} - b_2^{'}\right) / \left(2a_1^{''} + 2a_2^{''}\right)$

Similarly for the third generator,

$$f_3(s_3) = \min_{0<P_3<s_3} \left(a_3^{''} P_3^2 + b_3^{'} P_3 + f_2(s_2)\right) \text{\$/hr}$$
$$= \min_{0<P_3<s_3} \left(a_3^{''} P_3^2 + b_3^{'} P_3 + f_2(s_3 - P_3)\right) \text{\$/hr} \quad (17)$$

Solving further we arrive at the value of P_3 as:

$$P_3 = \frac{\left[\begin{array}{l}\left(2a_1^{''} + 2a_1^{''} A_2^2 - 4a_1^{''} A_2 + 2a_2^{''} A_2^2\right) s_3 + \\ \left(\begin{array}{l} 2a_1^{''} A_2 B_2 - 2a_1^{''} B_2 + b_1^{'} - b_1^{'} A_2 + 2a_2^{''} A_2 B_2 + \\ b_2^{'} A_2 - b_3^{'} \end{array}\right)\end{array}\right]}{\left(2a_1^{''} + 2a_1^{''} A_2^2 - 4a_1^{''} A_2 + 2a_2^{''} A_2^2 + 2a_3^{''}\right)} \quad (18)$$

$$\text{i.e. } P_3 = A_3 s_3 + B_3$$

Substitution of cost coefficients, emission coefficients and the total load on the system in the above equation will provide the optimum generation for the third generator.

Proceeding in this fashion and expanding sequentially as per the equations $F_i(P_i) = \left(a_i^{''} P_i^2 + b_i^{'} P_i + c_i^{'}\right)$ and $s_{i-1} = s_i - P_i$ where 'i' varies from 1 to 6, we can arrive at the equations for all the six generators in the given test system 2. Substitution of cost, emission and loss coefficients and the load in the equation for P_i will yield the generation of i^{th} generator under optimum condition. This procedure can also be extended to any 'n' generator system and this brings out the efficacy of SADP.

While attempting to attain the objective, a suboptimal point using the above technique was found for the emission constrained economic dispatch condition, which neglected loss. Then the same procedure was applied for emission constrained economic dispatch condition with loss, using modified form of B-coefficient matrix. In the subsequent approach, a few iterations were required so that the same format suits the total generation with loss inclusion. Thus, an all round satisfactory performance forms the basis of system planning. The best performance addresses to all the three objectives mentioned in this paper, to be at their best possible values. Since simultaneous realization of their minima is impossible, a near optimal solution satisfying multi-objective criterion, with a small deviation from their individual minima has been realized in this paper.

6. RESULTS AND DISCUSSIONS

Test System 1:

A three-generator system [17] with cost, emission coefficients and power limits as listed in Table 2 and loss coefficients as in Table 3 was considered for our study.

The results of various cases from A to E are entered in Table 4. The best configuration arrived at corresponds to fine optimization approach. A single price factor (g) does not provide a solution for the best configuration, where all the three objectives are at their best possible values. It necessitates a comprehensive study about various price factors g_{min}, g_{max}, g_{ave} and g_{com}. Table 4 also helps to identify the price factor g_{min} with which compromise between the objectives are satisfied. While attempting to find a best suited price factor (g), a comparison among various penalty costs of emission (h) should be attempted. Table 4 clearly projects h_{max} as a well-suited one.

Test System 2:

An IEEE six-generator, 30-bus test system [7], [9], [10] with cost and emission coefficients and power limits as given in Table 5 and loss coefficients taken from Table 6 was considered as our next test system. The results of various case studies are entered in Table 7.

Results obtained for 700 MW using recursive approach have been compared with that arrived through conventional method and quick method [10], in Table 8. Accuracy of the proposed algorithm has been endorsed with this table, where the results of the proposed algorithm match with that of the conventional and score over the method in [10].

Comparison of iterations in Table 9 portrays the superiority in computational speed of SADP in comparison with conventional method in terms of the number of iterations required to arrive at the solution.

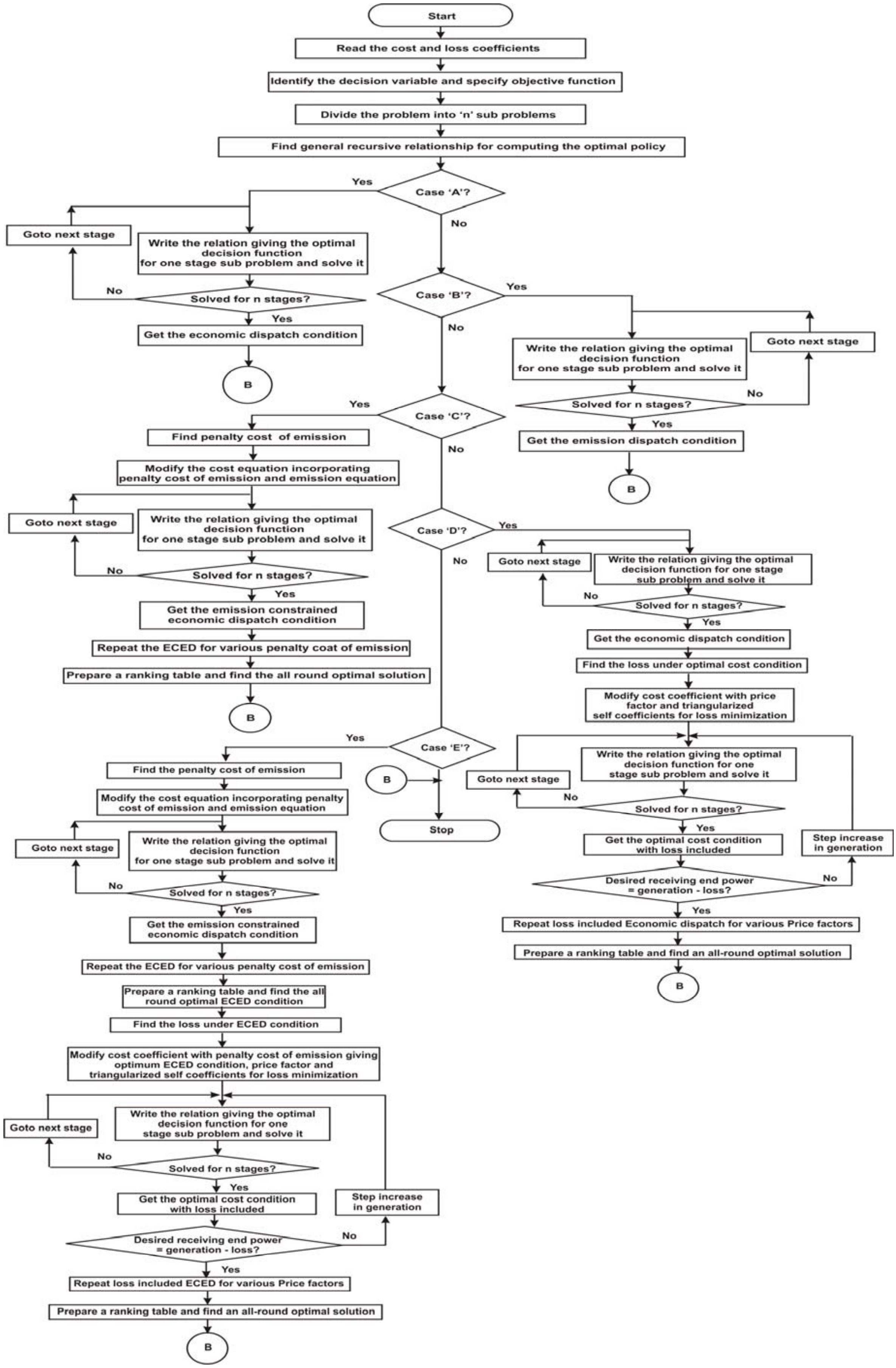

Fig. 1. SADP algorithm

Table 2. Cost, emission coefficients, and power limits for three generator system

Unit	a	b	c	d	e	f	Min load (MW)	Max Load (MW)
1	0.03546	38.30553	1243.5311	0.00683	-0.54551	40.2669	35	210
2	0.02111	36.32782	1658.5696	0.00461	-0.5116	42.89553	130	325
3	0.01799	38.27041	1356.6592	0.00461	-0.5116	42.89553	125	325

Table 3. Loss coefficients for three generator system

0.000071	0.000030	0.000025
0.000030	0.000069	0.000032
0.000025	0.000032	0.000080

Table 4. Performance comparison table with results for various cases of three generator system (for a load of 700MW)

		Cost	Emission	Loss
Economic Dispatch - Case A		34269.2	619.805	Loss not considered
Emission Dispatch - Case B		34336	606.377	
Emission Constrained Economic Dispatch - Case C	h_{max}	34302	607.694	
	h_{min}	34489.3	615.575	
	h_{ave}	34418.2	609.759	
	h_{com}	34328.3	606.424	
Economic Dispatch (loss included) – Case D	g_{max}	35424.7	662.221	23.8119
	g_{min}	35432.2	669.528	23.996
	g_{ave}	35427.3	665.675	23.7611
	g_{com}	35424.5	660.53	23.7611
Emission constrained Economic Dispatch (loss included) - Case E (with h_{max})	g_{max}	35442.5	653.047	23.4775
	g_{min}	35440.9	653.239	23.489
	g_{ave}	35441.8	653.102	23.4866
	g_{com}	35439.5	653.361	23.4966

Table 5. Cost, emission coefficients, and power limits for six generator system

Unit	a	b	c	d	e	f	Min load (MW)	Max Load (MW)
1	0.15247	38.53973	756.79886	0.00420	0.3300	13.86	10	125
2	0.10587	46.15916	451.32513	0.00420	0.3300	13.86	10	150
3	0.02803	40.39655	1049.9977	0.00683	-0.5455	40.267	35	225
4	0.03546	38.30553	1243.5311	0.00683	-0.5455	40.267	35	210
5	0.02111	36.32782	1658.5696	0.00460	-0.5112	42.9	130	325
6	0.01799	38.27041	1356.6592	0.00460	-0.5112	42.9	125	315

Table 6. Loss coefficient for six generator system

0.00014	0.000017	0.000015	0.000019	0.000026	0.000022
0.000017	0.00006	0.000013	0.000016	0.000015	0.000020
0.000015	0.000013	0.000065	0.000017	0.000024	0.000019
0.000019	0.000016	0.000017	0.000071	0.000030	0.000025
0.000026	0.000015	0.000024	0.000030	0.000069	0.000032
0.000022	0.000020	0.000019	0.000025	0.000032	0.000085

Table 7. Performance comparison table with results for various cases of six generator system (for a load of 800MW)

		Cost	Emission	Loss
Economic Dispatch - Case A		40678.8	633.299	Loss not considered
Emission Dispatch - Case B		42509.7	523.627	
Emission Constrained Economic Dispatch - Case C	h_{max}	41147.7	548.289	
	h_{min}	43858.4	538.62	
	h_{ave}	42415.9	526.769	
	h_{com}	41821.3	527.886	
Economic Dispatch (loss included) - Case D	g_{max}	41903.5	657.548	25.6179
	g_{min}	41918.6	671.977	26.0514
	g_{ave}	41908.6	664.471	25.8327
	g_{com}	41902	650.447	25.347
Emission constrained Economic Dispatch (loss included) – Case E (with h_{max})	g_{max}	42931.3	554.533	22.0892
	g_{min}	42968.3	553.963	22.0705
	g_{ave}	42949.6	554.243	22.0797
	g_{com}	42988.3	553.502	22.0394

Table 8. Comparison of results of ECED (loss included) for six generator system (for a load of 700MW)

	Conventional Iterative Method	Proposed Method	Method in [10]
P_1 (MW)	66.776	67.0243	65.2
P_2 (MW)	68.698	66.6589	64.8
P_3 (MW)	118.176	117.937	121.1
P_4 (MW)	117.705	117.852	120.6
P_5 (MW)	173.547	174.538	175.6
P_6 (MW)	171.715	172.996	173.4
Total cost ($/hr)	37648.7999	37636	37781.5
Total Emission(kg/hr)	436.3307	437.282	442.5
Total Loss (MW)	16.617	17.006	21.1

Table 9. Comparison of number of iterations required for various loads for six generator system

Load	Number of iterations	
	Proposed method	Conventional Iterative method
500MW	4	318
600MW	6	482
700MW	9	626
800MW	12	792
900MW	23	968

7. CONCLUSION

The paper as a whole has suggested an integrated approach to optimized generation planning by addressing all the three issues cost, emission, and loss. The regular conventional method involving common Lambda was totally eliminated. A novel form of recursive approach involving SADP was presented as an alternative to the conventional iterative method. Simple analytic solution procedure has been made possible and its results were at par with the one obtained using conventional approach.

The performance comparison table portrays the conclusive picture. Case A, cost minimum condition, is of theoretical interest with high emission, while Case B is with minimum emission and high cost. Case C corresponds to the loss neglected ECED while Case D discusses loss inclusion with emission neglected. Case E brings out a total integrated solution that provides an economical condition with less loss and restricted emission.

The method proposed is straightforward and elegant. This schema might serve as a boon for optimum power generation of any thermal power system.

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