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Dynamic Economic Load Dispatch with Emission and Loss using GAMS

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Abstract

*Dynamic economic dispatch (DED) is a real time problem of electric power system. DED intends to schedule the online generators outputs with the predicted load demands over a certain period of time in order to operate an electric power system most economically within its security limits. This paper introduces a solution of the dynamic economic dispatch (DED) problem including the loss and emission is participated among all generating units over time interval for a system using General Algebraic Modeling System (GAMS). The objective of the collective problem can be expressed by taking the production cost including emission and losses into account with required constraints for 24 hour time interval of each generating unit. The general algebraic modeling system (GAMS) technique is guarantees the global optimality of the solution due to its look-further on capability. To validate practicability and robustness of the GAMS, it is tested on six generating unit system with different cases for determine minimum production cost of individual generating unit over a time period. In test case I only production cost without emission and loss, In test case II production cost with loss, In test case III production cost with including emission and without losses and In test case IV production cost including emission and losses for time interval of 24 hours***.**

Keyword— Dynamic economic dispatch (DED), security limits, general algebraic modeling system (GAMS), production cost etc.

1. Introduction

Economic dispatch problem is one of the most important problems in electric power system operation. Energy management has to perform more complicated and timely system control function to operate a large power system reliably an efficiently. Electric utility system is interconnected to accomplish the benefits of minimum production cost, maximum reliability and superior operating conditions [1]. The economic scheduling is the on-line economic dispatch, in which it is required to distribute the load among the committed generating units which are actually paralleled with the system, in such a way as to minimize the total cost of generation without violating constraints [2]. The Dynamic Economic Dispatch (DED), which is an extension of the conventional economic dispatch problem, determines the optimal generation schedule of on-line generators, so as to meet the predicted load demand over a time horizon satisfying the constraint.

The intention of economic load dispatch (ELD) is to work out the optimal amount of the generated power for the fossil-based generating units in the system by minimizing the fuel cost. So operating at absolute minimum cost may no longer be the only criterion for dispatching electric power due to increasing concern over the environmental considerations. In fact, the Clean Air Act Amendments have been applied to reduce poisonous gases emissions from such power plants. Poisonous gases generate during power production in thermal stations by burn fossil fuels, due to poisonous gases (CO, CO_2, SO_2, NO_X etc) effluent and these become a source of pollution for the environment. Lack of planning while generating power puts the economical aspect in difficulty. Within a plant, however, there is transmission loss; also pollution exists due to emission. The cost minimum condition matchup to minimum cost with considerable amount of loss and emission. Similarly, the emission minimum condition produces minimum emission with higher deviation from minimum cost and loss. And also the loss minimum condition produces minimum loss with higher deviation from minimum cost and emission. These three conditions cannot be implemented simultaneously. Hence, the feasible optimum corresponds to a small deviation in cost with an allowable tolerance in loss and emission taking into account emission constraints and this type of economic load dispatch has been termed emission constrained economic dispatch (ECED) which comes under multiobjective problems[3].

The dynamic economic dispatch (DED), where optimization is done with respect to the dispatchable powers of the committed generation units for time particular given period and formulated as a minimization problem of the total cost over the dispatch period under some constraints[4]. The development of DED is still going on; it has though reached a certain level of development in terms of academic thoughts. Various optimization techniques have been proposed by many researchers to deal with this multiobjective programming problem with varying degree of success. In the recent past, stochastic search algorithms such as genetic algorithm (GA) [5], Particle Swarm Optimization (PSO) [6], evolutionary programming (EP) [7], simulated annealing (SA) [8] and Differential Evolution (DE) [9] and artificial immune system [10] methods are proven to be very effective in solving non-linear DED problems and provide a fast, reasonable nearly optimal solution.

In this paper General Algebraic Modeling System (GAMS) approach has been proposed to solve the objective of the collective problem can be expressed by taking the total production cost, losses and total emission into account with required constraints for 24 hour time interval. General Algebraic Modeling System (GAMS) is a high-level model development environment that supports the analysis and solution of linear, non linear and mixed integer optimization problems [11]. General Algebraic Modeling System is especially useful for handling large dimension and complex problem easily and accurately.

In this paper the effectiveness of the General Algebraic Modeling System (GAMS) is demonstrated using six generating unit system with different cases for determine minimum production cost of individual generating unit over a time period In test case I only production cost without emission and loss, In test case II production cost with loss, In test case III production cost with including emission and without loss and In test case IV production cost including emission and loss for time interval of 24 hours**.**

The paper is organized as follows: Section 2 provides a brief description and mathematical formulation of DED problems. The concept of General Algebraic Modeling System (GAMS) is discussed in Section 3. The performance of General Algebraic Modeling System (GAMS) and the simulation studies are discussed in Section 4. Finally, Section 5 presents the conclusions.

2. Dispatch Problem Formulation

The objective of solving the dynamic economic dispatch problem in electric power system is to determine the generation levels for all on-line units which minimize the total fuel cost and minimizing the losses and emission level of the system, while satisfying a set of constraints over a given dispatch period.

It can be formulated as follows:

Minimize $$F_{Tc} = \sum_{i=1}^{T}\sum_{i=1}^{N} F_{Ti}(P_i) \qquad (1)$$

Where

$$F_{Ti}(P_i) = F_i(P_i) + h_i\{E_i(P_i)\} \qquad (2)$$

F_{Tc} = is the total operating cost over the whole dispatch period,

$F_{Ti}(P_i)$= is the Emission constrained fuel cost of 'i^{th}' unit at time '*t*'

$F_i(P_i)$ = is the total fuel cost of a 'i^{th}' generating unit

$E_i(P_i)$ = is the total emission of a 'i^{th}' generating unit

h_i = cost penalty factor

P_i = is a function of its real power output of 'i^{th}' at time '*t*'.

T = is the number of hours in time horizon,

N = is the number of dispatch able units,

The fuel cost $F_i(P_i)$ of generating unit '*i*' at any time interval '*t*' is normally expressed as a quadratic function.

2.1 Objective Functions

2.1.1 Fuel Cost Objective

The classical economic dispatch problem of finding the optimal combination of power generation, which minimizes the total fuel cost of a generating unit is usually described by a quadratic function of power output P_i while satisfying the total required demand can be mathematically stated as follows:

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \ \text{\$/Hr} \qquad (3)$$

Where

a_i, b_i and c_i are the cost co-efficient of unit *i*.

2.1.2 Emission Objective

The minimum emission dispatch optimizes the above classical economic dispatch including emission objective of a generating unit is usually described by a quadratic function of power output P_i as [12]:

$$E_i(P_i) = d_i P_i^2 + e_i P_i + f_i \quad \text{Kg/Hr} \qquad (4)$$

Where
d_i, e_i and f_i are the emission co-efficient of unit *i*.

2.1.2 Emission constrained cost equation
: Economic and emission dispatch problem is converted into single optimization problem by introducing price penalty factor h [13]:
The Emission constrained cost equation can now be formulated as:

$$F_{Ti}(P_i) = a_i P_i^2 + b_i P_i + c_i + h_i(d_i P_i^2 + e_i P_i + f) \quad \text{\$/Hr} \qquad (5)$$

Where

$$h_i = F_{i\max}(P_{i\max}) / E_{i\max}(P_{i\max}) \qquad (6)$$

$$F_{i\max}(P_{i\max}) = a_i P_{i\max}^2 + b_i P_{i\max} + c_i \quad \text{Rs/Hr} \qquad (7)$$

$$E_{i\max}(P_{i\max}) = d_i P_{i\max}^2 + e_i P_{i\max} + f_i \quad \text{Kg/Hr} \qquad (8)$$

The price penalty factor h_i unifies the emission with the normal fuel costs and the total operating cost of the system (*i.e.*, the cost of fuel + the implied cost of emission). Once the value of price penalty factor is determined, the problem reduces to a simple economic dispatch problem. By proper scheduling of generating units, comparative reduction is achieved in both total fuel cost and emission.

2.2 Transmission Loss

The transmission losses P_t can be found using B_{mn} coefficients

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i B_{ij} P_i + \sum_{i=1}^{n} B_{oj} P_i + B_{oo} \qquad (9)$$

Where

B_{ij}, B_{oj} and B_{oo} are the transmission line coefficients

2.3. Constraints

2.3.1 Power Balance Constraints

The real power balance between generation and the load must be maintained at all times, while assuming the load at any time to be constant. The total supply must be equal to power demand.

$$\sum P_i = P_D + P_L \qquad (10)$$

Where
P_D is the load demand

2.3.1 Generator limit Constraints

Each generating unit is constrained by its lower and upper limits of real power output to ensure stable operation. The power generation of unit 'n' should be between its minimum and maximum limits.

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

Where

$P_{i\min}$ is the minimum generation limit of unit *i*

$P_{i\max}$ is the maximum generation limit of unit *i*

3. General Algebraic Modeling System (GAMS)

General Algebraic Modeling System provides a high-level (algebraic) language for the representation of large and complex models. It allows for unambiguous statements of algebraic relations that define an abstract system of variables and equations. It also provides several mechanisms for data management. The system performs appropriate data transformations to create a specific instance of the model. The General Algebraic Modeling System (GAMS) is a high-level model specially designed for modeling linear, nonlinear and mixed integer optimization problems [11]. GAMS can easily handle large and complex problems. It is especially useful for handling large complex problems, which may require much revision to establish an accurate model. Conversion of linear to nonlinear optimization is also very simple. Models can be developed, solved and documented simultaneously, maintaining the same GAMS model file. The basic structure of a mathematical model coded in GAMS has the components: sets, data, variable, equation, model and output [14] and the solution procedure are shown below in Figure 1.

A GAMS model is a collection of statements in the GAMS language. This statement define the variables of the model, specify the symbolic relationships between them in the form of equations specify data structures and assign values to them and instructs the computer to generate and solve the model. Other GAMS statements are used to handle output [14].

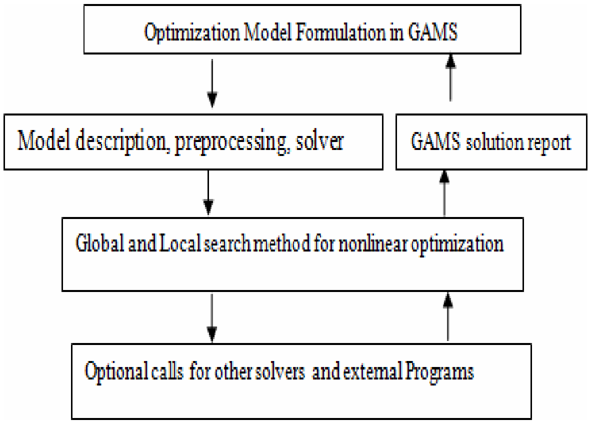


Figure 1. GAMS modeling and solution procedure

STEPS FOR PROBLEM Formulation WITH GAMS

GAMS formulation follows the basic format as given below:

1. SETS

Declaration

Assignment of members

2. Data (PARAMETERS, TABLES, SCALARS)

Declaration

Assignment of values

3. VARIABLES

Declaration

Assignment of type

Assignment of bounds and/or initial values (optional)

4. EQUATIONS

Declaration

Definition

5. MODEL and SOLVE statements
6. DISPLAY statements (optional)

4. Result and Discussion

The GAMS approach has been tested on four different test cases of a single six unit system of the dynamic economic dispatch problem. In test case I only production cost without taking loss and emission, In test case II production cost with loss and without emission, In test case III production cost with including emission and without loss and In test case IV total production cost including emission and loss for hourly time interval of 24 hours. The implementation model on GAMS with system configuration Core 2 Duo processor and 3GB RAM.

Table I. Cost and emission co-efficient of six unit system

a_i	b_i	c_i	d_i	e_i	f_i	P_{MIN}	P_{MAX}
0.003	2.45	105	0.01265	1.3552	22.983	150	600
0.005	3.51	44.4	0.01378	1.2489	173.37	100	400
0.006	3.89	40.6	0.00767	0.8051	363.705	50	200
0.004	2.78	66.9	0.0905	0.756	198.5	50	300
0.0026	2.86	87.67	0.0127	1.1677	11.67	75	500

Linear Coefficient of B losses are:

$\mathbf{B_{0j}}$ = [0.00003, 0.00009, 0.00012, 0.00007, 0.000085, 0.00011]

4.1. Test case I

The generator cost coefficients and generation limits of six units system are taken from Table I. For this test case emission coefficients and losses coefficients are not considered. In this test case production cost of six-unit system is calculated at different power demand over time period of 24 hours using GAMS. Table II shows the optimal solution of power output and production cost of each generator at different power demand over time period of 24 hours obtained using GAMS.

Table II. The optimal solution of total generation cost of each unit

Hour	P_{G1}	P_{G2}	P_{G3}	P_{G4}	P_{G5}	P_{G6}	Power Demand (MW)	**Generation cost ($/hr)**
1	245.868	100	50	143.151	204.847	56.134	800	**3168.751**
2	273.875	100	50	164.156	237.163	74.806	900	**3569.674**
3	301.882	100	50	185.162	269.479	93.477	1000	**3987.401**
4	329.889	100	50	206.167	301.795	112.148	1100	**4421.932**
5	364.815	112.889	62.408	232.361	342.094	135.432	1250	**5102.945**
6	329.889	100	50	206.167	301.795	112.148	1100	**4421.932**
7	343.404	100.043	51.702	216.303	317.39	121.158	1150	**4645.479**
8	354.11	106.466	57.055	224.332	329.742	128.295	1200	**4872.607**
9	386.226	125.736	73.113	248.42	366.799	149.706	1350	**5573.258**
10	407.637	138.582	83.819	264.478	391.504	163.98	1450	**6056.417**
11	418.342	145.005	89.171	272.507	403.857	171.117	1500	**6302.813**
12	407.637	138.582	83.819	264.478	391.504	163.98	1450	**6056.417**
13	396.932	132.159	78.466	256.449	379.152	156.843	1400	**5813.231**
14	329.889	100	50	206.167	301.795	112.148	1100	**4421.932**
15	354.11	106.466	57.055	224.332	329.742	128.295	1200	**4872.607**
16	354.11	106.466	57.055	224.332	329.742	128.295	1200	**4872.607**
17	364.815	112.889	62.408	232.361	342.094	135.432	1250	**5102.945**
18	375.521	119.312	67.76	240.39	354.447	142.569	1300	**5336.496**
19	396.932	132.159	78.466	256.449	379.152	156.843	1400	**5813.231**
20	418.342	145.005	89.171	272.507	403.857	171.117	1450	**6302.813**
21	354.11	106.466	57.055	224.332	329.742	128.295	1200	**4872.607**
22	329.889	100	50	206.167	301.795	112.148	1100	**4421.932**
23	287.879	100	50	174.659	253.321	84.141	950	**3776.437**
24	230.762	100	50	131.821	187.417	50	750	**2974.648**

4.2. Test case II

The generator cost coefficients, loss coefficients and generation limits of six units system are taken from Table I of six-unit system. For this test case emission coefficients are not considered. In this test case production cost with losses of six-unit system is calculated at different power demand over time period of 24 hours using GAMS. Table III shows the optimal solution of power output and production cost of each generator at different power demand over time period of 24 hours obtained using GAMS.

Table III. The optimal solution of total generation cost with power loss of each unit

Hour	P_{G1}	P_{G2}	P_{G3}	P_{G4}	P_{G5}	P_{G6}	Power Demand (MW)	**Power Loss (MW)**	**Total Power O/P (MW)**	**Generation cost ($/hr)**
1	252.77	100	50	145.694	198.43	61.471	800	**8.365**	**808.365**	**3201.99**
2	282.961	100	50	167.553	229.734	80.518	900	**10.766**	**910.766**	**3614.327**
3	313.376	100	50	189.518	261.037	99.613	1000	**13.544**	**1013.54**	**4045.941**
4	342.553	100.652	54.171	210.535	290.85	117.845	1100	**16.605**	**1116.61**	**4496.908**
5	377.582	120.974	71.044	235.699	326.367	139.622	1250	**21.287**	**1271.29**	**5203.722**
6	342.553	100.652	54.171	210.535	290.85	117.845	1100	**16.605**	**1116.61**	**4496.908**
7	354.197	107.415	59.788	218.908	302.69	125.097	1150	**18.095**	**1168.1**	**4728.766**
8	365.874	114.188	65.412	227.296	314.529	132.356	1200	**19.655**	**1219.66**	**4964.366**
9	401.095	134.578	82.333	252.548	350.039	154.171	1350	**24.764**	**1374.76**	**5693.768**
10	424.737	148.228	93.654	269.455	373.707	168.746	1450	**28.528**	**1478.53**	**6199.03**
11	436.607	155.07	99.326	277.931	385.54	176.043	1500	**30.518**	**1530.52**	**6457.408**
12	424.737	148.228	93.654	269.455	373.707	168.746	1450	**28.528**	**1478.53**	**6199.03**
13	412.9	141.397	87.989	260.994	361.874	161.456	1400	**26.61**	**1426.61**	**5944.489**
14	342.553	100.652	54.171	210.535	290.85	117.845	1100	**16.605**	**1116.61**	**4496.908**
15	365.874	114.188	65.412	227.296	314.529	132.356	1200	**19.655**	**1219.66**	**4964.366**
16	365.874	114.188	65.412	227.296	314.529	132.356	1200	**19.655**	**1219.66**	**4964.366**
17	377.582	120.974	71.044	235.699	326.367	139.622	1250	**21.287**	**1271.29**	**5203.722**
18	389.322	127.77	76.685	244.116	338.203	146.893	1300	**22.99**	**1322.99**	**5446. 851**
19	412.9	141.397	87.989	260.994	361.874	161.456	1400	**26.61**	**1426.61**	**5944.489**
20	424.737	148.228	93.654	269.455	373.707	168.746	1450	**28.528**	**1478.53**	**6199.03**
21	365.874	114.188	65.412	227.296	314.529	132.356	1200	**19.655**	**1219.66**	**4964.366**
22	342.553	100.652	54.171	210.535	290.85	117.845	1100	**16.605**	**1116.61**	**4496.908**
23	298.141	100	50	178.522	245.385	90.06	950	**12.108**	**962.108**	**3827.712**
24	237.757	100	50	134.803	182.779	51.965	750	**7.305**	**757.304**	**3002.983**

4.3. Test case III

The generator cost coefficients, emission coefficients and generation limits of six units system are taken from Table I of six-unit system. For this test case loss coefficients are not considered. In this test case production cost including emission of six-unit system is calculated at different power demand over time period of 24 hours using GAMS. Table VI shows the optimal solution of power output and production cost of each generator at different power demand over time period of 24 hours obtained using GAMS.

Table IV. The optimal solution of total generation cost including emission of each unit

Hour	P_{G1}	P_{G2}	P_{G3}	P_{G4}	P_{G5}	P_{G6}	Power Demand (MW)	**Generation cost ($/hr)**
1	150	123.369	200	50	137.057	139.573	800	**3281.586**
2	160.761	151.436	200	50	167.51	170.292	900	**3787.854**
3	186.279	174.861	200	50	192.928	195.932	1000	**4362.381**
4	211.797	198.286	200	50	218.345	221.571	1100	**5001.468**
5	250.074	233.424	200	50	256.471	260.031	1250	**6081.148**
6	211.797	198.286	200	50	218.345	221.571	1100	**5001.468**
7	224.556	209.999	200	50	231.054	234.391	1150	**5345.221**
8	237.315	221.712	200	50	243.763	247.211	1200	**5705.115**
9	275.592	256.849	200	50	281.889	285.67	1350	**6881.635**
10	301.11	280.275	200	50	307.306	311.31	1450	**7746.683**
11	313.869	291.987	200	50	320.015	324.129	1500	**8203.416**
12	301.11	280.275	200	50	307.306	311.31	1450	**7746.683**
13	288.351	268.562	200	50	294.597	298.49	1400	**7306.089**
14	211.797	198.286	200	50	218.345	221.571	1100	**5001.468**
15	237.315	221.712	200	50	243.763	247.211	1200	**5705.115**
16	237.315	221.712	200	50	243.763	247.211	1200	**5705.115**
17	250.074	233.424	200	50	256.471	260.031	1250	**6081.148**
18	262.833	245.137	200	50	269.18	272.85	1300	**6473.322**
19	288.351	268.562	200	50	294.597	298.49	1400	**7306.089**
20	301.11	280.275	200	50	307.306	311.31	1450	**7746.683**
21	237.315	221.712	200	50	243.763	247.211	1200	**5705.115**
22	211.797	198.286	200	50	218.345	221.571	1100	**5001.468**
23	173.52	163.148	200	50	180.219	183.112	950	**4067.048**

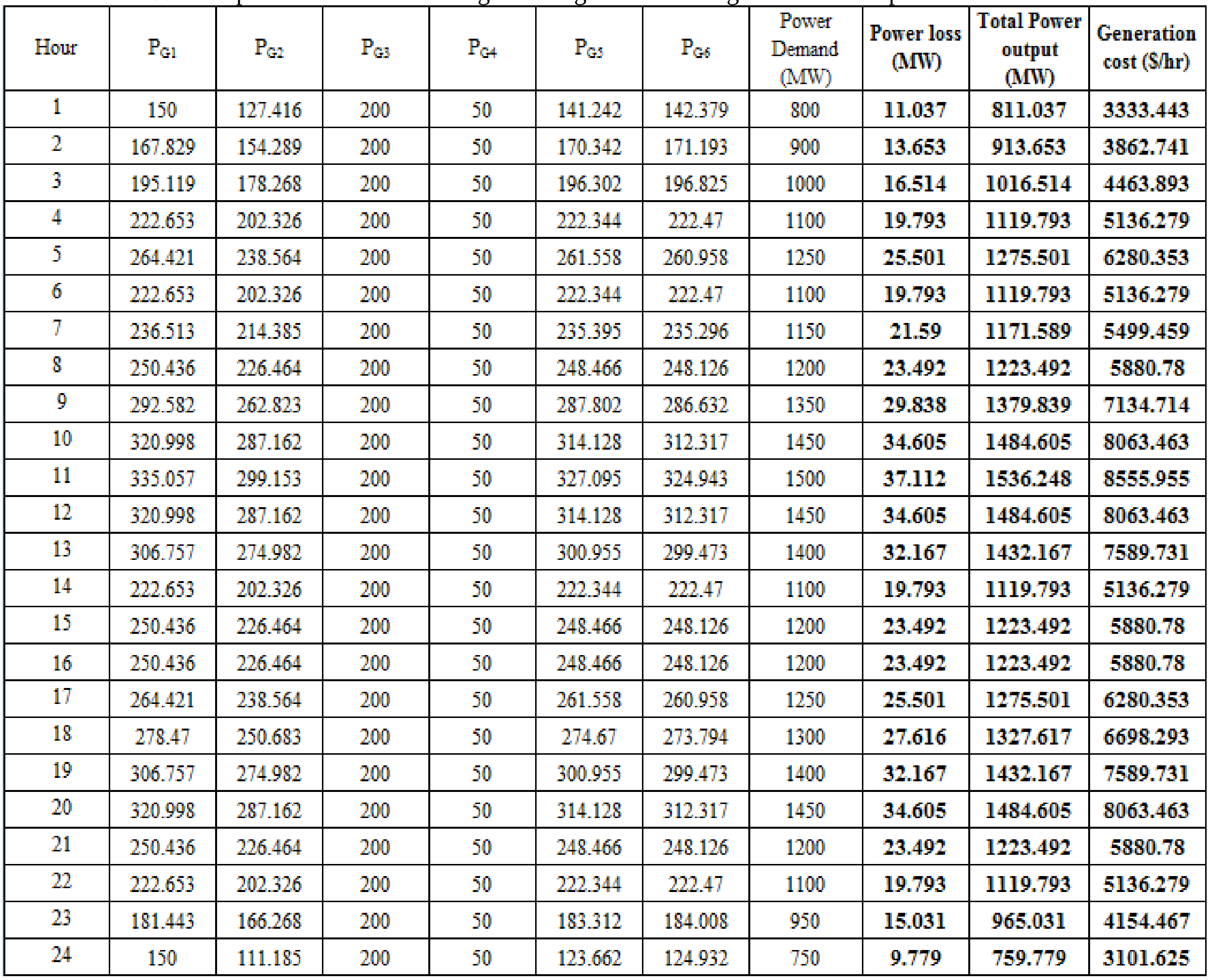
4.4. Test case IV

The generator cost coefficients, loss coefficients, emission coefficients and generation limits of six units system are taken from Table I of six-unit system. In this test case production cost including emission with power losses of six-unit system is calculated at different power demand over time period of 24 hours using GAMS. Table V shows the optimal solution of power output and production cost of each generator at different power demand over time period of 24 hours obtained using GAMS.

5. Conclusion

In this paper, General Algebraic Modeling System (GAMS) for optimization have been used for solving

Table V. The optimal solution of total generating cost including emission and power loss of each unit



Hour	P_{G1}	P_{G2}	P_{G3}	P_{G4}	P_{G5}	P_{G6}	Power Demand (MW)	**Power loss (MW)**	**Total Power output (MW)**	**Generation cost ($/hr)**
1	150	127.416	200	50	141.242	142.379	800	**11.037**	**811.037**	**3333.443**
2	167.829	154.289	200	50	170.342	171.193	900	**13.653**	**913.653**	**3862.741**
3	195.119	178.268	200	50	196.302	196.825	1000	**16.514**	**1016.514**	**4463.893**
4	222.653	202.326	200	50	222.344	222.47	1100	**19.793**	**1119.793**	**5136.279**
5	264.421	238.564	200	50	261.558	260.958	1250	**25.501**	**1275.501**	**6280.353**
6	222.653	202.326	200	50	222.344	222.47	1100	**19.793**	**1119.793**	**5136.279**
7	236.513	214.385	200	50	235.395	235.296	1150	**21.59**	**1171.589**	**5499.459**
8	250.436	226.464	200	50	248.466	248.126	1200	**23.492**	**1223.492**	**5880.78**
9	292.582	262.823	200	50	287.802	286.632	1350	**29.838**	**1379.839**	**7134.714**
10	320.998	287.162	200	50	314.128	312.317	1450	**34.605**	**1484.605**	**8063.463**
11	335.057	299.153	200	50	327.095	324.943	1500	**37.112**	**1536.248**	**8555.955**
12	320.998	287.162	200	50	314.128	312.317	1450	**34.605**	**1484.605**	**8063.463**
13	306.757	274.982	200	50	300.955	299.473	1400	**32.167**	**1432.167**	**7589.731**
14	222.653	202.326	200	50	222.344	222.47	1100	**19.793**	**1119.793**	**5136.279**
15	250.436	226.464	200	50	248.466	248.126	1200	**23.492**	**1223.492**	**5880.78**
16	250.436	226.464	200	50	248.466	248.126	1200	**23.492**	**1223.492**	**5880.78**
17	264.421	238.564	200	50	261.558	260.958	1250	**25.501**	**1275.501**	**6280.353**
18	278.47	250.683	200	50	274.67	273.794	1300	**27.616**	**1327.617**	**6698.293**
19	306.757	274.982	200	50	300.955	299.473	1400	**32.167**	**1432.167**	**7589.731**
20	320.998	287.162	200	50	314.128	312.317	1450	**34.605**	**1484.605**	**8063.463**
21	250.436	226.464	200	50	248.466	248.126	1200	**23.492**	**1223.492**	**5880.78**
22	222.653	202.326	200	50	222.344	222.47	1100	**19.793**	**1119.793**	**5136.279**
23	181.443	166.268	200	50	183.312	184.008	950	**15.031**	**965.031**	**4154.467**
24	150	111.185	200	50	123.662	124.932	750	**9.779**	**759.779**	**3101.625**

dynamic power dispatch problems. Three different test cases of a single six unit system of the dynamic economic dispatch problem are taken. In test case I only production cost without emission and loss, In test case II production cost with loss, In test case III production cost with including emission and without loss and In test case IV production cost including emission and loss for time interval of 24 hours.

An efficient economic dispatch algorithm for dealing with nonlinear functions such as the thermal cost, transmission loss and emission constraint is developed. The quality of the solutions generated by the General Algebraic Modeling System (GAMS) offers excellent approach to solve the dynamic thermal power dispatch problem. The solution is analytic in nature with high accuracy and it is used for any online application. The result shows that GAMS performs better so far for the above mentioned test cases. The GAMS algorithm has superior features, including quality of solution and good computational efficiency. Therefore, this results shows that GAMS is a promising technique for solving complicated problems in power system.

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