Dynamic model for thermal generation during change of the load

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ABSTRACT

It is intended to present a procedure for obtaining optimum economic dispatch with consideration of control over the generating units during change of the load in thermal power systems. Therefore, a mathematical model, which takes the transmission losses into account, was built. The deviation in each of the rotational speed, system frequency, electrical and mechanical power in addition to the deviation in transmission losses, generated output powers of each unit and in the corresponding generation costs can be computed during the change of the load from a time interval to the next one.

The steady-state deviations of the above mentioned items can be computed, also, in each time interval. The results, which were obtained from the application of this model on a power system, have been presented and compared with other results.

1. INTRODUCTION

The optimization time period (T) can be divided to (n) time intervals. The length of each of each time interval equals (Δt). The generation cost $(K_i)^{it}$ of the generating unit (i) can be expressed in a polynomial form as

$$(K_i)^{it} = a_i [(P_i)^{it}]^2 + b_i (P_i)^{it} + c_i \qquad \$/\text{hour} \qquad (1)$$

Where $(P_i)^{it}$ is the generated real power in time interval (it) ; a_i , b_i and c_i are parameters of the generating unit (i).

The total generation cost $(TK)^{it}$ of a power system containing (N) controllable generating units in time interval (it) will be obtained as

$$(TK)^{it} = \sum_{i=1}^{N} (K_i)^{it} \qquad \$/\text{hour} \qquad (2)$$

While the total generation cost $(TK)^{T}$ of the system in the time period (T) can be given by

$$(TK)^{T} = \sum_{it=1}^{n} (TK)^{it} (\Delta t) \qquad \$ \qquad (3)$$

By taking the transmission losses into account, the power balance requires that the sum of the controlled generation powers must equal the load demand $(P_L)^{it}$ plus the transmission losses $(P_l)^{it}$ each time interval (it). Therefore, the power balance equation can be written as

$$\sum_{i=1}^{N} (P_i)^{it} = (P_L)^{it} + (P_l)^{it} \tag{4}$$

If the transmission losses can be neglected, the balance equation will be rewritten as

$$\sum_{i=1}^{N} (P_i)^{it} = (P_L)^{it} \tag{5}$$

Each generating unit must not be operated above its rating or below some minimum value according to the following inequalities

$$(P_{i\ min}) \leq (P_i)^{it} \leq (P_{i\ max}) \quad \text{for} \quad i = 1, 2, \ldots\ldots \text{ and } N \tag{6}$$

Where $(P_{i\ min})$, $(P_{i\ max})$ are the minimum and maximum power permitted for the generating unit (i), respectively.

A set of real generation powers must be selected that will minimize the cost function in each time interval. Various techniques have been developed to solve the problem of power system economic dispatching and to allocate the system load on each generating unit [1-5]. In [6] a mathematical model has been built to calculate the steady-state deviations in each of the system frequency, mechanical and electrical power in addition to the generated output power of each generating unit without taking the transmission losses in consideration. Other models have been presented, also by the author in [7], when the transmission losses are taken into account. Thereby, the value of the load changes (ΔP_L) in each time interval has been taken as the difference between the load value in this interval and its value in the previous one. It has been taken, also as an optional specified constant value $(\Delta P_{L\ sp})$.

In this work a solution for the problem of power system economic dispatching is presented to allocate the system load on each generating unit in the system and to obtain the deviations in the all above mentioned variables during each subinterval of the building up or decaying time of the load from an interval to the next one.

2. THE MATHEMATICAL MODEL

The rotational speed of a generating unit driven by a steam turbine will be constant when the mechanical torque equals in magnitude the electrical torque. These both toques act on the rotating mass of the generating unit and oppose each other. If the electrical load is increased, the rotating system will begin to slow down. Thereby, the mechanical torque must be increased to restore equilibrium and vice v

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is again held constant when the two torque become equal. The previous process must be repeated constantly due to the changes of the electrical load in a power system.

The following equation gives the relation of the rate of change of a generating unit speed and the difference between the deviations in both mechanical (ΔP_m) and electrical power (ΔP_e), respectively.

$$(\Delta P_m) - (\Delta P_e) = M \frac{d(\Delta\omega)}{dt} \tag{7}$$

Where (M) is the angular momentum of the machine in watts per radian per second per second or in Mw / pu frequency / sec on machine base, (ω_n) is the nominal rotational speed (rad /sec), and ($\Delta\omega$) is the deviation from this nominal value. Very little error is involved by the assumption that (M) is constant and is equal to the value (I ω_n), where I is the moment of inertia of the machine in (Kg m^2).

Due to the change in the rotational speed, the change in load (ΔP_L)` , which is the frequency-sensitive load change, can be given by

$$(\Delta P_L)` = D(\Delta\omega) \tag{8}$$

Where (D) is defined as percent change in load divided by percent change in frequency.

The net change in the electrical power output is given by

$$(\Delta P_e) = (\Delta P_L) + (\Delta P_L)` = (\Delta P_L) + D(\Delta\omega) \tag{9}$$

Where (ΔP_L) is the nonfrequency –sensitive load change.

The change in mechanical power input can be related to the change in the rotational speed by

$$(\Delta P_m) = -(1/R)(\Delta\omega) \tag{10}$$

Where (R) is the ratio between the per unit change in frequency and the per unit change in output of the generating unit, R = the slope of the governor characteristic. Eqns. (7) to (10) are given in [8].

After damping out all synchronizing oscillations, the frequency will be constant and equal to the same value for each unit [9], mathematical models corresponding to this steady state ((d ($\Delta\omega$) / dt) = 0) have been developed by the author and presented in [6,7].

Now, to formulate the proposed mathematical models for a power system contains (N)-generating units to obtain a solution during the change of the load from $(P_L)^{it-1}$ to $(P_L)^{it}$. The load change $(\Delta P_L)^{it}$ can be given by

$$(\Delta P_L)^{it} = (P_L)^{it} - (P_L)^{it-1} \qquad , it = 2,3,......n$$

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Where $(P_L)^{it}$ and $(P_L)^{it-1}$ are the steady-state values of the load in intervals (it) and (it – 1), respectively.

Substitute Eqns. (9) and (10) in Eqn. (7), to obtain for unit (i) the following equation during synchronizing oscillations:

$$-(1/R_i)(\Delta\omega) - (\Delta P_{L\,i}) - D_i(\Delta\omega) = M_i \frac{d(\Delta\omega)}{dt} \quad , i = 1,2,\ldots\text{and } N \qquad (12)$$

$(\Delta P_{L\,i})$ can be defined as the change in the controlled generation of unit (i).

By taking the transmission losses into account, the power balance requires that the sum of the changes in the controlled generation powers must equal to the load change (ΔP_L) plus the change of transmission losses (ΔP_l) during synchronizing oscillations.

$$\sum_{i=1}^{N} (\Delta P_{L\,i}) = (\Delta P_L) + (\Delta P_l) \qquad (13)$$

i.e., $$(\Delta P_{L\,i}) = (\Delta P_L) + (\Delta P_l) - \sum_{\substack{j=1 \\ j\neq i}}^{N} (\Delta P_{L\,j}) \qquad (14)$$

From Eqns. (12) and (14), the following equation for unit (i) can be obtained

$$-[(1/R_i) + D_i](\Delta\omega) - M_i \frac{d(\Delta\omega)}{dt} = (\Delta P_{L\,i})$$

$$= (\Delta P_L) + (\Delta P_l) - \sum_{\substack{j=1 \\ j\neq i}}^{N} (\Delta P_{L\,j}) \qquad (15)$$

Add Eqns. (15) for the (N) generating units, to obtain

$$-\left[\sum_{i=1}^{N} (1/R_i) + \sum_{i=1}^{N} D_i\right](\Delta\omega) - \sum_{i=1}^{N} M_i \frac{d(\Delta\omega)}{dt}$$

$$= \sum_{i=1}^{N} (\Delta P_{L\,i}) = (\Delta P_L) + (\Delta P_l) \qquad (16)$$

Assume that, $$S_i = (1/R_i) + D_i \qquad (17)$$

And $$S_T = \sum_{i=1}^{N} (1/R_i) + \sum_{i=1}^{N} D_i = \sum_{i=1}^{N} S_i \qquad (18)$$

$$M_T = \sum_{i=1}^{N} M_i \qquad (19)$$

Substitute Eqns. (18) and (19) in Eqn. (16), to obtain the change in the rotational speed ($\Delta\omega$)

$$(\Delta\omega) = - \{ [(\Delta P_L) + (\Delta P_l)] / S_T \} - (M_T / S_T) \frac{d(\Delta\omega)}{dt} \tag{20}$$

Substitute Eqns. (17) and (20), to obtain the change in the controlled generation (ΔP_{Li}) of unit (i):

$$(\Delta P_{Li}) = (S_i / S_T) [(\Delta P_L) + (\Delta P_l)] + (1/ S_T) (S_i M_T - S_T M_i) \frac{d(\Delta\omega)}{dt} \tag{21}$$

Assume, $$(CP)_i = S_i / S_T \tag{22}$$

Where $(CP)_i$ can be defined as coefficient of participation of unit (i). Then,

$$(\Delta P_{Li}) = (CP)_i [(\Delta P_L) + (\Delta P_l)] + [(CP)_i M_T - M_i] \frac{d(\Delta\omega)}{dt} \tag{23}$$

When the transmission losses can be neglected ($\Delta P_l = 0$), we will obtain from Eqns. (20) and (23) the following corresponding equations:

$$(\Delta\omega) = - [(\Delta P_L) / S_T] - (M_T / S_T) \frac{d(\Delta\omega)}{dt} \tag{24}$$

And,

$$(\Delta P_{Li}) = (CP)_i (\Delta P_L) + [(CP)_i M_T - M_i] \frac{d(\Delta\omega)}{dt} \tag{25}$$

After damping out of synchronizing oscillations in the steady state, the following equations will be delivered by substituting $[(d (\Delta\omega) / dt) = 0]$ in Eqns. (20) and (23).

$$(\Delta\omega) = - [(\Delta P_L) + (\Delta P_l)] / S_T \tag{26}$$

$$(\Delta P_{Li}) = (CP)_i [(\Delta P_L) + (\Delta P_l)] \tag{27}$$

These two equations, which have been driven before in [7], will give the following two equations, which have been driven before also in [6], if the transmission losses are neglected:

$$(\Delta\omega) = - (\Delta P_L) / S_T \tag{28}$$

$$(\Delta P_{Li}) = (CP)_i (\Delta P_L) \tag{29}$$

From Eqns. (8) to (10) we can obtain the following corresponding equations for unit (i) in interval (it).

$$(\Delta P_{Li})` = D_i (\Delta\omega) \tag{30}$$

$$(\Delta P_{ei}) = (\Delta P_{Li}) + (\Delta P_{Li})` \tag{31}$$

$$(\Delta P_{mi}) = - (1 / R_i) (\Delta\omega) \tag{32}$$

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The steady-state value of the system frequency (f) and controlled generation power (P_i) of unit (i) will be obtained in the time interval (it) from their values in the previous one as follows, it = 2,3,……. and n:

$$(f) \quad = (f)^{it-1} + (\Delta\omega) f \tag{33}$$

$$(P_i) = (P_i)^{it-1} + (\Delta P_{Li}) \tag{34}$$

Runge-Kutta method is used to solve the differential Eqn. (20) during the building up or decaying time of the load between intervals (it –1) and (it), during the synchronizing oscillations. The length of this time is proportional inversely to the changing speed of the load. This time will be divided into subintervals, in each one the deviation in the rotational speed will be obtained by solving Eqn. (20). Also, deviations in system frequency and controlled generation power of each unit are delivered from Eqns. (33) and (34). Therefore, all deviations in each of the electrical, mechanical power and transmission losses can be obtained by solving the correspond-
ing equations of the mathematical model. Thereby, the effect of the change in frequency on the net load drawn by the system has been taken into account. The solution at the end of the changing time of the load gives the steady-state deviations.

Starting from an optimal economic solution in the first interval (it = 1), this suggested model satisfies the control of generation, holds the system frequency at or very close to the specified nominal frequency and maintains the generation of each generating unit at the most economic value during each subinterval of the load changing time and, also, in the steady state for each time interval.

3. TEST EXAMPLE AND RESULTS

The optimization time period, which is divided in 6 time intervals, is taken as 24 hours. Table (1) gives the load (P_L) and the corresponding load change (ΔP_L) in each time interval. Table (2) shows cost functions, power limits and other given data of each controlled generating unit of a power system.

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Table (1) : Daily load curve data.

Interval (it)	1	2	3	4	5	6
Load (Mw)	210.00	375.00	470.00	400.00	320.00	180.00
Load change	0.0	165.00	95.00	- 70.00	- 80.00	- 140.00

Table (2) : The given data of each controlled generating unit.

Unit	A_i	b_i	c_i	$P_{i\ max}$	$P_{i\ min}$	D_i	R_i	M_i
1	0.00533	11.669	213.1	200.0	50.0	0.80	0.01	4.00
2	0.00889	10.333	200.0	150.0	37.0	0.90	0.03	3.75
3	0.00741	10.833	240.0	180.0	45.0	1.00	0.02	3.50

Let the transmission losses (P_l) to be expressed by the following equation which gives (P_l) in per unit on 100 MVA base (all generation powers must be per unit on 100 MVA base).

$$P_l = \begin{bmatrix} P_1 & P_2 & P_3 \end{bmatrix} \begin{bmatrix} 0.06760 & 0.00953 & -0.00507 \\ 0.00953 & 0.05210 & 0.00901 \\ -0.00507 & 0.00901 & 0.02940 \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \\ P_3 \end{bmatrix}$$

$$+ \begin{bmatrix} -0.07660 & -0.00342 & 0.01890 \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \\ P_3 \end{bmatrix} + 0.040357$$

To apply the mathematical model without taking the transmission losses into account the following generating powers are taken as a solution for starting in the first time interval ($it = 1$, $P_L = 210$ Mw), [8]:

- $P_1 = 50$ Mw, $P_2 = 88.07$ Mw and $P_3 = 71.93$ Mw

When the transmission losses (P_l) will be considered, the corresponding starting values at the first interval are taken in mega-watts as follows, [8]:

- $P_1 = 60.268$, $P_2 = 79.446$, $P_3 = 80.150$ and $P_l = 9.865$

The starting value of the system frequency has been taken as 50 cycle/sec. The load change (ΔP_L)^{it} in interval (it) is the difference between the load of this interval and the load of the previous one. The length of the time (LT), at which the load will be built up or will be decayed from $(P_L)^{it-1}$ to the corresponding value in the next interval $(P_L)^{it}$, may be obtained from the following equation:

$$(LT) = \left| (\Delta P_L)^{it} / v \right| \tag{35}$$

Where v is the speed change of the load in Mw/min. When the transmission losses taken into account, Eqn. (33) can be rewritten as

$$(LT) = \left| \left\{ (\Delta P_L)^{it} + \frac{(P_l)^{it-1}}{(P_L)^{it-1}} (P_L)^{it} \right\} / v \right| \tag{36}$$

Where $[((P_l)^{it-1} / (P_L)^{it-1})(P_L)^{it}]$ represents an approximate estimated value for the transmission losses in interval (it).

To solve the differential equations, (20) or (24), Runge-Kutta method, [10], has been applied. The solution represents, step-by-step, a series of values for the dependent variable $(\Delta\omega)$ corresponding to selected values of the time (t) as an independent variable. The time (LT) is divided to subintervals (length of each subinterval (h) is taken as 0.1 minute). The procedure is to select values of the independent variable at these fixed subintervals.

Table (3) : The solution during the building up time of the load from 210 to 375 Mw (Transmission losses are neglected)

Time (min.)	$\Delta\omega$ x 10^{-6}	f cycle/s	ΔP_1	ΔP_2	ΔP_3	P_1	P_2	P_3
0.0	0.0	50.0	0.0	0.0	0.0	50.00	88.07	71.93
0.1	-3.9	49.99981	0.2456	0.1123	0.1421	50.25	88.18	72.07
0.2	-5.0	49.99956	0.2641	0.0975	0.1384	50.51	88.28	72.21
0.3	-5.3	49.99929	0.2691	0.0935	0.1374	50.78	88.37	72.35
0.4	-5.3	49.99903	0.2704	0.0924	0.1372	51.05	88.47	72.49
0.5	-5.4	49.99876	0.2708	0.0921	0.1371	51.32	88.56	72.62
……	…….	……….	…….	……..	……..	…….	…….	…….
32.8	-5.4	49.91224	0.2709	0.0920	0.1371	139.10	118.37	117.03
32.9	-5.4	49.91198	0.2709	0.0920	0.1371	139.37	118.46	117.17

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The initial values of the dependent and independent variables are taken $\Delta\,\omega\ =\ 0$ and t = 0. In each subinterval we can obtain the corresponding deviations in each of the rotational speed, system frequency and output power of each generating unit in addition to the deviations in mechanical and electrical power of the units. The deviation in the transmission losses can, also, be obtained.

Tables (3) and (4) show parts from the solution when the load builds up from 210 Mw in the first interval (it =1) to 375 Mw in the second interval (it =2), for both cases of the transmission losses.

Table (4) : The solution during the building up of the load from 210 – 375 Mw (Transmission losses are taken into account)

Time Min.	$\Delta\omega$ x 10^{-5}	f cycle/s	ΔP_1	ΔP_2	ΔP_3	P_1	P_2	P_3	ΔP_l	P_l
0.0	0.0	50.0	0.0	0.0	0.0	60.3	79.4	80.2	0.000	9.87
0.1	-0.4	49.9998	0.23	0.11	0.14	60.5	79.6	80.3	0.024	9.89
0.2	-0.5	49.9996	0.25	0.09	0.13	60.8	79.7	80.4	0.023	9.91
0.3	-0.5	49.9993	0.26	0.09	0.13	61.0	79.7	80.6	0.022	9.93
0.4	-0.5	49.9991	0.26	0.09	0.13	61.3	79.8	80.7	0.022	9.96
0.5	-0.5	49.9988	0.26	0.09	0.13	61.5	79.9	80.8	0.022	9.98
……	…….	……….	…..	……	……	……	……	……	……	…..
36.4	-0.6	49.9032	0.28	0.10	0.14	158.6	112.9	129.9	0.072	26.5
36.5	-0.6	49.9029	0.28	0.10	0.14	158.9	113.0	130.1	0.072	26.6

Tables (5) and (6) give parts of the solutions, when the load decays from 470 Mw in the third interval (it =3) to 400 Mw in the fourth one (it = 4), also for both cases of the transmission losses.

Table (5) : The solution during the decaying of the load from 470 Mw to 400 Mw (Transmission losses are neglected).

Time min.	$\Delta\omega$ x 10^{-6}	f cycle/s	ΔP_1	ΔP_2	ΔP_3	P_1	P_2	P_3
0.0	0.0	49.86000	0.0	0.0	0.0	190.84	135.94	143.21
0.1	3.9	49.86020	-0.246	-0.112	-0.142	190.63	135.79	143.07
0.2	5.0	49.86044	-0.264	-0.098	-0.138	190.37	135.70	142.93
0.3	5.3	49.86071	-0.269	-0.094	-0.137	190.10	135.61	142.79
0.4	5.3	49.86097	-0.270	-0.092	-0.137	189.83	135.51	142.65
0.5	5.4	49.86124	-0.271	-0.092	-0.137	189.56	135.42	142.52
……	…….	……….	…..	……	……	……	……	……
13.8	5.4	49.89702	-0.271	-0.092	-0.137	153.26	123.09	124.15
13.9	5.4	49.89729	-0.271	-0.092	-0.137	152.99	123.00	124.01

Results can be obtained for all changes of the load between the different time intervals. The obtained results at the end of the building up or decaying time of the load from an interval to the next one represent the steady state values, which belong this next interval.

All steady-state results for the intervals from (it =2) to (it = 6) are given in Tables (7) and (8). These are the results obtained at the last subinterval for the building up or decaying time of the load from an interval to the next one. Also, these tables contain for comparison the corresponding results, which are obtained from the steady-state mathematical models in [7].

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Table (6) : The solution during the decaying of the load from 470 to 400 Mw

(Transmission losses are taken into account)

Time Min.	$\Delta\omega$ x 10^{-5}	f cycle/s	ΔP_1	ΔP_2	ΔP_3	P_1	P_2	P_3	ΔP_1	P_1
0.0	0.0	49.8422	0.0	0.0	0.0	200.0	150.0	165.0	0.00	45.6
0.1	1.7	49.8431	-1.1	-0.50	-0.63	198.9	149.5	164.3	-1.1	44.5
0.2	1.5	49.8438	-0.75	-0.24	-0.37	198.2	149.3	164.0	-0.25	44.3
0.3	1.5	49.8446	-0.74	-0.25	-0.38	197.4	149.0	163.2	-0.25	44.0
0.4	1.5	49.8453	-0.74	-0.25	-0.38	196.7	148.8	162.8	-0.25	43.8
0.5	1.5	49.8461	-0.74	-0.25	-0.38	195.9	148.5	162.8	-0.25	43.5
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6.1	1.4	49.8871	-0.71	-0.24	-0.36	154.6	134.5	141.9	-0.19	31.1
6.2	1.4	49.8878	-0.71	-0.24	-0.36	153.8	134.2	141.6	-0.19	30.9

In Table (7), the comparison is made for the generated power of each unit, the total generated power, the deviation in the mechanical power of each unit (which equals, approximately, the deviation in the electrical power) and the deviation in the rotational speed in addition to the system frequency. When the transmission losses are taken into account, the comparison has been repeated again for all above mentioned variables in addition to the value of the transmission losses and it has been presented in Table (8).

Table (7) : Steady-state comparison, when the transmission losses have been neglected.

	Interval (it)	2	3	4	5	6
	P_L	375.0	470.0	400.0	320.0	180.0
	ΔP_L	165.0	95.0	-70.0	-80.0	-140.0
P_1	Results in [7]	139.40	190.88	152.95	109.60	50.0
	Obtained results	139.37	190.84	152.99	109.64	50.0
P_2	Results in [7]	118.43	135.91	123.03	108.31	82.55
	Obtained results	118.46	135.94	123.00	108.28	82.52
P_3	Results in [7]	117.16	143.21	124.02	102.09	47.45
	Obtained results	117.17	143.21	124.01	102.08	47.48
P_T	Results in [7]	347.99	470.00	400.00	320.00	180.00
	Obtained results	375.00	469.99	400.00	320.00	180.00
ΔP_{m1}	Results in [7]	88.69	51.67	-37.63	-43.01	-75.26
	Obtained results	88.59	50.97	-37.53	-42.90	-75.16
ΔP_{m2}	Results in [7]	29.57	17.02	-12.54	-14.33	-25.09
	Obtained results	29.53	16.99	-12.51	-14.30	-25.05
ΔP_{m3}	Results in [7]	44.35	25.53	-18.81	-21.50	-37.63
	Obtained results	44.30	25.48	-18.76	-21.45	-37.58
$\Delta \omega$	Results in [7]	-0.00178	-0.00102	0.00075	0.00086	0.00150
	Obtained results	-0.00177	-0.00102	0.00075	0.00085	0.00153
F	Results in [7]	49.911	49.860	49.898	49.941	50.016
	Obtained results	49.912	49.861	49.897	49.941	50.016

Table (8) : Steady-state comparison, when the transmission losses have been taken in consideration

	Interval (it)	2	3	4	5	6
	P_L	375.0	470.0	400.0	320.0	180.0
	ΔP_L	165.0	95.0	-70.0	-80.0	-140.0
P_1	Results in [7]	158.71	200.00	154.56	105.26	50.0
	Obtained results	158.91	200.00	153.84	104.45	50.0
P_2	Results in [7]	112.88	150.00	134.57	117.83	90.41
	Obtained results	112.99	150.00	134.22	117.39	89.92
P_3	Results in [7]	129.96	164.97	141.98	117.04	48.58
	Obtained results	130.09	166.12	141.55	116.53	49.34
P_l	Results in [7]	26.55	44.98	31.11	20.13	8.99
	Obtained results	26.61	45.59	30.89	19.95	11.07
P_T	Results in [7]	401.55	514.97	431.11	340.13	188.99
	Obtained results	401.98	516.12	429.61	338.37	189.26
ΔP_{m1}	Results in [7]	97.66	61.24	-45.08	-48.90	-80.09
	Obtained results	97.75	61.24	-45.63	-48.89	-80.05
ΔP_{m2}	Results in [7]	32.55	20.41	-15.03	-16.30	-26.70
	Obtained results	32.59	20.41	-15.21	-16.29	-26.68
ΔP_{m3}	Results in [7]	48.83	30.62	-22.54	-24.45	-40.05
	Obtained results	48.89	30.62	-22.81	-24.45	-40.02
$\Delta \omega$	Results in [7]	-0.00195	-0.00123	0.00090	0.00098	0.00160
	Obtained results	-0.00196	-0.00123	0.00091	0.00098	0.00160
F	Results in [7]	49.902	49.841	49.886	49.935	50.015
	Obtained results	49.903	49.842	49.888	49.937	50.017

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4. CONCLUSIONS

The proposed procedure gives the deviations in each of the rotational speed, electrical and mechanical power of each generation unit in addition to the deviations in frequency, transmission losses and generated power of each unit during the changing time of the load, either the load builds up or decays from an interval to the next interval.

The steady-state values of the above mentioned variables can, also, be calculated at the end of this changing time. The agreement between the obtained results and the results, which are obtained before in [7], verifies that the presented procedure is feasible and valid for the steady-state solution and the solution during the changing of the load. This last solution illustrates that the generated power of each generating unit in each subinterval of the changing time of the load is less than the steady-state value. This leads to reduce the optimum generating costs in each time interval.

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