MULTI-STATES RELIABILITY MODEL FOR TURBOGENERATOR GROUPS

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Abstract – The paper is structured in three parts. The first part shows how to assess the availability of thermal power plants using the binomial method. In the second part is presented the multi-state reliability model proposed by the authors to analyze the reliability of turbogenerator groups, achieving a case study for a 60 MW group. The last part presents the assessment of energy availability at the level of 3x60 MW thermal power plants.

Keywords: modelling, reliability, thermal power plant

1. INTRODUCTION

The assessment of power availability of a thermal power plant (TPP) is very important; one of the main objectives of predictive reliability analyses is to determine the amount of power and energy that may be delivered by a TPP for a specified period of time, therefore allowing the forecast of electric energy production for that time interval. On the other hand, since TPP are very complex structures, assessment of power availability involves difficulties in modelling their reliability [4, 5]. That is the reason why simplifying assumptions must be accepted; even knowing they will affect – in a certain extent, however determinable – the accuracy of calculations.

The values utilized in calculating the reliability indicators of each component of TPP are very important for the results credibility [6]. The method used for reliability analysis is equally important. Therefore, the recommended method [1, 2, 3] which is very often used for availability assessments of TPP is the binomial one. When applying this method, it is generally accepted that the thermo-generator group is characterized by two states: operating, having probability (p) and failure, having probability (q). Obviously, that hypothesis is not according to reality, therefore the results will be, in a certain extent, erroneous.

2. ASSESSMENT OF POWER AVAILABILITY OF A THERMAL POWER PLANT USING BINOMIAL METHOD

2.1. Binomial method

Let's consider a system consisting of n independent elements, characterized by two states (operation/failure). Each element has an operation probability p, and a failure probability q. The probability that $(n - k)$ elements are in operation (respectively, k are not working) is given by the following relation [1, 2, 3]:

$$P_n(k) = C_n^k \cdot p^{n-k} \cdot q^k \tag{1}$$

expression that corresponds to *(k+1)* term of Newton's binomial expansion:

$$(p+q)^n = \sum_{k=0}^{n} C_n^k \cdot p^{n-k} \cdot q^k \tag{2}$$

The distribution of random variable „number of defective elements" is:

$$K : \begin{pmatrix} 0 & 1 & \dots & k & \dots & n \\ C_n^0 p^n q^0 & C_n^1 p^{n-1} q^1 & \dots & C_n^k p^{n-k} q^k & \dots & C_n^n p^0 q^n \end{pmatrix}$$

or

$$P(K \le k) = \sum_{i=0}^{k} P_n(i) = \sum_{i=0}^{k} C_n^i p^{n-i} q^i \tag{3}$$

The mean value and dispersion of this random variable are:

$$M(K) = n \cdot q; \quad D(K) = n \cdot p \cdot q \tag{4}$$

For high enough values of n ($n \ge 20$) and also very small values of q ($q \le 0,05$), the binomial distribution tends to a Poisson distribution having as parameter $m = n \cdot q$. In this case:

$$P_n(k) = P(k) = \frac{m^k}{k!} \cdot e^{-m} \tag{5}$$

If the n elements of the system are not identical, being characterized by (p_i, q_i) values, the above defined probabilities $P_n(k)$ will be calculated by expanding the binomial product:

$$\prod_{i=1}^{n} (p_i + q_i) = 1 \tag{6}$$

2.2. Assessment of energy availability using binomial method

We consider a thermal power plant equipped with n identical turbo-generator groups, each having P_n rated power. The operation probability of groups is p, and the failure one is $q = 1 - p$. All possible states of thermal power plant, as well as the specific parameters of each state are presented in table 1.

Table 1. States and characteristic parameters

Number of state	No. of groups in operation	State probability	Available power P_i [MW]	Annual mean duration T_i [h/year]
0	n	p^n	$n \cdot P_n$	$p^n \cdot 8760$
1	n - 1	$C_n^1 \cdot p^{n-1} \cdot q$	$(n - 1) \cdot P_n$	$C_n^1 \cdot p^{n-1} \cdot q \cdot 8760$
2	n - 2	$C_n^2 \cdot p^{n-2} \cdot q^2$	$(n - 2) \cdot P_n$	$C_n^2 \cdot p^{n-2} \cdot q^2 \cdot 8760$
. . .				
k	n - k	$C_n^k \cdot p^{n-k} \cdot q^k$	$(n - k) \cdot P_n$	$C_n^k \cdot p^{n-k} \cdot q^k \cdot 8760$
. . .				
n	0	q^n	0	$q^n \cdot 8760$

Table 2. States of turbo-generator groups from TPP

Number of state	No. of groups in operation	State probability	Available power P_i [MW]	Annual mean duration T_i [h/year]
0	3	$p^3 = 0.8493$	180	7440
1	2	$3 \cdot p^2 \cdot q = 0.1426$	120	1249
2	1	$3 \cdot p \cdot q^2 = 0.0080$	60	70
3	0	$q^3 = 0.0001$	0	1

Power availability of entire thermal power plant is calculated with:

$$D_W = \frac{\sum_{k=0}^{n} P_i \cdot T_i}{n \cdot P_n \cdot 8760} = \frac{\sum_{k=0}^{n} (n-k) \cdot P_n \cdot C_n^k \cdot p^{n-k} \cdot q^k \cdot 8760}{n \cdot P_n \cdot 8760} =$$
$$= \frac{\sum_{k=0}^{n} (n-k) \cdot C_n^k \cdot p^{n-k} \cdot q^k}{n} \qquad (7)$$

In the following, we exemplify the application of binomial method for power availability assessment of a TPP, equipped with 3 turbo-generator groups of 60 MW, their operation probability being p = 0.947 [8]. Table 2 shows all possible states of turbo-generator groups from TPP.

Based on data shown in Table 2, the curve of available power that may be delivered by TPP, during 1year (8760 hours), is presented in Fig. 1.

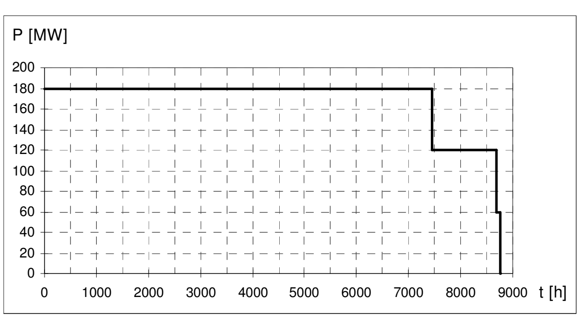

Fig. 1. Diagram of TPP annual available power

The power availability of TPP is:

$$D_W = \frac{180 \cdot 7440 + 120 \cdot 1249 + 60 \cdot 70}{3 \cdot 60 \cdot 8760} = 0.947032 \qquad (8)$$

This method of analysis is unrealistic because the groups are characterized, also, by intermediate levels of operation (partial success). The figures obtained after applying this method are very optimistic, going far beyond the values occurring in real operation. Thus, the coal fired thermal power plants the literature indicates values of D_W = (0.6 ÷ 0.8) or even less for energy availability.

To get plausible values for power plant energy availability we must operate with credible values of reliability indicators of power plant components on one hand and, on the other hand, we have to use adequate methods of analysis that will allow a realistic reliability modeling of turbo-generator groups (having intermediate operating states between the extreme levels - 100% and 0%). These are the main objectives of this study.

3. MULTI-STATES RELIABILITY MODEL FOR TURBO-GENERATOR GROUPS

3.1. Identifying the structure of turbo-generator group subsystems

The turbo-generator group is a very complex system, consisting of several subsystems that serve its proper operation. Obviously, these subsystems determine the operation of group and, inevitably, on the analyzed time interval (T_A) they will be characterized by intermediate operating states (states of partial success), corresponding to operating levels existing between the extreme ones: failure (availability 0%) and rated level (availability 100%). Modeling the evolution of turbo-generator group by only two states (availability 100% and, respectively, 0%) is, as shown above, inexact and optimistic. Therefore, a realistic modeling – that involves taking into consideration the intermediate states of availability – is necessary.

The block diagram of a turbo-generator group is shown in fig. 2, indicating also its component subsystems.

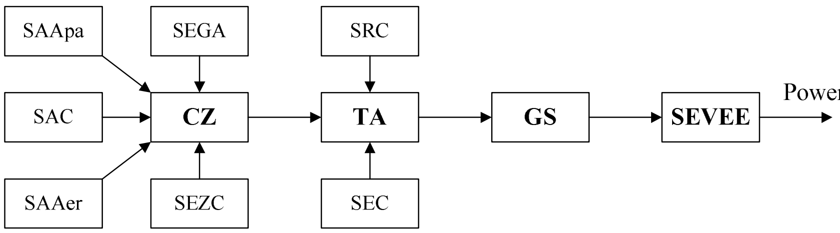

Fig. 2. Block diagram of a turbo-generator group

SAC – coal feed subsystem; SAAer – air feed subsystem; SEGA – burning gases exhaust subsystem; SAApa –water feed subsystem; SEZC – slag and ash exhaust subsystem; SRC – cooling the condenser subsystem; SEC – condensate exhaust subsystem; CZ - steam boiler; TA – steam turbine; GS – synchronous generator; SEVEE – power delivery subsystem

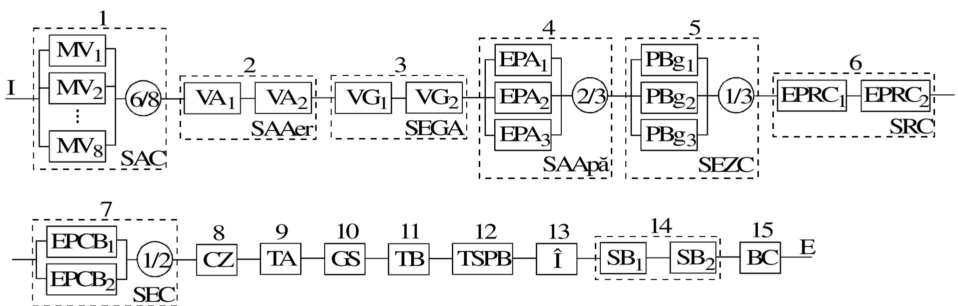

Fig. 3. Reliability equivalent diagram of turbo-generator group for 100% availability level

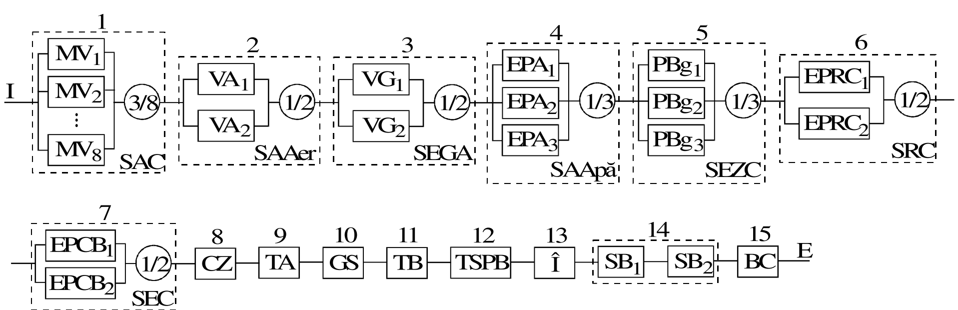

Fig. 4. Reliability equivalent diagram of turbo-generator group for an availability level ≥ 50%

For the analyzed TPP, subsystems of the 60 MW turbo-generator group have the following characteristics:

- Steam boiler (CZ): 420 t steam/h;
- Steam turbine (TA): 60 MW;
- Synchronous generator (GS): 75 MVA (60 MW);
- Subsystem for coal feed (SAC): 8 coal mills (MV), dimensioned „6-out-of-8" (meaning that from a total of 8 mills, 6 mills are running);
- Subsystem for air feed (SAAer): 2 air fans (VA), dimensioned 2x50%;
- Subsystem for burning gases exhaust (SEGA): 2 gas ventilators (VG), dimensioned 2x50%;
- Subsystem for water feed the steam boiler (SAApa): 3 water feeding pumps (EPA), dimensioned „2-out-of-3";
- Subsystem for slag and ash evacuation (SEZC): 3 Bagger pumps (PBg), dimensioned „1-out-of-3";
- Subsystem for cooling the condenser (SRC): 2 cooling pumps (EPRC), dimensioned 2x50%;
- Subsystem for condensate evacuation (SEC): 2 condensate pumps (EPCB), dimensioned 1-out-of-2;
- Subsystem for electric energy delivery (SEVEE) comprising of:
  - 1 block power transformer for power delivery (TB);
  - 1 power transformer for auxiliaries (TSPB);
  - 1 circuit breaker (I), 2 disconnectors (SB) and 1 bus bar (BC).

To be able to quantitatively evaluate the reliability indicators of the group, we must know the values of failure intensity (λ) and repair intensity (μ) of all subsystems of the group. Thus, for the turbo-generator group belonging to the analyzed TPP, these indicators have the values recommended in [8].

3.2. Availability assessment for turbo-generator groups using multi-states reliability model

Studying the structure of turbo-generator group and its subsystems we can see that the availability levels of the group are 100%, 83%, 67%, 50% and 0%. Starting from the structure presented in fig. 2, a reliability equivalent diagram is built for each availability level. This diagram includes all subsystems of the group. Based on the reliability equivalent diagram, the specific reliability indicators are assessed [7].

3.2.1. Availability level of 100%

The reliability equivalent diagram corresponding to this level of group availability is shown in fig. 3.

For the type of subsystems "*s*-out-of-*n*" (*s* elements in operation from a total of *n* elements), intensity of failure, respectively intensity of repair, are calculated using relations [8]:

$$\begin{cases} \lambda_e = \dfrac{\dfrac{n!}{(s-1)!\,(n-s)!}\cdot\dfrac{\lambda^{n-s+1}}{\mu^{n-s}}}{\sum\limits_{i=0}^{n-s}\left[\dfrac{n!}{i!\,(n-i)!}\cdot\left(\dfrac{\lambda}{\mu}\right)^i\right]} \\ \mu_e = (n-s+1)\cdot\mu \end{cases} \tag{9}$$

Applying the values of failure intensity and repair intensity shown in [8], the following values result:

- The equivalent intensities of failure and repair for the group are:

$$\begin{cases} \lambda_{e(100\%)} = \sum\limits_{i=1}^{15}\lambda_i = 181.76\cdot10^{-4}\ \ h^{-1} \\ \mu_{e(100\%)} = \dfrac{\lambda_{e(100\%)}}{\sum\limits_{i=1}^{15}\dfrac{\lambda_i}{\mu_i}} = 205.55\cdot10^{-4}\ \ h^{-1} \end{cases}$$

- Probability of success for availability level 100% is:

$$P_{S(100\%)} = \frac{\mu_{e(100\%)}}{\lambda_{e(100\%)}+\mu_{e(100\%)}} = 0.530712$$

- Mean annual time of group operation at full capacity (100%):

$$M_{(100\%)}[\alpha(T_A)] = P_{S(100\%)}\cdot T_A = 4649\ \ h/year$$

- Mean annual number of transitions (failures) from full capacity operating state:

$$M_{(100\%)}[\nu(T_A)] = P_{S(100\%)}\cdot\lambda_{e(100\%)}\cdot T_A = 84.5\ \ failures/year$$

3.2.2. Availability level 83%

This level of availability is achieved if the subsystem for coal feed (SAC) is of type "5-out-of-8", all other group subsystems are the same as in reliability equivalent diagram (fig. 3). Therefore:

- The equivalent intensities of failure and repair for the group are:

$$\begin{cases} \lambda_{e(67\%)} = 83.52\cdot10^{-4}\ \ h^{-1} \\ \mu_{e(67\%)} = 134.65\cdot10^{-4}\ \ h^{-1} \end{cases}$$

- Probability that group availability is at least 67%:

$$P_{S(\geq 67\%)} = \frac{\mu_{e(67\%)}}{\lambda_{e(67\%)}+\mu_{e(67\%)}} = 0.617179$$

- Probability that group availability is exactly 67%:

$$P_{S(67\%)} = P_{S(\geq 67\%)} - P_{S(100\%)} - P_{S(83\%)} = 0.024948$$

- Mean annual time of group operation at 67% of its capacity:

$$M_{(67\%)}[\alpha(T_A)] = P_{S(67\%)}\cdot T_A = 219\ \ h/year$$

- Mean annual number of transitions (failures) from operating state at 67% of group capacity:

$$M_{(67\%)}[\nu(T_A)] = P_{S(67\%)}\cdot\lambda_{e(67\%)}\cdot T_A = 1.8\ \ failures/year$$

3.2.3. Availability level 67%

This availability level occurs when the subsystem of coal feed (SAC) is of type "4-out-of-8", all other group subsystems are the same as in reliability equivalent diagram (fig. 3). Therefore:

- For the turbo-generator group we'll have:

$$\begin{cases} \lambda_{e(67\%)} = 83.52\cdot10^{-4}\ \ h^{-1} \\ \mu_{e(67\%)} = 134.65\cdot10^{-4}\ \ h^{-1} \end{cases}$$

- Probability that group availability is at least 67%:

$$P_{S(\geq 67\%)} = \frac{\mu_{e(67\%)}}{\lambda_{e(67\%)}+\mu_{e(67\%)}} = 0.617179$$

- Probability that group availability is exactly 67%:

$$P_{S(67\%)} = P_{S(\geq 67\%)} - P_{S(100\%)} - P_{S(83\%)} = 0.024948$$

- Mean annual time of group operation at 67% of its capacity:

$$M_{(67\%)}[\alpha(T_A)] = P_{S(67\%)}\cdot T_A = 219\ \ h/year$$

- Mean annual number of transitions (failures) from operating state at 67% of group capacity:

$$M_{(67\%)}[\nu(T_A)] = P_{S(67\%)}\cdot\lambda_{e(67\%)}\cdot T_A = 1.8\ \ failures/year$$

3.2.4. Availability level 50%

Reliability equivalent diagram corresponding to this availability level is shown in fig. 4.

- For turbo-generator group results:

$$\begin{cases} \lambda_{e(50\%)} = \sum\limits_{i=1}^{15}\lambda_i = 53.51\cdot10^{-4}\ \ h^{-1} \\ \mu_{e(50\%)} = \dfrac{\lambda_{e(50\%)}}{\sum\limits_{i=1}^{15}\dfrac{\lambda_i}{\mu_i}} = 139.1\cdot10^{-4}\ \ h^{-1} \end{cases}$$

- Probability that group availability is at least 50%:

$$P_{S(\geq 50\%)} = \frac{\mu_{e(50\%)}}{\lambda_{e(50\%)} + \mu_{e(50\%)}} = 0.722185$$

- Probability that group availability is exactly 50%:

$$P_{S(50\%)} = P_{S(\geq 50\%)} - P_{S(100\%)} - P_{S(83\%)} - P_{S(67\%)} = 0.105006$$

- Mean annual time of group operation at 50% of its capacity:

$$M_{(50\%)}[\alpha(T_A)] = P_{S(50\%)} \cdot T_A = 920 \ \text{h / year}$$

- Mean annual number of transitions (failures) from operating state at 50% of group capacity:

$$M_{(50\%)}[\nu(T_A)] = P_{S(50\%)} \cdot \lambda_{e(50\%)} \cdot T_A = 4.9 \ \text{failures / year}$$

The results of the above calculations are centralized in table 3.
Power availability of the turbo-generator group is:

$$D_W = \frac{P_n \cdot 4649 + 0.83 \cdot P_n \cdot 539 + 0.67 \cdot P_n \cdot 219 + 0.5 \cdot P_n \cdot 920}{P_n \cdot 8760} =$$
$$= 0.651039$$

In conclusion, applying the developed method of direct assessment of groups availabilities based on reliability equivalent diagrams, we can identify – beside the extreme states (operating at rated capacity or nor operating at all) – also states characterized by a partial availability. The developed method allows the assessment of reliability and availability performances of turbo-generator group. In the end, based on these performances we can evaluate the energy safety indicators of the group. There are obvious advantages of this method comparing to present–used modeling where only two states are considered (operation/failure) and therefore only the evaluation of time-dependent safety indicators is possible.

Table 3. Values of reliability indicators of turbo-generator group

Number of state	Availability level [%]	Probability of state	Mean annual time of state occupancy [h/year]	Mean annual number of failures [failure/year]
1	100	0.530712	4649	84.5
2	83	0.061519	539	6.3
3	67	0.024948	219	1.8
4	50	0.105006	920	4.9
5	0	0.277815	2433	-

4. ASSESSMENT OF ENERGY AVAILABILITY FOR ENTIRE THERMAL POWER PLANT

4.1. Assessment method principle

In order to be able to perform an evaluation of electric energy availability for entire power plant, the following data must known:

- availability levels corresponding to each group: D_{kj};
- levels of available power for each group: $D_{kj} \cdot P_{nk}$;
- probability that the group will provide that certain level of availability: $Prob_{kj}$,

where: $k = (1, 2, \ldots, n)$ marks the turbo-generator group;

$j = (1, 2, \ldots, m)$ represents the level of availability (from 100% to 0%);

P_{nk} is the rated power of k group.

To assess the electric energy availability for the entire power plant we must determine the pairs "available power of the entire power plant – probability to provide (ensure) this power" (P_i, $Prob_i$). To achieve this we'll apply the ***polynomial method***. According to this [1, 2, 3], the probabilities of all possible states result from the expansion of the following expression:

$$\prod_{k=1}^{n} \left(Prob_{k1} + Prob_{k2} + \ldots + Prob_{km} \right) \tag{10}$$

If the turbo-generator groups are identical (most common situation), the probability that from n identical groups, k_1 provide (ensure) power ($D_1 \cdot P_n$), k_2 provide power ($D_2 \cdot P_n$), ... , k_m provide power ($D_m \cdot P_n$) is:

$$Prob\left(k_1, k_2, \ldots, k_m\right) = \\ = \frac{n!}{k_1! k_2! \ldots k_m!} \cdot \left(Prob_1\right)^{k_1} \cdot \left(Prob_2\right)^{k_2} \cdot \ldots \cdot \left(Prob_m\right)^{k_m} \tag{11}$$

For this particular state, the available power of the entire power plant will be:

$$P\left(k_1, k_2, \ldots, k_m\right) = \\ = \left(k_1 \cdot D_1 + k_2 \cdot D_2 + \ldots + k_m \cdot D_m\right) \cdot P_n \tag{12}$$

4.2. TPP case study

The analyzed TPP is equipped with three identical turbo-generators of 60 MW each. The availability levels of these groups and their probabilities, calculated in chapter 3, are presented in Table 3.

The available power of the entire power plant and the probability of ensuring this power, determined using the above mentioned polynomial method, are shown in Table 4.

Cumulating the results obtained for each level of available power, the power availability of entire thermal power plant is determined (Table 5).

Data from Table 5 allow setting the annual curve of available power of analyzed TPP (fig. 5).

Power availability of TPP is:

$$D_W = \frac{\sum_i P_i \cdot M_i[\alpha(T_A)]}{3 \cdot P_n \cdot T_A} = 0.616102$$

Table 4. Reliability indicators of TPP

State no.	Availability level of groups [%] 100	83	67	50	0	State probability	Available power of TPP [MW]	Mean annual time [h/year]
1.	3	-	-	-	-	$(Prob_1)^3 = 0.077964$	180	683
2.	2	1	-	-	-	$3\cdot(Prob_1)^2\cdot Prob_2 = 0.072325$	170	634
3.	2	-	1	-	-	$3\cdot(Prob_1)^2\cdot Prob_3 = 0.029784$	160	261
4.	2	-	-	1	-	$3\cdot(Prob_1)^2\cdot Prob_4 = 0.046592$	150	408
5.	2	-	-	-	1	$3\cdot(Prob_1)^2\cdot Prob_5 = 0.164907$	120	1444.5
6.	1	2	-	-	-	$3\cdot Prob_1\cdot(Prob_2)^2 = 0.022364$	160	196
7.	1	1	1	-	-	$6\cdot Prob_1\cdot Prob_2\cdot Prob_3 = 0.018420$	150	161
8.	1	1	-	1	-	$6\cdot Prob_1\cdot Prob_2\cdot Prob_4 = 0.028815$	140	253
9.	1	1	-	-	1	$6\cdot Prob_1\cdot Prob_2\cdot Prob_5 = 0.101986$	110	893.5
10.	1	-	2	-	-	$3\cdot Prob_1\cdot(Prob_3)^2 = 0.003793$	140	33
11.	1	-	1	1	-	$6\cdot Prob_1\cdot Prob_3\cdot Prob_4 = 0.011866$	130	104
12.	1	-	1	-	1	$6\cdot Prob_1\cdot Prob_3\cdot Prob_5 = 0.041999$	100	368
13.	1	-	-	2	-	$3\cdot Prob_1\cdot(Prob_4)^2 = 0.009281$	120	81
14.	1	-	-	1	1	$6\cdot Prob_1\cdot Prob_4\cdot Prob_5 = 0.065700$	90	575.5
15.	1	-	-	-	2	$3\cdot Prob_1\cdot(Prob_5)^2 = 0.116268$	60	1019
16.	-	3	-	-	-	$(Prob_2)^3 = 0.002305$	150	20
17.	-	2	1	-	-	$3\cdot(Prob_2)^2\cdot Prob_3 = 0.002848$	140	25
18.	-	2	-	1	-	$3\cdot(Prob_2)^2\cdot Prob_4 = 0.004455$	130	39
19.	-	2	-	-	1	$3\cdot(Prob_2)^2\cdot Prob_5 = 0.015768$	100	138
20.	-	1	2	-	-	$3\cdot Prob_2\cdot(Prob_3)^2 = 0.001173$	130	10
21.	-	1	1	1	-	$6\cdot Prob_2\cdot Prob_3\cdot Prob_4 = 0.003669$	120	32
22.	-	1	1	-	1	$6\cdot Prob_2\cdot Prob_3\cdot Prob_5 = 0.012987$	90	114
23.	-	1	-	2	-	$3\cdot Prob_2\cdot(Prob_4)^2 = 0.002870$	110	25
24.	-	1	-	1	1	$6\cdot Prob_2\cdot Prob_4\cdot Prob_5 = 0.020316$	80	178
25.	-	1	-	-	2	$3\cdot Prob_2\cdot(Prob_5)^2 = 0.035953$	50	315
26.	-	-	3	-	-	$(Prob_3)^3 = 0.000161$	120	1.5
27.	-	-	2	1	-	$3\cdot(Prob_3)^2\cdot Prob_4 = 0.000755$	110	6.5
28.	-	-	2	-	1	$3\cdot(Prob_3)^2\cdot Prob_5 = 0.002674$	80	24
29.	-	-	1	2	-	$3\cdot Prob_3\cdot(Prob_4)^2 = 0.001182$	100	10
30.	-	-	1	1	1	$6\cdot Prob_3\cdot Prob_4\cdot Prob_5 = 0.008366$	70	73
31.	-	-	1	-	2	$3\cdot Prob_3\cdot(Prob_5)^2 = 0.014806$	40	130
32.	-	-	-	3	-	$(Prob_4)^3 = 0.000616$	90	5.5
33.	-	-	-	2	1	$3\cdot(Prob_4)^2\cdot Prob_5 = 0.006544$	60	57
34.	-	-	-	1	2	$3\cdot Prob_4\cdot(Prob_5)^2 = 0.023161$	30	203
35.	-	-	-	-	3	$(Prob_5)^3 = 0.027325$	0	239

Table 5. Power availability of TPP

Available power [MW]	Mean annual time [h/year]	Available power [MW]	Mean annual time [h/year]	Available power [MW]	Mean annual time [h/year]
180	683	120	1559	60	1076
170	634	110	925	50	315
160	457	100	516	40	130
150	589	90	695	30	203
140	311	80	202	0	239
130	153	70	73		

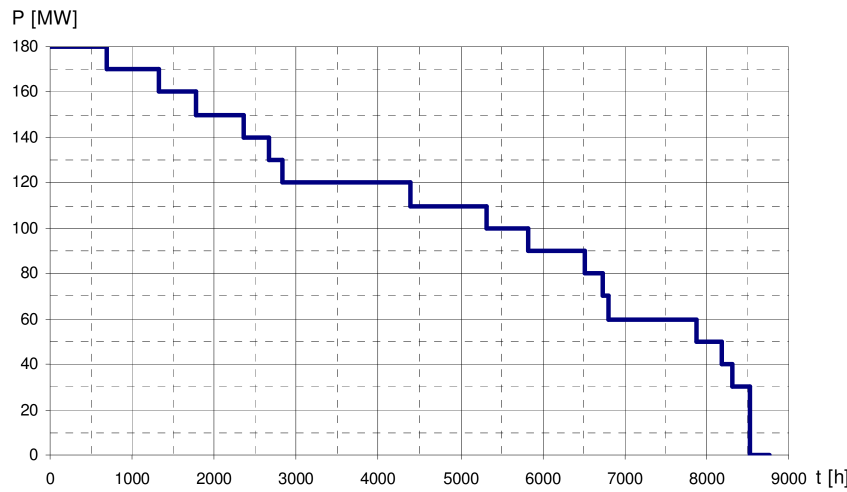

Fig. 5. Annual curve of TPP available power

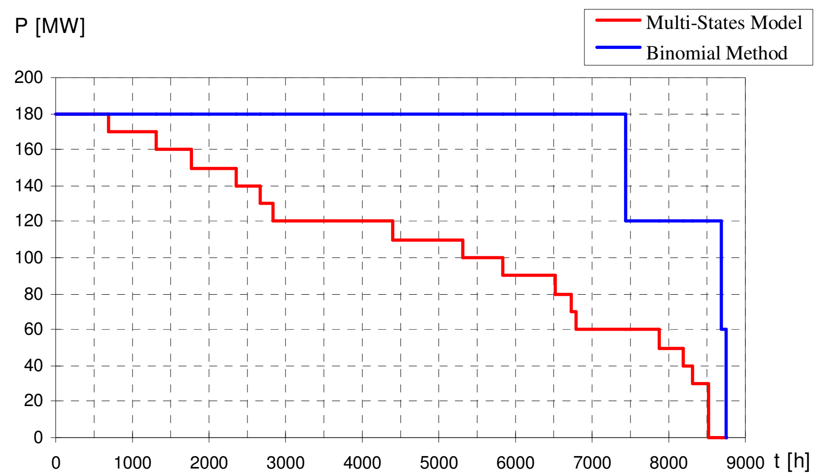

Fig. 6. Annual available power of studied TPP, for both methods: binomial and multi-states modeling

4. CONCLUSIONS

Based on done analyses and obtained results, the following conclusions may be set:

1. The most frequent used method for determining the electric energy availability of TPP is the binomial method. The results obtained after applying this method are optimistic, mainly due to the fact that turbo-generator groups are considered bivalent from number of states point of view (they can have only two states: operation/failure). This hypothesis leads to relatively high errors. To have a quantitative imagine of these errors, fig. 6 presents the curves of annual available power of studied TPP in both cases: binomial method, respectively polynomial method.
   The energy availability of TPP – calculated with the first method (binomial method) – is D_W = 0.947032, respectively D_W = 0.616102 - calculated with this new developed method. Normally, the operating values (gathered from sites) belong to (0.6 ÷ 0.8) interval. Therefore, results obtained after applying binomial method cannot be used even as rough guide values, because errors are far beyond the acceptable limits, while the developed analysis model shows credible values, much close to the operating ones.
2. In order to have a realistic assessment of power availability for thermal power plants, turbo-generator groups must be modeled as multivalent elements (from number of possible states point of view). Therefore, we recommend application of following analysis methods:
   * polynomial method;
   * a direct analysis, based on equivalent reliability diagrams and failure groups for different levels of availability;
   * Monte Carlo simulation method.
3. Multi-states reliability model is developed for availability assessment of turbo-generator groups and is based on equivalent reliability diagrams. It allows identification and quantification of states having partial availability – beside the two extreme states (operation at full capacity and failure). The model also allows the assessment of reliability and

availability performances of turbo-generator group, and based on them the energy safety indicators of group and power plant, may be evaluated. These are obvious advantages of this method, comparing with two states modeling (operation/failure), where only time dependent safety indicators may be evaluated.

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