Journal of Energy

VOLUME 69 Number 2 | 2020

journal homepage: http://journalofenergy.com/

Mićo Klepo
mklepo@hera.hr
Croatian Energy Regulatory Agency,
Ul. grada Vukovara 14.
10 000 Zagreb

Vladimir Mikuličić
vladimir.mikulicic@fer.hr
Faculty of Electrical Engineering and Computer Science,
Unska 3.
10 000 Zagreb

Zdenko Šimić
zdenko.simic@gmail.com
Faculty of Electrical Engineering,
Computer Science and Information Technology Osijek,
Kneza Trpimira 2B.
31000 Osijek

Peak Plant Models in the Electric Power System Model of Reliability and Availability

SUMMARY

The work sets out the results of the theory/methodological refinement of models whereby peak generating plants are included in the reliability and availability patterns of electricity systems while operational planning operations are taking place. Account shall be taken of the technical and energy characteristics of such generating units, as well as of the specific conditions and requirements imposed on such generating units, resulting from their location and the role in covering peak loads and consumption of the electricity system.

KEYWORDS

Peak plant model, plant failure during operation, plant failure during start-up, postponable outage, power system availability and reliability

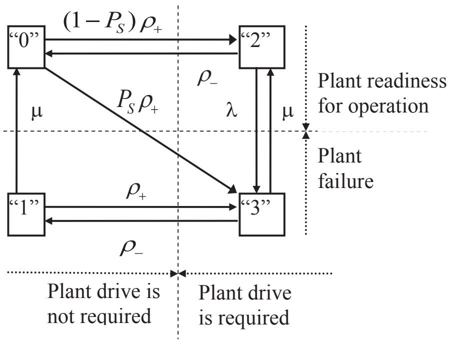
INTRODUCTION

The general problem of data collection, statistical treatment and calculation of parameters and indicators for the establishment of generating units models during operational planning operations, as well as the means of access and solutions to the problem of the incorporation of generating units in the reliability and availability model of the electricity system, have so far been further processed and exposed in a number of works (L1 to L1 6). Processing in this work includes a general model of a peak load power plant, but also complex models, an extended model which distinguishes between peak plants and start-up failures at the start and during operation, and the model of the peak load plant with the possible postponement of exit from the operation.

The complex models shall be with a view to distinguishing between failures during start-up and failures during operation mode of the peak load plant, but also to include the possibility of plant outage postponability, depending on the gravity and type of failure during operation. This introduces the possibility to include additional demands and operative characteristics in the calculations of indicators of the availability and reliability of generating units which cover peak portions of the load diagram, which means that they are relatively often entering and leaving the plant, often changing rapidly the load level, which is subject to specific additional stress and heavier operating conditions, including special additional requirements and operational features. Of course, the possibility of distinguishing the degree and the seriousness of failure at the starting and running of the peak generating unit opens the possibility for part of the faults incurred at the start to be removed during the presence of the need or by the requirement to drive the peak generating unit, and to enter the plant. In a similar manner, the distinction between the degree and the seriousness of failure during operation, or rather, by introducing the possibility that depending on the degree of failure, the peak plant remains in operation, allows for the extension of its operation. Both have a direct impact on the status and indicators of the availability and reliability of the power system.

FOUR-STATE PEAK PLANT MODEL

The four-state peak plant model, as shown in Figure 1, shall be used to include in the estimation of the reliability and availability indicator of the electric power system the plants that cover the peak part of the load diagram, which are subjected to higher stresses due to frequent entries and exits from operation i.e. start-ups and shut-offs [L9], [L10] and [L11]. In addition to the faults occurring during the operation, failures can occur when the plant is placed in operation. The failure of the installation shall result in the plant being unable to meet the prescribed load for part of for the entire duration of the need for that load. The repeated reattempt at commissioning of the same plant for a specified period of service shall not be treated as more than one starting failure. Therefore, the probability of the commissioning plant shall be carefully assessed in case when data are kept for the overall number of putting into service only.



Legend (Figure 1):

"0" - the state of the plant reserve shut-down,

"1" - the state of the plant failure when drive is not being required,

"2" - the state of the plant drive when drive is being required,

"3" - the state of the plant failure when drive is being required,

λ - the plant failure rate,

μ - the plant repair rate,

ρ_+ - the rate of occurrence of the need for the drive,

ρ_- - the rate of termination of the need for the drive,

P_S - the probability of plant failure during the start-up.

Figure 1 – The four-state model of the peak load plant

There is no transition from the status of the plant reserve shut-down to the condition of failure when its activation is not required, due to the fact that the number of such transition is negligible and it is reasonable to assume that the plan cannot fail when it is shut off because of the reserve or if it is not in operation. Any discovery of conditions that may lead to forced unavailability on the basis of a back-up disconnection may be associated with cases of repeated failures, such as the occurrence of such conditions during inspection or overhaul.

According to Figure 1, the Markov process, which describes the four-state model of the peak load plant, describes the following system of linear differential equations:

$$\begin{aligned}
\dot{P}_0(t) &= -\rho_+ P_0(t) + \mu P_1(t) + \rho_- P_2(t) \\
\dot{P}_1(t) &= -(\mu+\rho_+)P_1(t) + \rho_- P_3(t) \\
\dot{P}_2(t) &= (1-P_s)\rho_+ P_0(t) - (\rho_- + \lambda)P_2(t) + \mu P_3(t) \\
\dot{P}_3(t) &= P_s\rho_+ P_0(t) + \rho_+ P_1(t) + \lambda P_2(t) - (\rho_- + \mu)P_3(t)
\end{aligned} \tag{1}$$

where:

$\dot{P}_i(t)$ - $(=\frac{dP_i(t)}{dt})$ - is the derivation of probability of state "i" in relation to time "t",

$P_i(t)$ - is probability of state "i" (i = 0, 1, 2, ..., n).

Under the assumption that when t = 0, the power plant is functional, the starting conditions are:

$$P_0(0)=1, P_1(0)=0, P_2(0)=0, P_3(0)=0. \tag{2}$$

A stationary solution is being sought, i.e. the solution when is

$$\dot{P}_n(t)=0; n=0,1,2,3. \tag{3}$$

Under condition (3), system (1) takes on a new form:

$$\begin{aligned}
0 &= -\rho_+ P_0 + \mu P_1 + \rho_- P_2 \\
0 &= -(\mu+\rho_+)P_1 + \rho_- P_3 \\
0 &= (1-P_s)\rho_+ P_0 - (\rho_- + \lambda)P_2 + \mu P_3 \\
0 &= P_s\rho_+ P_0 + \rho_+ P_1 + \lambda P_2 - (\rho_- + \mu)P_3
\end{aligned} \tag{4}$$

System (4) with an identity equation

$$P_0+P_1+P_2+P_3=1 \tag{5}$$

results in the stationary probability of states :

$$\begin{aligned}
P_0 &= \frac{\mu}{\rho_+}(\mu+\rho_+ +\lambda+\rho_-)/\Delta \\
P_1 &= (\lambda+P_s\rho_-)/\Delta \\
P_2 &= \mu[\frac{1}{\rho_-}(\mu+\rho_+)+1-P_s]/\Delta \\
P_3 &= \frac{1}{\rho_-}(\mu+\rho_+)(\lambda+P_s\rho_-)/\Delta \\
\Delta &= \frac{\mu}{\rho_+}(\mu+\rho_+ +\lambda+\rho_-)+(\lambda+P_s\rho_-)[1+\frac{1}{\rho_-}(\mu+\rho_+)]+\mu[\frac{1}{\rho_-}(\mu+\rho_+)+1-P_s]
\end{aligned} \tag{6}$$

In order to determine model parameters, the following data is needed:

g - the average time that the plant spent in operation, between the forced outage states due to failures, excluding forced outages as a result of faults or defects during start-up,

m - the average of the repair period or the average duration of the failure in the event of the failure,

Y - the average time that the plant is in operation on presence of the need for drive and the load, i.e. the duration of the work cycle,

X – the average duration of spare shutdown between the time periods when work is required, excluding maintenance time and other times of planned unavailability of the plant, where the following criterion is valid:

$$X+Y=\frac{RH}{\vartheta}, \tag{7}$$

u - the number of the plant failures,

ω - the number of times when the plant is shut down for economic reasons,

ϑ - the total number of the plant launches, i.e. entries into service,

P_1 - the probability of the plant failure during the entry into service, in terms of the expression:

$$P_s=\frac{NPS}{NUP+NPS},$$

NPS - the number of the plant failures during the entry into service,

NUP - the number of the successful entries.

The ω model parameters are:

$$=\frac{u-P_s*\vartheta}{SP}=\frac{1}{g} \;;\; \mu=\frac{u}{SK}=\frac{1}{m} \;;\; \rho_+=\frac{\vartheta}{RH-\frac{\vartheta}{\rho}}=\frac{1}{X} \;;\; \rho_-=\frac{(1-P_s)*\vartheta}{SP}=\frac{1}{Y} \tag{8}$$

where:

SP - the number of hours of operation of the peak plant,

RH - the number of hours of the peak plant availability for work,

SK - the number of hours of the peak plant inability for work.

The risk of the plant failure may be defined as

$$FOR=\frac{P_1+P_3}{P_1+P_2+P_3} \tag{9}$$

However, this is not a good measure of risk that the plant will not be able to cover the intended part of the peak load, provided it occurs. This measure is defined by the term

Mićo Klepo, Vladimir Mikuličić, Zdenko Šimić, Peak Plant Models in the Electric Power System Model of Reliability and Availability, Journal of Energy, vol. 69 Number 2 (2020), p. 24–36
https://doi.org/10.37798/202069230

$$FOR_P = \frac{P_3}{P_2 + P_3} = \frac{(P_s + \frac{\lambda}{\rho_-})(\mu + \rho_+)}{\mu[\frac{1}{\rho_-}(\mu + \rho_+) + 1] + \frac{\lambda}{\rho_-}(\mu + \rho_+)} \quad (10)$$

In fact, it is a reasonable conditional probability in relation to the phenomenon and the length of the need for drive, which means provided that the need arises. As the duration of operation is prolonged, thus P_1 tends to zero, and the risks of the plants in terms of (9) and (10) are put on an equal footing. A conditional probability can easily be estimated as follows: for a longer period of time, an estimated value of P_2 can be obtained as a ratio between the hours of operation (SP) and the sum of the hours of availability (RH) and the contingency hours (SK) (L11 and L13):

$$\hat{P}_2 = \frac{SP}{RH + SK} \quad (11)$$

where:

P_2 - the estimated value of the peak plant probability of operation when operation is needed.

Thus, the period of time of situation when the plant is out of operation due to repairs, maintenance, or any other planned shutdown is excluded. The probability of failure, i.e. $P_1 + P_3$, is estimated as the ratio of the number of hours when the plant is not available for work due to failures (SK) and the sum of the number of hours when it is available (RH) and the contingency hours (SK):

$$(\hat{P}_1 + \hat{P}_3) = \frac{SK}{RH + SK} \quad (12)$$

where:

P_1- the estimated value of the peak plant failure probability when drive is not needed,
P_2 - the estimated value of the peak unit failure probability when drive is needed.

In order to determine the risk of unavailability of the plant in the event of the need for drive, taking account of the estimated values by terms (11) and (12), factor ξ shall be introduced into term (10) determined as

$$\xi = \frac{P_3}{P_1 + P_3} = \frac{\mu + \rho_+}{\mu + \rho_+ + \rho_-} = \frac{\frac{1}{m} + \frac{1}{X}}{\frac{1}{m} + \frac{1}{X} + \frac{1}{Y}} \quad (13)$$

after which the probability of the plant unavailability for operation when drive is needed, i.e. the estimated value of this probability, shall have the following forms:

$$FOR_p = \frac{P_3}{P_2 + P_3} = \frac{\xi(P_1 + P_3)}{P_2 + \xi(P_1 + P_3)} \quad (14)$$

$$F\hat{O}R_p = \frac{\xi(\frac{SK}{RH + SK})}{\frac{SP}{RH + SK} + \xi(\frac{SK}{RH + SK})} = \frac{\xi * (SK)}{SP + \xi * (SK)} \quad (15)$$

The ξ factor ξ for weighting is the contingency hours (SK) reflecting the cumulative number of contingencies occurring during the period of operation. Depending on the operating cycle and the duration of contingencies, this factor represents the contribution of hours of the plant failure when operation needed to the total number of hours when the plant is disabled for operation. Thus, this factor includes in the equation the effect of the operation cycle and the duration of the peak plant failures, reducing the number of hours of failure by the above-mentioned effects.

There is a clear similarity between the factor ξ defined by the term (13) with the correction or adjustment factor modifying the base plant model in order to cater for the calculation of the reliability and availability parameters of the plant design, i.e. its failure can only start during the load time of the plant and not over the plant reserve shut-down time between the periods of need for operation (L13). The difference between them is that the modified base plant model does not include a presumption that any forced failure can arise from the start or during the need for operation of the plant, which leads to an understatement of the amount of that factor.

The correction error is low if the plant repair time is relatively long compared to the plant average suspension time for the reserve (m>>X). Where the repair time is short, factor ξ is approaching the unit. The corrected number of contingency hours during the period of need for operation may be estimated as follows:

$$SK_{cor} = \xi \cdot (SK) \quad (16)$$

The following problem presents the difficulty of assessing the impact of a change in the duty cycle on the risk of unavailability of the plant when its operation is needed. Indeed, the risks of unavailability of the plant are in fact chosen at random in one way if they are working on a weekly basis, compared to the cycle of service with daily start and shut-down. It is possible to solve the problem in two ways.

The first is that records and data the outages of the plant exposed to operational cycles corresponding to the expected type of use, and on the basis of them, determine the model's parameters for the plant. Another way is to adapt the available statistical data to the plant's new mode and the calculation of model parameters for these new conditions. The adjustment should in particular relate to intermediate to the failure, the probability of failure at the start-up and the mean repair time of the plant. By extrapolation, account should be taken of the changes in the relative difficulties of the start and the load, the speed of the load changes and the urgency of the exits.

With the increasing number of plant covering the peak part oy the system load the need to determine as precisely as possible the parameters for the availability budget of each of these plants is also growing. Since in the first years of operation, i.e. in the case of new on-site plants, there is, as a general rule, insufficient 'good' data to determine the model parameters, it is then reasonable to apply the increased fault rates from the facility, i.e. the increased rate of failures.

The exposed fur-state model in addition to the peak facility may also be used for the layout and analysis of intermittent work, that is, the base drive firing a longer perimeter of work and spare exclusion, significantly different from the operating cycle and the duration of the work at the peak operation. The distinction between intermittent work and working with a base charge is not always clear. The limits shall only determine the duration of the operation. In fact, according to the term (13), the value of the weight factor ξ is higher and tends to unit as the duration of the need for the operation of the plant is in excess of the periods of spare exclusion and repair. In this case, the conditional probability determined by the phrase (10) is to aim for the ratio m/(m + g), which is the analytical equivalent of the contingency risk (FOR), subject to a long load condition. Thus, the conditional probability of the plant unavailability, provided that the need arises, becomes the same as the risk of the plant failure as the factor ξ is approaching the unit.

In the four-state model, the frequency of the plant failure shall determine the product of the probability of unit failure when operation is needed (state "3"), i.e. P_3, and the sum of the plant repair rate and the rate $\xi\xi$ of the need for the drive termination.

$$f_3 = P_3(\mu + \rho_-) \quad (17)$$

This value corresponds to the product of the probability of the plant unavailability when is its operation is needed as defined by the term (14), the probability of the occurrence of the need for the operation ($P_2 + P_3$) and the rate of the plant shut-downs, whether due to the repair or the operation is no longer needed.

The frequency of occurrence of the operating state when operation is needed, i.e. state "2" in the peak load model, shall be equal to the product of the probability of this state and to the sum of the rate of the need for the drive termination and the plant failure rate:

$$f_2 = P_2(\rho_- + \lambda) \quad (18)$$

It is the sum of the frequency of transition from the state "2" to "0" and "3." For a longer time period, the ratio between the two frequencies is equal to the g/Y ratio, i.e. the number of transitions from the state “2” to the state ”0” and from the state “2” to the state “3.”

Where more detailed data are known about the number of transitions between states, i.e. the residence times under the individual the states, then the modelling parameters may also be determined as follows.

The average duration of the state “2” is determined by the term

$$T_2 = \frac{1}{\rho_+ + \lambda} = \frac{gX}{g+X} = \frac{\Sigma T_2}{N_{2,0} + N_{2,3}} \tag{19}$$

where:

ΣT_2- the cumulative retention in the state “2”, i.e. (SP),

$N_{2,0}, N_{2,3}$- the number of transitions from the state “2” to the state “0” and “3” respectively, for which:

$$N_{2,0} = \frac{\Sigma T_2}{Y} \tag{20}$$

$$N_{2,3} = \frac{\Sigma T_2}{m} \tag{21}$$

With that terms, based on data regarding operation statistics, the parameters of g and Y shall be determined.

The transitions form the state “0” are possible only to the states “2” and “3”. The time period spent in the state “0” is determined as follows:

$$T_0 = \frac{1}{\rho_+} = X = \frac{\Sigma T_0}{N_{0,2} + N_{0,3}} \tag{22}$$

where:

ΣT_0- the cumulative duration of the state “0”, i.e. (RH-SP),

$N_{2,0}, N_{2,3}$- the number of transitions from the state “0” to state “2” and “3” respectively, for which:

$$N_{0,2} = \frac{(1-P_s)\Sigma T_0}{X} \tag{23}$$

$$N_{0,3} = \frac{P_s \Sigma T_0}{X} \tag{24}$$

With that terms, based on data regarding operation statistics, the parameters P_3 and X shall be determined. The parameter m still remains. It is possible to determine it as follows. The plant failure frequency, whether or not its operation is needed (states “1” and “3”), is equal to the product of the sum of the probabilities of the states “1” and “3” and the transition rates from these states:

$$f_{1,3} = \mu P_1 + \mu P_3 = \mu(P_1 + P_3) \tag{25}$$

Whereas the average duration of the failure to operate or to repair, notwithstanding the need for operation, is equivalent to an inverse of the repair frequency value, the following shall be valid:

$$m = \frac{1}{\mu} = \frac{P_1 + P_3}{f_{1,3}} = \frac{\Sigma(T_1 + T_3)}{N_1 + N_3} \tag{26}$$

where:

$\Sigma(T_1+T_3)$- the cumulative time of failure, i.e. (SK),

$(N1 + N3)$ - the total number of failures, i.e. the transitions to the states “1” and “3”.

A specific problem introduces the partial failure of the peak load plant. In that case, three approaches may be followed. The first is that partial failures should be set aside, which can be done if those failures do not contribute significantly to the number and duration of the faults in the power system, that is to say, depending on the other installations of the power system. The second is when these failures have a major impact on the operation of the power system, when more complex models are needed, which is the subject of special treatment in the following chapters. Finally, in the third approach, the baseline of the four-state model is retained as a basis for the calculation of the indicator, but the failure risk is used in the modified form.

Under partial contingency, it shall be assumed that the plant is loaded with a part load during the entire contingency period and the contingency hours shall be added to the full contingencies in the phrase (15), as the equivalent hours, resulting in an equivalent contingency risk of the facility;

$$F\hat{O}R_p = \frac{\xi * (SK) + ekv(SK)}{SP + \xi * (SK)} \tag{27}$$

where:

$ekv(SK)$ - the hourly equivalent of the plant partial failure obtained as follows:

$$ekv(SK) = \frac{\sum_{i=1}^{\pi}(O_i^{isp} * SK_i^{isp})}{O_{\max}}; \tag{28}$$

i - the ordinal number of the partial load outage (i=1, 2,..., π),

0_i^{isp}- the part of the load outage during outage »i«,

0_{max}- the maximum load of the plant in the observed period,

SK_i^{isp}- the duration of partial contingency »i«.

As regards the exposed four-state peak load model (Figure 1), i.e. the main model of the peak load, it is also necessary to add the following. In the most general case, this model may also be used for inclusion in the calculation of the reliability and availability indicators of the wind farm production unit. In order to be able to use the model as the wind farm model, it is necessary to label the state “plant drive is not required” as the state “not sufficient wind to drive plant”, while the state “plant drive is required” to label as the state “sufficient wind to drive plant”. Adequate, the state “0” of the plant spare shut-down status and the state “1” of the condition of the plant failure when the plant is not required to drive, shall become the condition of the suspension or the condition of the failure condition in the weather conditions when there is no sufficient wind for the plant to drive. On the other hand, the state “2” of the plant when the plant is required to drive and the state “3” of the plant failure when the plant is being sought, become the operational status or the condition of the plant failure in the weather conditions when the wind is sufficient to propel the wind farm. The duration of the weather conditions where there is no sufficient wind for the wind farm to drive shall also include the duration of the very strong wind or storm weather during which the wind farm must be removed from the operation for protection purposes. Finally, in order to be able to use the model as a wind farm model the rate of occurrence of the need for drive $\rho+$ should be replaced by the rate of occurrence of weather conditions when wind is sufficient to propel (e.g. code ‘v’ – the rate of occurrence of sufficient wind time for the plant operation), while the rate of termination of the need for drive $\rho-$ should be replaced by the rate of weather conditions when the wind is not sufficient or is too high to propel the wind farm, i.e. the wind farm is switched off due to a thunderstorm.

Examples are provided below of the application of the four-state peak load model to two peak plants, namely: the peak load plant A, whose work cycles are short, often entrances and exits from the operation, thus covering the highest parts of the load diagram of the power system (daily work cycle), and peak load plant B, whose work cycles last longer, thus covering the intermediate parts of the load diagram of the power system (weekly working cycle).

Tables 1.1 and 1.2 present for peak load plant A and peak load plant B the input data to calculate the input parameters and the model parameters of the peak generating units, the stationary state probabilities for the input parameters thus determined, and the other parameters and indicators as the results of the four-state model application, relevant for the reliability and availability patterns of the power systems while operational planning operations are taking place.

Table 1.1 - The four-state peak load plant model parameters, the stationary probabilities of states and the other indicators of the peak load plant A

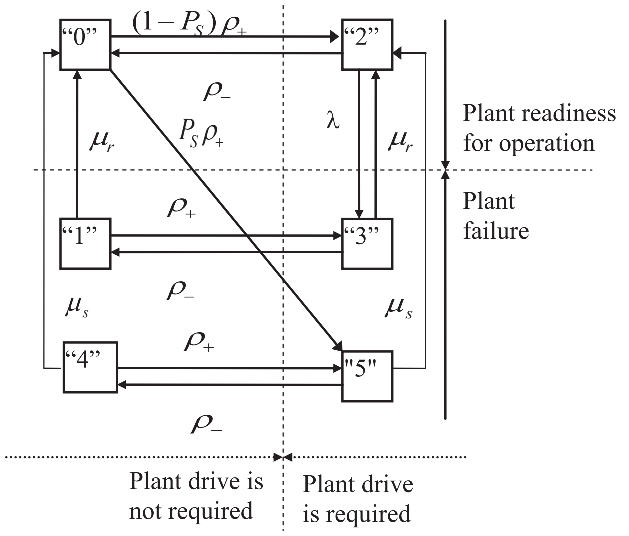
Data for the calculation of the plant parameters and the parameters of the peak load model states		Stationary state probabilities of the peak load plant		Other parameters and model indicators of the peak load plant operational conditions	
g	714,3	P_0	0,27020	P_1+P_3	0,09216
m	68,2	P_1	0,01963	*FOR, term (9)*	0,12628
X	34,7	P_2	0,63764	$FOR_{p,}$ *term (10)*	0,10448
Y	84,9	P_3	0,07253	P_2 *(EST), term (11)*	0,60901
$X+Y$	119,6			P_1+P_3 *(EST), term (12)*	0,08871
u	7			ζ, (EST), term(13)	0,78705
ω	34			$FOR_{p,}$ *(EST), term (14)*	0,10214
$u+\omega$	41			$FOR_{p,}$ *(EST), term (15)*	0,10286
NPS	3			f_3	0,00192
NUP	48			f_2	0,00840
P_s	0,05882			T_2	75,930
SP	3.278,0			T_0	84,962
SK	477,5			$f_{1,3}$	0,00135
RH	4.905,0				
λ	0,00140				
μ	0,01466				
ρ_+	0,02884				
ρ_-	0,01177				

Table 1.2 - The four-state peak load plant model parameters, the stationary probabilities of states and the other indicators of the peak load plant B

Data for the calculation of the plant parameters and the parameters of the peak load model states		Stationary state probabilities of the peak load plant		Other parameters and model indicators of the peak load plant operational conditions	
g	714,3	P_0	0,27020	P_1+P_3	0,09216
m	68,2	P_1	0,01963	*FOR, term (9)*	0,12628
X	34,7	P_2	0,63764	$FOR_{p,}$ *term (10)*	0,10448
Y	84,9	P_3	0,07253	P_2 *(EST), term (11)*	0,60901
$X+Y$	119,6			P_1+P_3 *(EST), term (12)*	0,08871
u	7			ζ, (EST), term(13)	0,78705
ω	34			$FOR_{p,}$ *(EST), term (14)*	0,10214
$u+\omega$	41			$FOR_{p,}$ *(EST), term (15)*	0,10286
NPS	3			f_3	0,00192
NUP	48			f_2	0,00840
P_s	0,05882			T_2	75,930
SP	3.278,0			T_0	84,962
SK	477,5			$f_{1,3}$	0,00135
RH	4.905,0				
λ	0,00140				
μ	0,01466				
ρ_+	0,02884				
ρ_-	0,01177				

SIX-STATE (EXTENDED) MODEL OF PEAK LOAD UNIT

The six-state (extended) peak plant model is the modified four-state peak load plant model that distinguish the failure of the plant at the starting from the failure of the plant unit during the operation (Figure 2.1) [L9], [L10] and [L11]. The consequences of these failures are also different. Finally, it means that the way in which the plant failures are repaired are also different. For the four-state model data shall be collected on the durability of the repair time for all faults during the observation period that the repair frequency is calculated from the average value of these durations and the number of corresponding transitions. However, the number and type of the failures of the plant are particularly dependent on the plant operating cycle, in particular when the performance is at an early occurrence at a relatively high probability. On the other hand, for this type of failure, they are linked to relatively shorter periods of contingency, i.e. to repair, compare to the malfunctions occurring during the longer period of operation. The duty cycle inevitably has an impact on total, which means also the average repair rate of the power plant. As a result, this problem is addressed by an explicit distinction between the failures during start-up and failures during operation of the plant, and the introduction of two separate repair rates, one for the repairs following failure events at the starting and other repairs after the failures occurred during operation.



Legend (Figure 2.1):

"0" - the state of the plant reserve shut-down,

"1"- the state of the plant failure when drive is not being required, but after the failure that occurred during operation,

"2" - the state of the plant drive when drive is being required,

"3" - the state of the plant repair when drive is being required, but after the failure that occurred during operation,

"4" – the state of the plant when operation is not being required, but after the failure that occurred during start-up,

"5" - the state of the plant repair when operation is being required, but after the failure that occurred during start-up,

λ - the plant failure rate during operation,

μ_r - the plant repair rate after failure occurred during operation,

μ_S - the plant repair rate after failure occurred during start-up,

ρ_+ - the rate of occurrence of the need for the drive,

ρ_- - the rate of termination of the need for the drive,

P_S - the probability of the plant failure during the start-up.

Figure 2.1 – The six-state (extended) model of the peak load plant

According to Figure 2.1, the Markov process, which describes the six-state model of the peak load plant, describes the following system of linear differential equations:

$$
\begin{aligned}
\dot{P}_0(t) &= -\rho_+ P_0(t) + \mu_r P_1(t) + \rho_- P_2(t) + \mu_s P_4(t) \\
\dot{P}_1(t) &= -(\mu_r + \rho_+)P_1(t) + \rho_- P_3(t) \\
\dot{P}_2(t) &= (1-P_s)\rho_+ P_0(t) - (\rho_- + \lambda)P_2(t) + \mu_r P_3(t) + \mu_s P_5(t) \\
\dot{P}_3(t) &= \rho_+ P_1(t) + \lambda P_2(t) - (\rho_- + \mu_r)P_3(t) \\
\dot{P}_4(t) &= -(\mu_s + \rho_+)P_4(t) + \rho_- P_5(t) \\
\dot{P}_5(t) &= P_s \rho_+ P_0(t) + \rho_+ P_4(t) - (\rho_- + \mu_s)P_5(t)
\end{aligned} \tag{29}
$$

The initial conditions are:

$$P_0(0) = 1, P_1(0) = 0, P_2(0) = 0, P_3(0) = 0, P_4(0) = 0, P_5(0) = 0\,. \tag{30}$$

A stationary solution is being sought, i.e. the solution when it is

$$\dot{P}_n(t) = 0; n = 0,1,2,3,4,5. \tag{31}$$

Under conditions (31), the system (29) takes a new form

$$
\begin{aligned}
0 &= -\rho_+ P_0(t) + \mu_r P_1(t) + \rho_- P_2(t) + \mu_s P_4(t) \\
0 &= -(\mu_r + \rho_+)P_1(t) + \rho_- P_3(t) \\
0 &= (1-P_s)\rho_+ P_0(t) - (\rho_- + \lambda)P_2(t) + \mu_r P_3(t) + \mu_s P_5(t) \\
0 &= \rho_+ P_1(t) + \lambda P_2(t) - (\rho_- + \mu_r)P_3(t) \\
0 &= -(\mu_s + \rho_+)P_4(t) + \rho_- P_5(t) \\
0 &= P_s \rho_+ P_0(t) + \rho_+ P_4(t) - (\rho_- + \mu_s)P_5(t)
\end{aligned} \tag{32}
$$

The equation of identity is:

$$P_0 + P_1 + P_2 + P_3 + P_4 + P_5 = 1 \tag{33}$$

The stationary solution, i.e. stationary state probabilities are:

$$
\begin{aligned}
P_0 &= \frac{\mu_r \mu_s}{\rho_+} \frac{(\mu_s + \rho_+)(\mu_r + \rho_+ + \rho_- + \lambda)}{\Delta} \\
P_1 &= \frac{\lambda \mu_s (\mu_s + \rho_+)}{\Delta} \\
P_2 &= \frac{\mu_r \mu_s}{\rho_-} \frac{(\mu_r + \rho_+ + \rho_-)(\mu_s + \rho_+)}{\Delta} \\
P_3 &= \frac{\lambda \mu_s}{\rho_-} \frac{(\mu_r + \rho_+)(\mu_s + \rho_+)}{\Delta} \\
P_4 &= \frac{P_s \rho \; \mu_r (\mu_r + \rho_+ + \rho_- + \lambda)}{\Delta} \\
P_5 &= \frac{P_s \mu_r (\mu_s + \rho_+)(\mu_r + \rho_+ + \rho_- + \lambda)}{\Delta}
\end{aligned} \tag{34}
$$

$$
\begin{aligned}
\Delta = & \frac{\mu_r}{\rho_+}(\mu_r + \rho_+ + \rho_- + \lambda)[\mu_s(\mu_s + \rho_+ + \rho_-) + P_s \rho_+ (\mu_s + \rho_+ + \rho_-)] + \\
& + \frac{\mu_s}{\rho_-}(\mu_r + \rho_+ + \rho_-)(\mu_s + \rho_+)(\lambda + \mu_r)
\end{aligned}
$$

The probability of the plant failure according to the six-state model is determined by the sum of the probabilities finding in the failure states, that is, states »1«, »3«, »4«, and »5«, hence:

$$P_{k\,var} = P_1 + P_3 + P_4 + P_5 \tag{35}$$

In stationary conditions, the frequency of occurrence of the failure condition shall be:

$$f_{k\,\mathrm{var}} = P_1 \mu_r + P_3 \mu_r + P_4 \mu_s + P_5 \mu_s \tag{36}$$

The mean plant repair rate shall be determined by the ratio of the failure frequency and failure probability:

$$\mu_{sred} = \frac{\mu_r (P_1 + P_3) + \mu_s (P_4 + P_5)}{P_1 + P_3 + P_4 + P_5} \tag{37}$$

However, the mean plant repair rate expressed in such way is insensitive to the differences between fault types, i.e. the differences between the faults occurring at the starting and the fault conditions during the operation are not recognised, nor the differences between the conditions of repair of the plant after different failures. The mean plant repair rate by default (37) shall be equal to the plant repair rate of the four-state peak load plant model, which in accordance with the above 'hides' the different transitions from the states "1" and "4" to the state "0" or from the states "3" and "5" through the state "2" to the state "0".

For the sake of simplicity, it is possible to use the main peak load plant model with the four states as the six-state model, but subject to separate operating statistics on the rates of the transition for every single state when the plant is ready for operation, i.e. the states "0" or '2', depending on the operating cycle conditions, in particular whether the failure occurred at the starting or during the operation.

Model parameters shall be calculated in a similar manner from the operation statistics as in the baseline of the four state model, but separate statistics of the number and duration of the failures shall be introduced after the start-up and operational failures, of course, depending on whether the repairs are performed during or after the end of the operation.

The extended peak load plant model, with an adequate change, as stated for the main model of the peak load plant, can be used as a model for inclusion in the calculation of the reliability and availability indicators of the wind farm production unit.

It is necessary that special attention be given to the failures during the start of the peak load plant, which means introduction of the distinctive parameters for the probability of failure of the peak production unit at the start and the appropriate rate of repair of the plant after the start-up failures. In fact, the repair rate of the plant from the main model of the peak load plant μ in the expanded peak load plant model is "divided" into two parameters: μ_r – the peak plant repair rate after failure occurred during operation, and μ_s – the peak load plant repair rate after failure occurred during start-up. It is necessary to take account of the conditionality and the compatibility of these three parameters.

Tables 2.1 and 2.2 present the input parameters for application of the extended, the peak load stationary state probabilities so specified input parameters, and other parameters and model indicators of the peak load plant operational conditions for the peak load plants A and B, whose structures, characteristics and input data for the calculation of the model parameters are identical to those given in Tables 1.1 and 1.2. The changes in relation to the model parameters listed in Tables 1.1 and 1.2 constitute the differences between the average duration of the repairs, that is, the average duration of failures on the occurrence of the failures at the starting and the occurrence of the failures during the operation, at the end the resulting differentiation of the corresponding repair rates of the peak load plant. The model parameters for application of the six-state peak load plant model and the peak plant stationary probability of the states for the peak load plant A as results listed in Table 2.1 were obtained on the assumption that the mean peak load plant A repair rate after all failures in the phrase (37) is 0,07937. Thus, the mean value of the repair rate of the peak load plant A is equal to the repair rate of the same plant from the basic model as indicated in Table 1.1. Adequately, the model parameters for application of the six-state peak load plant model and the peak plant stationary probability of the states for the peak load plant B as results listed in Table 2.1 were obtained on the assumption that the mean peak load plant B repair rate after all failures in the phrase (37) is 0,01466. Thus, the mean value of the repair rate of the peak load plant B is equal to the repair rate of the same plant from the basic model as indicated in Table 1.2.

Table 2.1 - The six-state peak load plant model parameters, the stationary probabilities of states and the other indicators of the peak load plant A

Data for the calculation of the plant parameters and the parameters of the peak load model states		Stationary state probabilities of the peak load plant		Other parameters and model indicators of the peak load plant operational conditions	
l	0,00329	P_0	0,39638	P_{kvar}, term (35)	0,05029
μ_r	0,03981	P_1	0,01637	f_{kvar}, term (36)	0,00399
μ_s	0,47619	P_2	0,55333	μ_{sred}, term (37)	0,07937
ρ_+	0,14706	P_3	0,02936		
ρ_-	0,10417	P_4	0,00065		
P_s	0,03191	P_5	0,00391		

Table 2.2 - The six-state peak load plant model parameters, the stationary probabilities of states and the other indicators of the peak load plant B

Data for the calculation of the plant parameters and the parameters of the peak load model states		Stationary state probabilities of the peak load plant		Other parameters and model indicators of the peak load plant operational conditions	
l	0,00140	P_0	0,26644	P_{kvar}, term (35)	0,09785
μ_r	0,01130	P_1	0,01787	f_{kvar}, term (36)	0,00143
μ_s	0,02857	P_2	0,63571	μ_{sred}, term (37)	0,01466
ρ_+	0,02884	P_3	0,06092		
ρ_-	0,01177	P_4	0,00324		
P_s	0,05882	P_5	0,01582		

The application of the six-state peak load plant or the extended peak load plant model and the calculation of the stationary state probabilities of the peak load plant under this model are, in particular, sensitive to the ratio of the respective parameters with which the peak unit design incorporates features of the peak plant in relation to the failures at the starting and the failure conditions during the operation. In the case of peak load plant A, whose work cycles are short, often entering and leaving the drive, that is to say covering the highest parts of the power system's load diagram, the application of the extended peak load model is justified for the average time of repair of the plant after the failure during the starting which often do not last more than a few hours. In the case of the peak load plant B, whose work cycles last longer, that is to say covering the intermediate parts of the power system's load diagram, the application of the extended peak load model is justified for the average time of repair of the peak load plant after the failure during the starting which can last as long as tens of hours. Of course, in both cases, it is appropriate to take into account and correct the ratios of the peak load plants duration of repair after the failures during the operation and the failures at the starting. Any previous base on the assumption that the average repair time of the peak load plant after failure occurred during operation is significantly longer than its average repair time after failure at the starting.

Figures 2.2 and 2.3 show the results of the analysis of the corresponding repair times and the plant repair rates after the failures occurred at the starting and during operation, the average duration of the repairs and the mean repair rates on the occurrence of the all plant failures for the peak load plant A and the peak load plant B respectively.

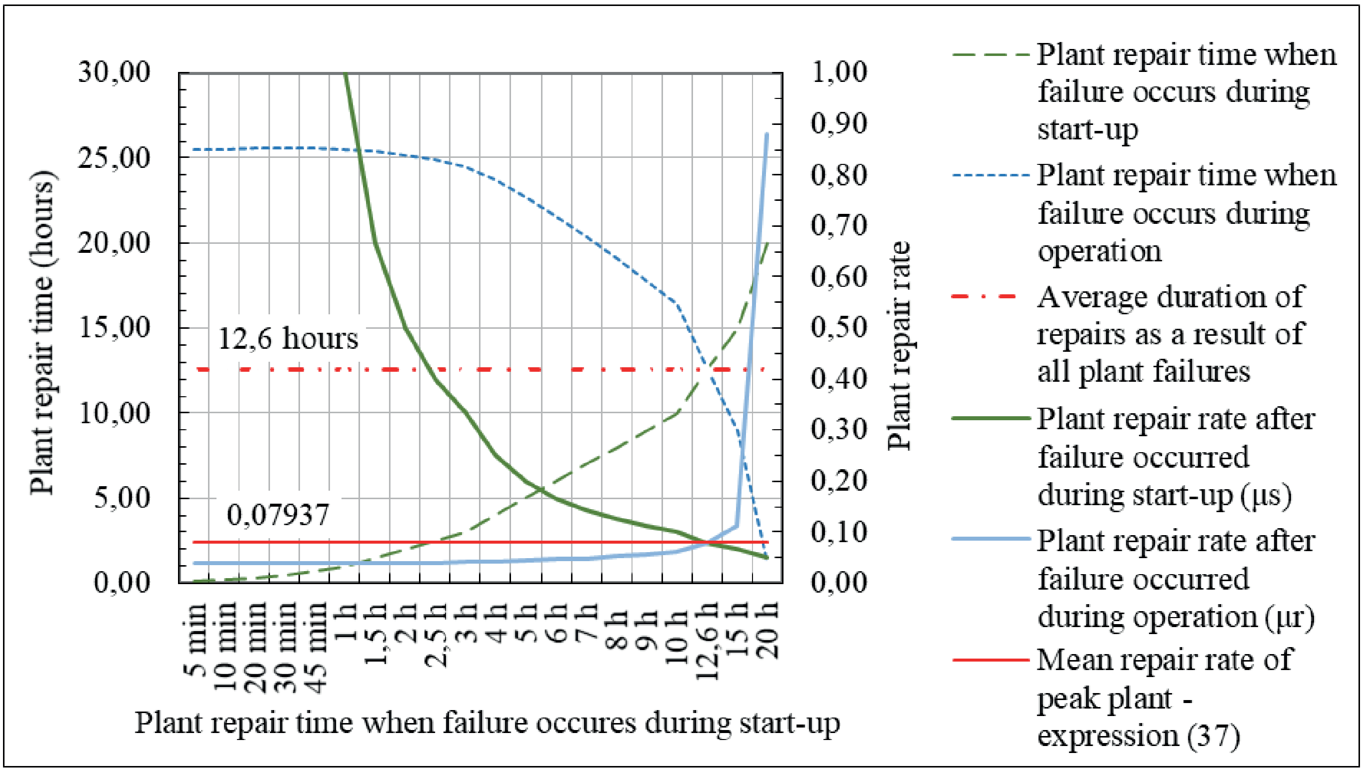


Figure 2.2 - Relationship between the repair time and repair rate, the average duration of repairs and mean repair rate for unit failures occurred during start-ups and operation – peak load plant A

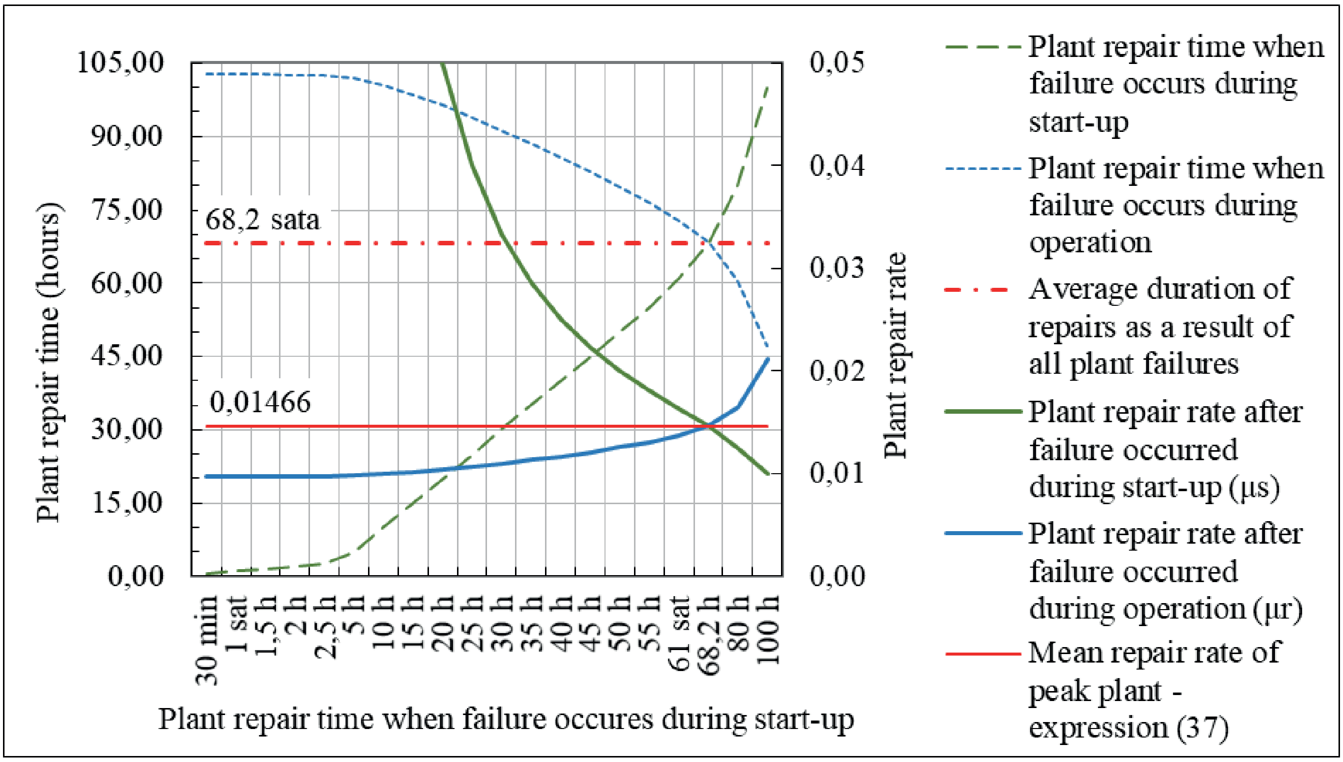


Figure 2.3 - Relationship between the repair time and repair rate, the average duration of repairs and mean repair rate for unit failures occurred during start-ups and operation – peak load plant B

SEVEN-STATE PEAK LOAD PLANT MODEL – MODEL OF PEAK LOAD PLANT WITH POSTPONABLE OUTAGES

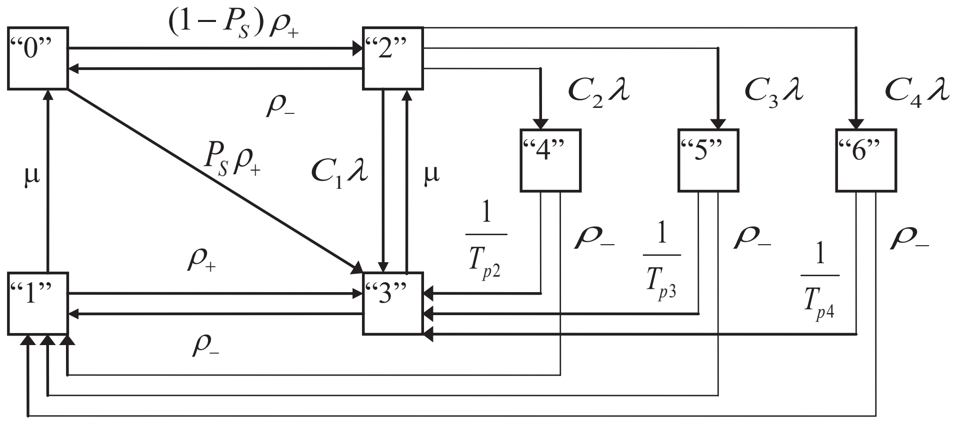
The basis of the seven-state peak load plant model is once again the four state peak load plant model which includes some plant states that reflect the possibilities that some plant component failures would not cause outages of the plant during its operation, that is, in spite of the component failures the plant remains in operation or it is possible to postpone or delay its disconnection from the power system. When the plant will be shut down for the repair, depends of the degree of postponability. The seven-state peak load plant model as an extension includes the various postponable plant outage categories (Figure 3.1). It is obvious that greater number of the peak load plant states could be added in the basic model, each representing the separated plant postponable outage category [L9], [L10] and [L11]. At the end it is likely that some component failures could cause the plant failures that are postponable for a relatively long period of time, beyond the weekend or even longer, enabling the plant to be repaired during the period when the plant operation would not be required. This is a reason why treatment of the data and the model calibration in this case should be very precise.

The peak unit model with the possible postponement or delay in the outage or exit shall reflect the conditions when, in some cases, after the failure the plant for some period of time remains in operation because of the system needs or the other reasons. That time may be relatively long, giving the opportunity to preserve the integrity of the system by including the spare capacities or otherwise maintain the integrity of the system. On the other hand, that time must not be too long to avoid even much seriously failures. In some cases, especially in the case of the outages of the plant that have been delayed over the weekend, the failure of the plant do not in fact appear at all. It is very likely that the planned exit from the drive which has delayed for a relatively long period of time can be removed during the period in which the operation of the plant is not required. The severity of the failure is the primary criterion of the drive or removal of the plant from the operation after the failure, which may essentially be classified in four categories, namely [L9]:

(a) immediate exit of the plant from the operation,

(b) exit of the plant from the operation postponed for the period of up to six hours,

(c) exit of the plant from the operation postponed from the six-hour period to the weekend, and



Legend (Figure 3.1):

“0” - the state of the plant reserve shutdown,

“1” - the state of the plant failure when drive is not being required,

“2” - the state of the plant drive when drive is being required,

“3” - the urgent unpostponable shutdown (outage) of the plant after the failure of class i=1,

“4” - the postponable plant shutdown (e.g. until six o'clock) after the failure of class i=2,

“5” - the postponable plant shutdown (e.g. until the weekend) after the failure of class i=3,

“6”- the postponable plant shutdown (e.g. until the several days) after the plant failure of class i=4,

λ - the mean rate of the all unplanned plant failures,

μ - the plant repair rate,

ρ_+ - the rate of occurrence of the need for the drive,

ρ_- - the rate of termination of the need for the drive,

P_S - the probability of the plant failure during the start-up,

C_i ,i=1,2,3,4 - the probability of the plant failure of class "i" during the drive,

T_{pi} ,i=1,2,3,4 – the mean time of the postponability after the failure of class "i".

Figure 3.1 - The seven-state peak load plant model - model with the postponable outage

Mićo Klepo, Vladimir Mikuličić, Zdenko Šimić, Peak Plant Models in the Electric Power System Model of Reliability and Availability, Journal of Energy, vol. 69 Number 2 (2020), p. 24–36
https://doi.org/10.37798/202069230

(d) exits of the plant from operation postponed over the weekend.

Of course, for the peak load plants whose work cycles are short, thus covering the highest parts of the power system load diagram, the possibility to delay exit is much shorter, i.e. the maximum delay time is no longer than the few hours. Of course, in such conditions the calculation of the peak load plant model parameters is much more demanding.

As regards postponability the four-state peak load plant model, the plant failure rate λ in the general aspect shall include the possibility to delay the outage, and thus the occurrence of the unplanned outages and any part failures of the respective class, i.e. the probability that the malfunction will occur during the operation shall be of the class 1, 2 or 3. In fact, it is more accurate to say that the failure rate in the four states model represents the medium frequency of the failure which cannot be postponed over the weekend or at the time when the peak plant is not required to operate.

The influence of the explicit modelling capability of the exit from the operation is of the utmost importance for plants operating close to the base part of the power system load curve. In the case of plants with the very short operating cycles, the postponement of exit is of less importance, as that plants terminate their operation before the end of the shortest postponable time period. In many cases the effect of the postponement to the weekend will be lost. This is way the risk of the plant failure in some cases shall be reduced.

According to Figure 3.1, the Markov process, which describes the seven-state peak load plant model - the peak load plant model with postponable outages, describes the following system of linear differential equationsλ:

$$
\begin{aligned}
&P_0(t) = -\rho_+ P_0(t) + \mu P_1(t) + \rho_- P_2(t)\\
&P_1(t) = -(\mu + \rho_+)P_1(t) + \rho_- P_3(t) + \rho_- P_4(t) + \rho_- P_5(t) + \rho_- P_6(t)\\
&P_2(t) = (1 - P_s)\rho_+ P_0(t) - (\rho_- + \lambda \sum_{i=1}^{4} C_i)P_2(t) + \mu P_3(t)\\
&P_3(t) = P_s\rho_+ P_0(t) + \rho_+ P_1(t) + C_1\lambda P_2(t) - (\mu + \rho_-)P_3(t) + \frac{P_4(t)}{Tp_2} + \frac{P_5(t)}{Tp_3} + \frac{P_6(t)}{Tp_4}\\
&P_4(t) = C_2\lambda P_2(t) - (\rho_- + \frac{1}{Tp_2})P_4(t)\\
&P_5(t) = C_3\lambda P_2(t) - (\rho_- + \frac{1}{Tp_3})P_5(t)\\
&P_6(t) = C_4\lambda P_2(t) - (\rho_- + \frac{1}{Tp_4})P_6(t)
\end{aligned} \tag{38}
$$

The initial conditions are:

$$P_0(0) = 1, P_1(0) = 0, P_2(0) = 0, P_3(0) = 0, P_4(0) = 0, P_5(0) = 0, P_6(0) = 0. \tag{39}$$

A stationary solution is being sought, i.e. the solution when it is

$$\dot{P}_n(t) = 0; n = 0,1,2,3,4,5,6. \tag{40}$$

Under conditions (40), the system (38) takes the form of:

$$
\begin{aligned}
&0 = \rho_+ P_0(t) + \mu P_1(t) + \rho_- P_2(t)\\
&0 = (\mu + \rho_+)P_1(t) + \rho_- P_3(t) + \rho_- P_4(t) + \rho_- P_5(t) + \rho_- P_6(t)\\
&0 = (1 - P_s)\rho_+ P_0(t) - (\rho_- + \lambda \sum_{i=1}^{4} C_i)P_2(t) + \mu P_3(t)\\
&0 = P_s\rho_+ P_0(t) + \rho_+ P_1(t) + C_1\lambda P_2(t) - (\mu + \rho_-)P_3(t) + \frac{P_4(t)}{Tp_2} + \frac{P_5(t)}{Tp_3} + \frac{P_6(t)}{Tp_4}\\
&0 = C_2\lambda P_2(t) - (\rho_- + \frac{1}{Tp_2})P_4(t)\\
&0 = C_3\lambda P_2(t) - (\rho_- + \frac{1}{Tp_3})P_5(t)\\
&0 = C_4\lambda P_2(t) - (\rho_- + \frac{1}{Tp_4})P_6(t)
\end{aligned} \tag{41}
$$

The equation of identity is:

$$P_0 + P_1 + P_2 + P_3 + P_4 + P_5 + P_6 = 1 \tag{42}$$

The stationary solution, i.e. the stationary state probabilities are:

$$
\begin{aligned}
&P_0 = \frac{\mu}{\rho_+}\frac{\left[\mu + \rho_+ + \rho_- + \lambda(\mu A + C)\right]}{\Delta}\\
&P_1 = \frac{\lambda(\mu A + C) + P_s\rho_-}{\Delta}\\
&P_2 = \frac{\mu\left[\frac{1}{\rho_-}(\mu + \rho_+) + 1 - P_s\right]}{\Delta}\\
&P_3 = \frac{\frac{1}{\rho_-}\left[(\mu + \rho_+)(\lambda C + P_s\rho_-)\right] - (1 - P_s)\lambda\mu A}{\Delta}\\
&P_4 = \frac{Tp_2C_2}{\rho_- Tp_2 + 1}\frac{\lambda\mu\left[\frac{1}{\rho_-}(\mu + \rho_+) + 1 - P_s\right]}{\Delta} = A_1\lambda P_2\\
&P_5 = \frac{Tp_3C_3}{\rho_- Tp_3 + 1}\frac{\lambda\mu\left[\frac{1}{\rho_-}(\mu + \rho_+) + 1 - P_s\right]}{\Delta} = A_2\lambda P_2\\
&P_6 = \frac{Tp_4C_4}{\rho_- Tp_4 + 1}\frac{\lambda\mu\left[\frac{1}{\rho_-}(\mu + \rho_+) + 1 - P_s\right]}{\Delta} = A_3\lambda P_2
\end{aligned} \tag{43}
$$

where:

$$
\begin{aligned}
&\Delta = \frac{\mu}{\rho_+}\left[\mu + \rho_+ + \rho_- + \lambda(\mu A + C)\right] + \mu\left[\frac{1}{\rho_-}(\mu + \rho_+) + 1 - P_s\right] +\\
&\left[\lambda(\mu A + C) + P_s\rho_-\right]\left[1 + \frac{1}{\rho_-}(\mu + \rho_+)\right]\\
&A_1 = \frac{Tp_2C_2}{\rho_- Tp_2 + 1} \quad A_2 = \frac{Tp_3C_3}{\rho_- Tp_3 + 1} \quad A_3 = \frac{Tp_4C_4}{\rho_- Tp_4 + 1}\\
&A = A_1 + A_2 + A_3\\
&C = C_1 + C_2 + C_3 + C_4 = 1
\end{aligned} \tag{44}
$$

In contrast to the terms for the stationary state probabilities of the main four-state peak load plant model, i.e. P_0, P_1, P_2 and P_3, in the corresponding terms using the seven-state model, i.e., P_0, P_1, P_2 and P_3^*, the plant failure rate λ is further multiplied by the term (μA+C), i.e. (μA+1). The failure rate of the plant in the four-state plant model may be taken with an equivalent size of multiplying the value of the seven-state model, and vice versa.

On the other hand, term P_3 is the sum of the probabilities of different degree of the plant failures, i.e. the sum of the postponable outage states »3,« »4,« »5,« and »6,« hence

$$P_3^{\bullet} = P_3 + P_4 + P_5 + P_6 = \frac{1}{\rho_-}\frac{\{(\mu + \rho_+)[\lambda(\mu A + C) + P_s\rho_-]\}}{\Delta} \tag{45}$$

where:

Δ - as in the phrase (44).

then the term for the probability of the state »3«, i.e. the state the immediate exit after the failure class *i=1* may be written in the following format:

$$
\begin{aligned}
&P_3 = P_3^{\bullet} - (P_4 + P_5 + P_6) = P_3^{\bullet} - \lambda A P_2 =\\
&= \frac{1}{\rho_-}\frac{\{(\mu + \rho_+)[\lambda(\mu A + C) + P_s\rho_-]\}}{\Delta} - \frac{\lambda A\mu}{\rho_-}\frac{[(\mu + \rho_+) + (1 - P_s)\rho_-]}{\Delta}
\end{aligned} \tag{46}
$$

where:

Δ - as in the phrase (44).

The probability of the plant failure in the four-state model can be considered equivalent to the sum of the different degrees of the outage delay in the modelling of the contingencies with the seven-state model. This means that the additional operation conditions of the peak plant which is explicitly delayed by the outages can be seen as an »expansion« of the states »3« in four-state model. When certain parameters Tp_i; $i=2,3,4$ and ρ_-, i.e. the mean time for postponable outage of the plant after the failure of class "i" and the rate of termination of the need for the drive, are known, it can easily be observed that the relationship of the probability ratio of the sate »3« (the state for which the failure causes the emergency outage of the plant) and the states »4,« »5,« and »6« determines only the probability of the failure of the defined class of the failure »i«, i.e. C_i; $i=1,2,3,4$.

The operation statistics shall correspond, in essence, to the operational statistics of the main four-state peak load plant model, with the addition of the above parameters, which is in effect the state »3« in the base model, on a number of situations characterised by the probability of occurrence and times of duration.

Tables 3.1 and 3.2 present for the peak load plant A and the peak load plant B the input data for calculating the parameters of the peak plant model operational states and the possible postponement of exit from the drive, the stationary probability of these peak load plant states for the input parameters so defined and the other parameters of the seven-state peak model of the peak load plants A and B. The change in relation to the model parameters listed in Tables 1.1 and 1.2 constitutes a distinction between different categories of the delay of exit of the completed plant.

Also with regard to the application of the peak load plant model with the possible delay in the contingency or exit from the operation the model input parameters and the stationary probabilities of the peak plant states are determined by the location and operating mode of the generation plant in the power system. However, as this is not a significant conditionality, the choice of the averaging periods after different failure classes during operation of the peak plant is not limited in advance. However, it is appropriate to adapt it to the operational requirements placed on a specific peak power plant, in particular to bring it into line with the corresponding operating cycles of the peak power plant.

Table 3.1 – The seven-state peak load plant model parameters, the stationary probabilities of states and the other indicators of the peak load plant A

Data for the calculation of the plant parameters and the parameters of the peak load model states		Stationary state probabilities of the peak load plant		Other parameters and model indicators of the peak load plant operational conditions	
λ	0,00329	P_0	0,39916	P_3*, term (45)	0,03366
μ	0,07937	P_1	0,01547	P_3, term (46)	0,03103
ρ_+	0,14706	P_2	0,55171		
ρ_-	0,10417	P_3	0,03100		
P_s	0,03191	P_4	0,00023		
C_1	0,34000	P_5	0,00098		
C_2	0,27000	P_6	0,00145		
C_3	0,21000				
C_4	0,18000				
T_{p2}	0,50				
T_{p3}	3,50				
T_{p4}	8,00				

Table 3.2 – The six-state peak load plant model parameters, the stationary probabilities of states and the other indicators of the peak load plant B

Data for the calculation of the plant parameters and the parameters of the peak load model states		Stationary state probabilities of the peak load plant		Other parameters and model indicators of the peak load plant operational conditions	
λ	0,00140	P_0	0,26864	P_3*, term (45)	0,07831
μ	0,01466	P_1	0,02116	P_3, term (46)	0,07037
ρ_+	0,02884	P_2	0,63189		
ρ_-	0,01177	P_3	0,07027		
P_s	0,05882	P_4	0,00113		
C_1	0,34000	P_5	0,00263		
C_2	0,27000	P_6	0,00429		
C_3	0,21000				
C_4	0,18000				
T_{p2}	5,00				
T_{p3}	17,00				
T_{p4}	38,00				

Finally, Figures 3.2 and 3.3 show the stationary state probabilities of the peak load plant A and the peak load plant B respectively, calculated according to the basic four state peak load model, the six-state peak load model (extended) and the seven-state peak load model with the possible delay in exiting the plant from drive.

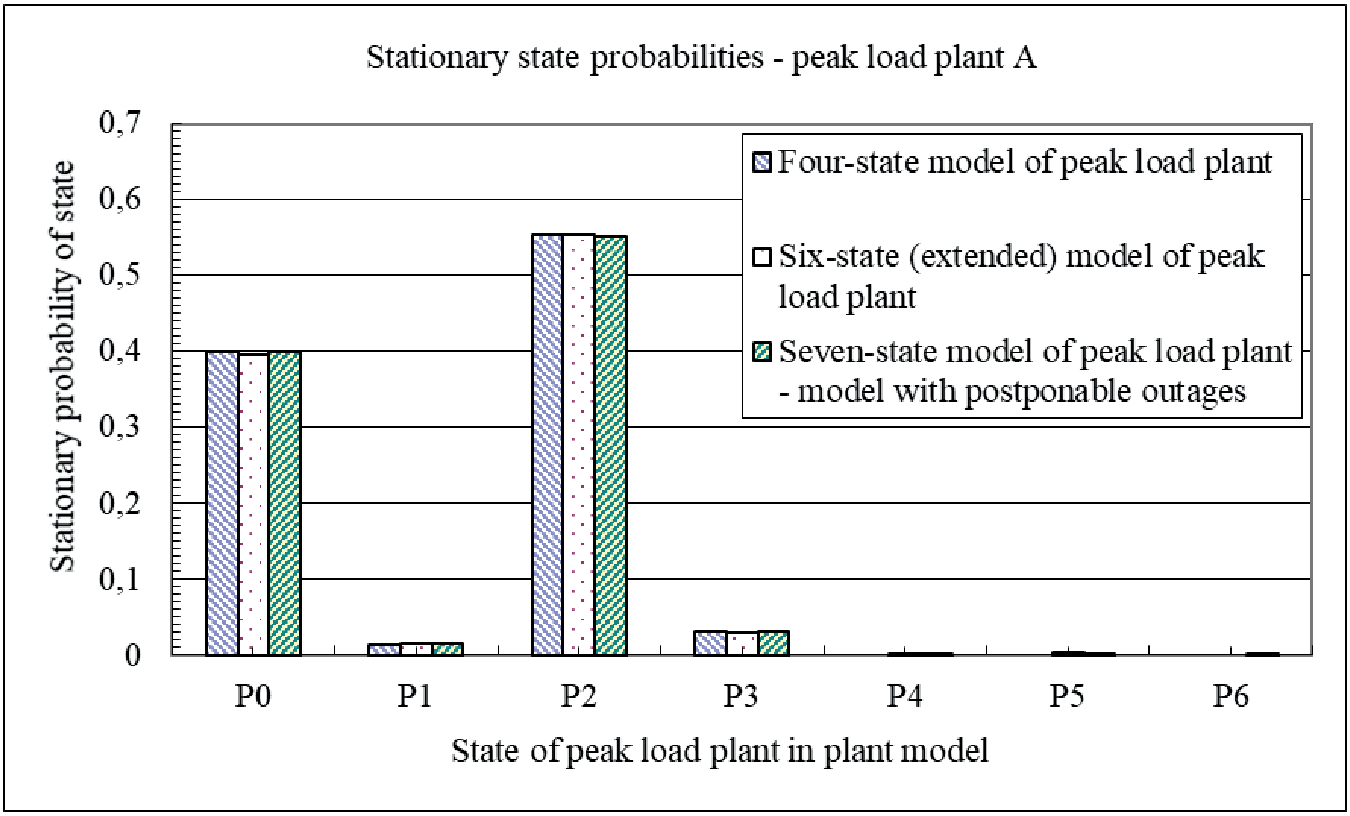


Figure 3.2 – The stationary state probabilities of the peak load plant A in the peak plant models

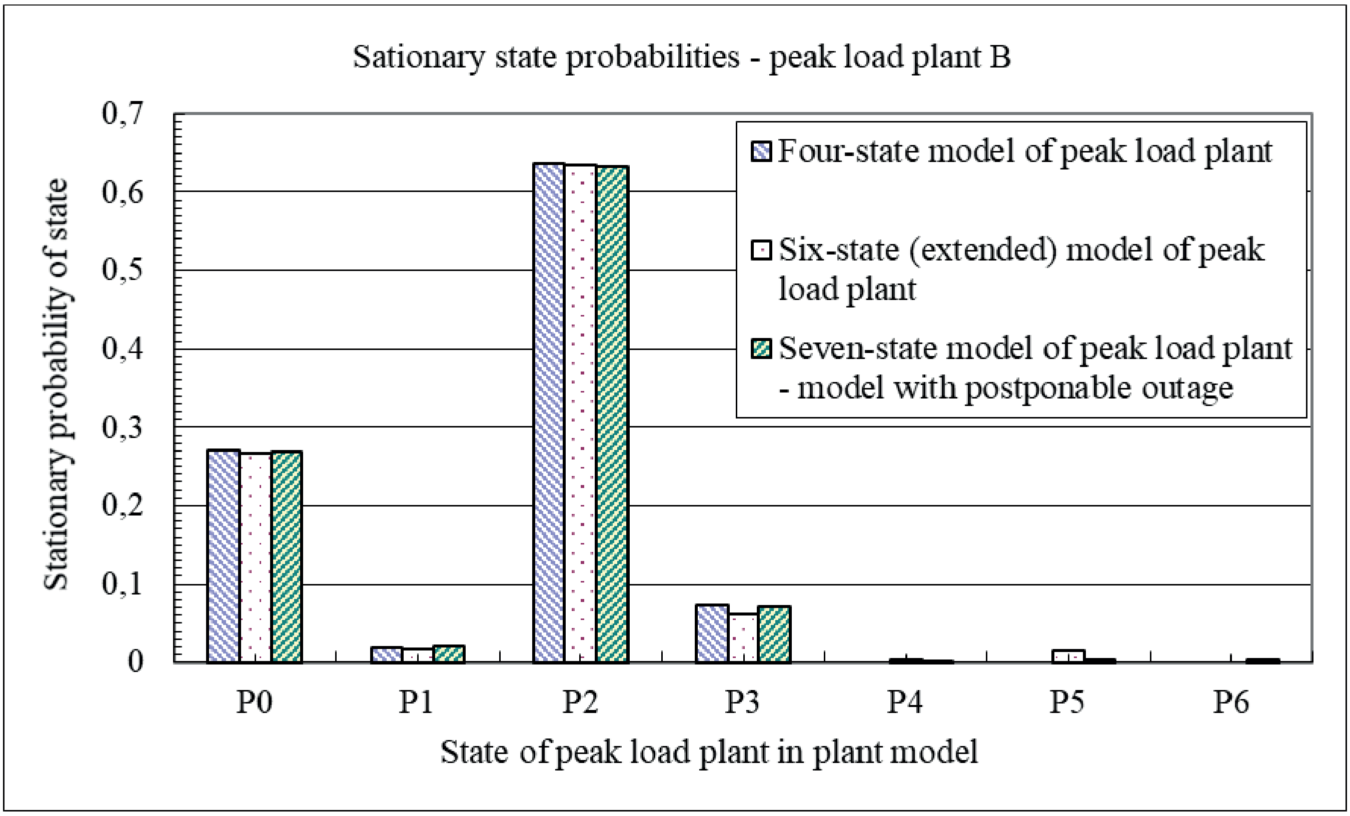


Figure 3.3 – The stationary state probabilities of the peak load plant B in the peak plant models

CONCLUSION

The peak load plant models have been developed and exposed to calculate the reliability and availability parameters and indicators that the peak generating plants include in the reliability and availability patterns of the power systems when operating schedules. The developed models, hence the associated reliability and availability indicators are dictated by the technical and energy characteristics of the plants that cover the peak load curve, i.e. the peak part of the power system load profile, but they also include and reflect the specific conditions and requirements that can be installed in the facilities or from the operation on such facilities in view of the dynamics resulting from their location and role in covering the load and the consumption of the power system. In particular, through the separate different models for the calculation of the parameters and indicators of reliability and availability of peak load plants, they include the possibility of explicit differentiating between the failures at the start and during the operation, which are usually different in terms of the severity of the effects, including the duration of the repairs, and the possibility to delay the outage or removal from the drive through several categories of the peak plant outage deferral.

Each of the expose peak load plant model was applied on the peak load plants with the different operating cycle durations and operating requirements, the model parameters and other modelling parameters and indicators have been calculated, demonstrating the applicability of the peak load plant models.

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