

# **THESIS SUMMARY**

## **NEW DEVELOPMENTS IN LOLP APPLICATIONS** **Reliability description of extraction condensing and back-pressure steam** **turbine power plant units by application of the Markov model**

**Summary of PhD thesis**

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## **B. Introduction**

### **B.1. Subject and aims of the theses**

This is a summary of the doctoral thesis --*New Developments in LOLP Applications – Reliability description of extraction condensing and back-pressure steam turbine power plant units by application of the Markov model*. The subject of the thesis is an extension of the application of the Loss-of-Load Probability (LOLP) indicator, providing improved accuracy of LOLP calculations through a differentiated reliability description of extraction condensing and back-pressure steam turbine power plant units. The thesis brings together the results of the first phase of a long term research project. The long-term research is aimed at developing probability theory-based computation methods for use in the determination of system-level capacity reserves and regulation capacity, and at improving the practical application of these methods. As the first stage of this research, a description of the stochastic changes of operating state of extraction condensing and back-pressure steam turbine power plant units was developed using the Markov model (discrete state space and discrete time parameter Markov chains and discrete state space and continuous time parameter Markov processes). The new procedure offers substantial improvements in the accuracy of calculating LOLP and thus the reliability of power generation systems, enabling more differentiated planning of reserve capacity at system level.

### **B2 The problem**

For the purposes of calculating the reliability of power generation systems, combined heat and power plants have hitherto always been modelled as “must-run”, “quasi-must-run” or “aggregated” power plant units. In many cases, the capacity of cogenerated power plant units is simply subtracted from the system-level power demand. This implies a two-state reliability model, i.e. incorporation of the available capacity of cogeneration power plant units without regard to capacity reduction due to heat output. The two-state reliability model states that the power plant unit is either operational with full capacity or non-operational with zero capacity. The two-state reliability description of power plant units only produces a result of satisfactory accuracy if the modelled power plant units have a high annual operating time, i.e. are in operation for most of the year. It is clear without further explanation that the two-state reliability model gives a very rough approximation of the real operation of extraction condensing and back-pressure power plant units which cogenerate heat and power. There are basically two reasons for this. Firstly, the annual utilisation of these power plant units, although considerably greater than that of peak-operation units, is considerably less than that of base-load units. Secondly, cogeneration requires that, for a certain portion of the operating period, extraction condensing and back-pressure steam turbine power plant units make less than their nominal capacity available to the power system. Consequently, the two-state reliability description is not suitable for differentiated reliability modelling of cogeneration power plants. This situation is not remedied by an attempt to incorporate heat output-induced capacity loss using some kind of average figure for the whole period (heat output shortfall [MW]).

By implication, this problem arises most seriously in systems where cogeneration power plant units are present in substantial proportions. This is the case in the Hungarian power system. The proposals and novel computational procedure described here are aimed at solving this problem.

### **B3 Current relevance of the problem**

The total cost of maintaining reserve capacity in the Hungarian power system in 2010 is estimated at over HUF 100 billion. This figure alone bears out how important it is to achieve precise computation of the minimum system reserve capacity which ensures a given level of power generation reliability, and to improve the accuracy of calculations.

## **1. Review of relevant literature and currently-applied computational procedures**

### **1.1. Hungarian literature**

Design procedures based on probability calculations and on the application of probability indicators to the characterisation of power generation system reliability started in Hungary in the 1980s, with the application of the WASP computer system. Péter Dörfner and János Hoffer published a paper on the cumulative method and its use in power system reliability calculations in 1989 [3]. Alajos Stróbl wrote a two-part review on the structure of the system-level capacity balance, the various types of reserve capacity required in the system, system regulation and related planning issues [4], [5]. This paper covered international regulations and the planning practices of MVM Zrt. and MAVIR Zrt., and referred to the application of LOLP calculations. Its approach to the issues was essentially practical. Of particular interest is a paper by Béla Potecz treating the relationships between LOLP and optimal security reserve in the system [6]. The results presented there include LOLP figures for specific capacity restrictions. The paper proposed a means of planning based on reserve planning economy considerations is proposed, showing the relationship between reserve capacity and consumer restriction losses. University textbooks and monographs on power generation do not deal with the LOLP calculation and theory. A book by Tibor Tersztyánszky published more than fifteen years ago, on the subject of improving the viability of the electrical power system [7], is concerned mainly with theoretical issues of frequency reduction in a system with capacity shortfalls. The simulation calculations in the book are based on probability theory. The second chapter of Appendix 3 to the book (Indices and indicators for evaluating the reliability of power supply and distribution) reviews probability indices, but the two and a quarter pages devoted to this only present the basic concepts. It does, however, include several modern probability indices for the reliability of power generation systems. Capacity planning at system level is covered in detail in the first volume of a monograph on the planning of power systems by András István Fazekas [8]. In the second volume [9], there is a section devoted to the reliability of the power plant subsystem (power generation) and the distribution subsystems, presenting modern probability theory-based planning methods.

A survey of papers and books published on the subject in Hungary shows that there are no publications on the subject of this thesis. None of the very few papers referring to LOLP extend its application to extraction condensing and back-pressure power plant units, and the findings of this thesis are not touched upon anywhere in scientific literature published in Hungary.

### **1.2. Review of foreign literature related to the thesis**

There is a broad foreign-language (primarily English and German) literature on reliability theory in general, and specifically on reliability studies of power systems and power generation. Specific theoretical treatments of the reliability of power plant systems, power generation and distribution have been produced primarily by two authors, Roy Billinton ([10], [11], [12]) and John Endrényi ([13]). It is no exaggeration to state that their books cover every theoretical and practical aspect of the reliability analysis of electrical power systems. There are also a very large number of journal papers on the subject. The arbitrary  $n$ -state probability model has also been developed and presented. Three- and even four-state reliability descriptions of power plant units have appeared in the literature, ([10], p.272, p.291.), [12], p.155-161.), but rarely applied in practice. Because of the very high computational requirements these involve, and the lack of reliable input data (statistical database), general applications are even now confined to the two-state model. The novelty of the proposed three-and-more state modelling of extraction condensing and back-pressure power plant units is not the development of the three-and-more state model itself (which already existed), but the application of the three-and-more state state-space model to the probability modelling of these power plant units. There are no examples of this in the English- or German-language literature. One of the main reasons for this is that the power systems of countries most advanced in the development and application of probability-theory studies do not contain a large proportion of cogeneration, and the problem thus carries less urgency. For the same reason, neither is there a precedent in the foreign literature for the computational procedure proposed in this thesis for determining of the input data describing the probability behaviour of power plant units, as required for the three-and-more state modelling of back-

pressure and extraction condensing power plant units. A further novelty of the proposal is that the probability of operation with reduced capacity, i.e. of occupation of this operating state, is determined from the duration diagram of the ambient temperature.

The survey of German- and English-language literature, therefore, has established that findings of this thesis are not contained in existing publications.

## 2. Conclusion 1

### 2.1 Definition of LOLP

Calculation of LOLP is covered in detail in [1] and [2]. LOLP is defined by the relation:

$$g = \sum_j P(C = C_j)P(L > C_j). \quad (2.1-1)$$

where

$g$	is LOLP [-];
$P$	is the probability [-];
$C$	is the system-level available power capacity in one test interval [MW];
$C_j$	is a specific value of system-level available power capacity [MW];
$L$	is the system-level load [MW].

This relation shows LOLP to be the joint probability that the available power capacity in the system has magnitude  $C = C_j$  [MW] and that the system-level load ( $L$  [MW]) is greater than this.

LOLP calculations require determination of the probability distribution (probability distribution function) of the system-level power demand and the probability distribution function of the instantaneous available power capacity of the power plant system. The system-level probability distribution function may be determined by combinatoric means from the distribution function of available power capacity of each power plant units, taking account of all possible capacity configurations of the system. The objective is therefore to find the probability distribution function of the instantaneously available power capacity of each power plant unit – in other words, to determine the probability of each power plant occupying each of its defined operating states. This allows determination of the availability factor and failure factor for each operating state. These reliability characteristics constitute the input data for LOLP calculations.

### 2.2 Statement of Conclusion 1

The differentiated reliability description (=three-and-more state reliability modelling) of extraction condensing and back-pressure power plant units is made possible by determining, for each power plant unit, the distribution function for the probability of occupation of its operating states. A precondition for the three-and-more state reliability description of power plant units, therefore, is knowledge of the distribution of the occupation probabilities of all defined operating states (during the period of study). The two-state reliability description assumes that the power plant unit exclusively occupies either the “failed, zero capacity” or “operational at full capacity” operating states. The discrete probability distribution function required for the two-state reliability description may be defined from the fault statistics of each power plant unit. The three-and-more state reliability description calls for statistical data which is not available in the great majority of cases. The control technology of extraction condensing and back-pressure power plant units, however, is such that their current available maximum power capacity is a function of the average daily ambient temperature, because the majority (80-90%) of these units operate as heat sources for heating systems, and this makes possible their three-and-more state reliability description. This fact is stated in **Conclusion 1**:

*The random variable representing the maximum available power capacity of extraction condensing and back-pressure power plant units ( $\chi_{LPP_{max}}$ ) is a transform of the random variable representing the daily average ambient temperature ( $\zeta_{Tk}$ ). Consequently, the probability distribution and distribution function ( $F_{\chi_{LPP_{max}}}$ ) of the instantaneous maximum available power capacity of these power plant units may be defined on the basis of the known probability distribution and distribution function ( $F_{\zeta_{Tk}}$ ) of the ambient temperature at the given place and period.*

It should be stressed that the novelty content of this conclusion lies not in the fact that the instantaneous maximum available power capacity of these power plant units is a function of instantaneous heat output and therefore of average daily ambient temperature, but in the recognition that this relationship permits their three-and-more state reliability description by virtue of the desired random variable ( $\chi_{LPP_{max}}$ ) being a transform of the random variable ( $\zeta_{Tk}$ ). This permits calculation of the probability of occupation of each defined operating state (in the test period). **Conclusion 1** follows from the arguments given below.

### 2.3. Brief exposition of Conclusion 1

Extraction condensing and back-pressure power plant units obey the relation

$$L_{PP_{max}} = f(\dot{Q}(T_k)). \quad (2.3.-1)$$

Here,  $\dot{Q}$  ([MW]) is the current heat output of the power plant unit. The ambient temperature and, consequently, its daily average vary randomly in time. In the description of this random process, event space  $\Omega_{E_i}$  is filled by event elements  $E_i: \Omega_{E_i} = \{E_1, E_2, \dots, E_i, \dots, E_n\}$ . Every event element  $E_i$  occurs when the daily mean ambient temperature ( $T_k$ ) falls in the range  $-(T_{k,i-1}, T_{k,i}]$ . The probability distribution of the daily mean ambient temperature is known for each geographical point. This means that in a given geographical region, in the average over a specific period, the probability of occurrence of each temperature, i.e. for each possible value of the random variable  $\zeta_{Tk}$ . The distribution function is defined as

$$F_{\zeta_{Tk}}(T_k) = P(\zeta_{Tk} < T_k) \quad (2.3-2)$$

extraction condensing and back-pressure steam-turbine power plant units operate as heat sources for heat consumers whose instantaneous heat demand changes in proportion to the daily average ambient temperature (2.3.-1). The power plant unit heat output is defined by the relation

$$\dot{Q}_i = f(T_{k,i}) \quad (2.3-3)$$

The maximum power output of extraction condensing and back-pressure power plant units is a function of current temperature, i.e. obeys the relation

$$L_{PP_{max,i}} = f(\dot{Q}_i) \quad (2.3-4)$$

Consequently, instantaneous available power capacity (= maximum possible power output at the given heat output) varies with daily average ambient temperature as follows:

$$L_{PP_{max,i}} = f(T_{k,i}) \quad (2.3-5)$$

It is thus possible to determine the related quantities  $T_{k,i}$ ,  $\dot{Q}_i$  and  $L_{PP\max,i}$ , i.e. for the occurrence of random event  $E_i$ , the resulting values of  $\dot{Q}_i$  and  $L_{PP\max,i}$  may be obtained. Analogously, the random variable  $\zeta_{Tk}$  may be used to define the power plant heat output random variable  $\omega_Q$  and the power plant maximum power output (=maximum available power capacity) random variable  $\chi_{LPP\max}$ . From relations (2.3-1), (2.3-3), (2.3-4) and (2.3-5),

$$\omega_Q = \omega_Q(\zeta_{Tk}), \quad (2.3-6)$$

$$\chi_{LPP\max} = \chi_{LPP\max}(\omega_Q) \quad (2.3-7)$$

and finally

$$\chi_{LPP\max} = \chi_{LPP\max}(\zeta_{Tk}). \quad (2.3-8)$$

This means that the power plant heat output random variable  $\omega_Q$  and the power plant maximum power output (=maximum available power capacity) random variable  $\chi_{LPP\max}$  are both transforms of the daily average ambient temperature variable  $\zeta_{Tk}$ .

The probability distribution of each random variable and its transform may be determined from the following theorem: if  $\xi$  is a discrete random variable whose possible values are the numbers  $x_1, x_2, \dots$ , and  $y = r(x)$  is an arbitrary function, then the distribution of the random variable  $\eta = r(\xi)$  is defined by the probabilities

$$P(\eta = y_k) = \sum_{r(x_i)=y_k} P(\xi = x_i), \quad (k = 1, 2, \dots), \quad (2.3-9)$$

where  $y_1, y_2, \dots$  are non-equal values of  $r(x_1), r(x_2), \dots$ . This follows from the fact that an event  $\eta = y_k$  occurs if and only if the value  $x_i$  taken by  $\xi$  is the value for which  $r(x_i) = y_k$ . Clearly,

$$\sum_k P(\eta = y_k) = 1. \quad (2.3-10)$$

In general, therefore, it may be stated that

$$P(\chi_{LPP\max} = L_{PP\max,r}) = \sum_{L_{PP\max}(T_{k,i})=L_{PP\max,r}} P(\zeta_{Tk} = T_{k,i}), \quad (r = 1, 2, \dots). \quad (2.3-11)$$

This statement may naturally also be expressed for the heat outputs, in which case it takes the form:

$$P(\omega_Q = \dot{Q}_r) = \sum_{\dot{Q}(T_{k,i})=\dot{Q}_r} P(\zeta_{Tk} = T_{k,i}), \quad (r = 1, 2, \dots). \quad (2.3-12)$$

## 2.4 Author's publications related to Conclusion 1

The author's own publications related to **Conclusion 1** are: [9], [**14**], [**15**], [**16**], [**17**], [20], [21], [22], [23], [24], [25], [26], [27]. Those published in impact factor journals are in bold type.

## 3. Conclusion 2

### 3.1. Statement of Conclusion 2

The calculation procedure presented above may be greatly simplified in practice. It is possible to derive the desired probability distribution function via a special transformation of the duration diagram of the daily average ambient temperature. This is stated in **Conclusion 2**, as follows:

*The probability distribution function of the maximum available power capacity as a random variable ( $\chi_{LPP_{\max}}$ ) may be derived via special transformations from the duration diagram of the daily average ambient temperature for a given geographical location ( $T_{k,i}$ ). This is possible in the "proportional" range, i.e. in the range of output in which the maximum available power capacity of the power plant unit ( $L_{PP_{\max,i}}$ ) has a direct correspondence with the daily average ambient temperature ( $T_{k,i}$ ).*

### 3.2 Brief exposition of Conclusion 2

Where  $T_k$  [°C] represents the daily average ambient temperature and  $t_k$  [°C] is an arbitrary temperature value,  $D(t_k)$  [h] gives the duration within a test period when the relation  $T_k \geq t_k$  holds, i.e. the number of hours during the reference period when the daily average ambient temperature is greater than or equal to a specified temperature  $t_k$  [°C]. The duration diagram of the daily average ambient temperature for the period under examination may be determined from meteorological statistical data for the given geographical location. The daily average ambient temperature duration diagram for a given period may be rendered into a daily average ambient temperature random variable via a multi-step transformation. The first step is to transform the time values on the abscissa into relative time values. The values on the abscissa of the resulting diagram may be viewed as probabilities that the daily average ambient temperature is greater than or equal to the corresponding daily average ambient temperature value, i.e. the probability  $P(T_k \geq t_k)$ . The second transformation step is to exchange the abscissa and the ordinate. This puts probabilities on the ordinate and daily average ambient temperature values on the abscissa. The curve obtained from these two transformations may be viewed as the complementary curve of the distribution function of the random variable  $T_k$ , i.e.

$$d(t_k) = 1 - F_{T_k}(t_k) \quad (3.2-1)$$

In this relation,

$d(t_k)$  is the relative duration [-], when  $T_k \geq t_k$ , ( $D(t_k)/\tau$ );  
 $F_{T_k}(t_k)$  is the probability distribution function of random variable  $T_k$   
 $\tau$  reference time interval [h].

It follows that the probability distribution function of random variable  $T_k$  is defined by the relation

$$F_{T_k}(t_k) = 1 - d(t_k) \quad (3.2-2)$$

and this gives the relative duration in which  $T_{k,i} < T_k$ . The relative duration may be viewed as a probability. Then the relative duration is equivalent to the probability that  $T_{k,i} < T_k$ , i.e.

$$F_{T_k}(t_k) = P(T_k < t_k). \quad (3.2-3)$$

$F_{T_k}(t_k) = P(T_{k,i} < t_k)$ , and so gives the probability that the daily average ambient temperature ( $T_{k,i}$  [°C]) is smaller than  $t_k$ . The relation thus defined may be proved to satisfy the requirements of a distribution function

### 3.3 Author's publications related to Conclusion 2

The author's own publications related to **Conclusion 2** are: [9], [**14**], [**15**], [20], [21], [22], [23], [24], [25], [26], [27]. Those published in impact factor journals are in bold type.

## 4. Conclusion 3

### 4.1 Statement of the conclusion

The findings of **Conclusions 1** and **2** permit definition of the probability that extraction condensing and back-pressure power plant units occupy each of their defined operating states, i.e. the unconditional probability of occupation of each operating state. **Conclusion 3** may thus be expressed as follows:

*A three-or-more state state-space description is proposed for extraction condensing and back-pressure steam turbine power plant units in reliability calculations for power generation systems and power plant subsystems in cases when such power plant units are predominantly (81-91 %) used to satisfy heat demands of heating systems or processes with well-known characteristics.*

### 4.2 Brief exposition of Conclusion 3

The thesis presents reliability modelling of power plant units using a state-space description method. This involves characterising each power plant unit or power plant system (power plant units in the power plant system) with defined operating states and probabilities of transitions among these states. For reliability purposes, the states of a power plant unit or power plant system are given in terms of the probability distribution of the operating states which power plant units constituting the power plant system may occupy at a given time. The state of the system or operating state of the power plant unit at a given time is clearly defined if the probability distribution of possible operating states and system configurations are known for that time. The operating states which are customarily defined include “operational at full capacity”, “failed (non-operational)”, “operational at reduced capacity”, “in reserve”, “failed in reserve”, etc. The advantage of the state-space description method is that – in the great majority of cases – the transition from one system state to another may be described using the Markov model, and the changes in system states by successive applications of this. A condition of applying the Markov model is that the probability of transition by each system element from one operating state to another depends only on the operating state immediately preceding the change of state and does not depend on any previous system states, i.e. on the operating states the power plant unit was in several steps before the given operating state change. The same is true for system configuration changes. The random state changes of power plant units and the configuration changes of power plant systems may be described by discrete time-parameter, discrete state-space Markov chains and continuous time-parameter, discrete state space Markov processes. The thesis presents the application of the method in both cases.

Owing to the time scale of studies involved in reliability analysis of power generation systems, the probability distribution of interest is that which develops in the long term. The problem thus narrows to determination of the long-term or stationary probability distribution for these models. For the power

plant units under study, the occupation of operating states will follow the stationary distribution in the long term. There arises the fundamental questions as to whether the stationary distribution can be proved to exist in these cases and, if so, how it may be determined, preferably by a simple method. The first question may be answered by finding whether the Markov chains describing the operation of extraction condensing and back-pressure power plant units are ergodic. The thesis gives a proof that the Markov chains describing the random operation of power plant units are in fact ergodic Markov chains, and so the desired stationary distribution exists.

### 4.3 Author's publications related to Conclusion 3

The author's own publications related to **Conclusion 3** are: [1], [2], [9], **[14]**, **[15]**, **[16]**, **[17]**, **[18]**, **[19]**, [20], [21], [22], [23], [24], [25], [26], [27]. Those published in impact factor journals are in bold type.

## 5. Conclusion 4

### 5.1 Statement of Conclusion 4

The most important calculated quantities for the description of the reliability behaviour of power plant units and for LOLP calculations are the availability factor and the failure factor. The availability factor gives the proportion of time in which the power plant unit is operational. The failure factor is defined in a similar way, being the non-operational time as a proportion of the total reference time. **Conclusion 4** gives definitions of availability and failure factors for each operational operating state in the case of a three-and-more state reliability description.

*For extraction condensing and back-pressure steam-turbine power plant units, the availability factor for each operational operating state ( ${}^d K_{Ui}$ , [-]) may be calculated as the time of occupation of each operational operating state as a proportion of the total reference period. This relative time may be determined from the probability distribution function of the maximum available power capacity, and represents the probability that at any time the power plant unit occupies that operating state. The availability factor for all of the power plant unit's operational operating states may be determined with the constraint that the periods of occupation of the operational and failed operating states add up to the total reference period. The failure factor ( ${}^d K_D$ , [-]) may be calculated in the usual way.*

### 5.2. Brief exposition of Conclusion 4

Extraction condensing and back-pressure steam-turbine power plant units obey the following relations:

$$\sum_{i=1}^{i=d-1} {}^d T_{Ui} + {}^d T_D = {}^d T \quad (5.2-1)$$

$$\begin{aligned} {}^d K_{Ui} &= \frac{{}^d T_{Ui}}{{}^d T} = \frac{{}^d T_{Ui}}{(\sum_{i=1}^{d-1} {}^d T_{Ui}) + {}^d T_D} = P(L_{PP,max,Ui a} \leq \chi_{LPP,max} < L_{PP,max,Ui f}) = \\ &= F_{\chi_{LPP,max}}(L_{PP,max,Ui f}) - F_{\chi_{LPP,max}}(L_{PP,max,Ui a}) \end{aligned} \quad (5.2-2)$$

$${}^d K_D = \frac{{}^d T_D}{{}^d T} = \frac{{}^d T_D}{(\sum_{i=1}^{d-1} {}^d T_{Ui}) + {}^d T_D} \quad (5.2-3)$$

In the foregoing:

$d$	is the number of possible defined operating states [-];
${}^d T_{U_i}$	is the duration of occupation of the $i$ th operational operating state [h];
${}^d K_{U_i}$	is the availability factor for the $i$ th operational operating state [-];
${}^d T_D$	is the duration of occupation of the “failed” operating state [h];
${}^d K_D$	is the failure factor for the “failed” operating state [-];
${}^d T$	is the total duration of the reference period [-];
$L_{PP,max,U_{ia}}$	is the lower limit of the output range of the $i$ th operational operating state [MW];
$L_{PP,max,U_{if}}$	is the upper limit of the output range of the $i$ th operational operating state [MW];

### 5.3 Author’s publications related to Conclusion 4

The author’s own publications related to **Conclusion 4** are: [9], [14], [15], [17], [18], [20], [21], [22], [23], [24], [25], [26], [27]. Those published in impact factor journals are in bold type.

## 6. Conclusion 5

### 6.1. Statement of Conclusion 5

A further important item of input data for LOLP computations is the average power capacity for each defined operational operating state ( $\overline{L_{PP,U_k}}$  ([MW])). **Conclusion 5** states the principle of determination this average capacity as follows:

*The principle of calculation of the average capacity for each defined operational operating state is that the electrical energy actually output during occupation of a given capacity range should be equal to the energy output calculated with the average value. The average power in the  $k$  th operational operating state ( $\overline{L_{PP,U_k}}$  ([MW])) is the probability of occurrence-weighted sum of power*

*values in the operating state ( $\sum_{i \in G_{U_k}} p_i L_{PP,max,i}$ ) divided by the sum of the probabilities of the power*

*values ( $\sum_{i \in G_{U_k}} p_i$ ).*

The results of this computation permit the determination, by combinatoric means, of the possible system capacity configurations. The purpose of determining the possible system capacity configurations is to determine the probability distribution functions of the power capacity available at system level. Knowledge of this probability distribution and the probability distribution of system load permits direct calculation of LOLP.

### 6.2 Author’s publications related to Conclusion 5

The author’s own publications related to **Conclusion 5** are: [14], [15], [17], [18], [20] [27]. Those published in impact factor journals are in bold type.

## OF Summary of results

The question naturally arises as to how much the newly-developed procedure improves the accuracy of computation. *Experience has shown improvement in accuracy of 10-30%. The greatest improvement is found in cases where there are considerable temperature swings during the test period.*

The new computation procedure is applicable to the three-and-more state reliability description of extraction condensing and back-pressure power plant units where the heat output is *predominantly* generated for heating purposes, i.e. heat output is proportional to daily average ambient temperature. The reason for such a strict constraint on the area of application is that the probability distribution of maximum available power capacity for such power plant units may be derived from the probability distribution of the daily average ambient temperature. This is because the three-and-more state reliability description assumes a knowledge of the probability of occupation of each defined operating state. *This also means that the new computation procedure is applicable in all cases when there is a means for determining the probability distribution of the defined operating states.*

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