ON CALCULATION OF THE TIME OF MAXIMUM LOSSES BY LOAD GRAPH

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Introduction

The determination of active energy losses is important in technical and economical aspects [1;2]. Most simple and effective way of determining the energy losses is to measure the active energy on both sides of the line. The difference in the readings of an electricity meter on both line ends gives the sought-for value of energy losses. All losses are taken into account, included corona losses. The task can be implemented also by way of calculation, for example by program MUSTANG [3]. But this method can't be used for distribution grids because they are too complicated and ramified (besides, in these grids the corona losses are too small to be taken into account). The no-load losses can be estimated precisely enough as concerns those of the transformer. However to determine the load losses is much more difficult task. One of the methods targeting this goal is based on the use of the utilization time of maximum power losses (UTL), τ [1;2]. According to this method, energy ΔA of load losses can be expressed as

$$\Delta A = \frac{R S_{\max}^{2}}{U_{nom}^{2}} \tau , \tag{1}$$

where τ is the UTL for load S during time span T; S_{max} – maximum load over time span T.
If the maximum loads and UTL values are known one can calculate the energy losses in the considered time interval, since it is necessary to find UTL values as precise as possible.

Consideration of proposed UTL calculation methods

The consideration will be carried out applying relative values [4]: time t^*, maximum load time (MLTR) T_m^*, utilization time of maximum power losses (UTLR) τ^*, load S^*, and the minimum load S^*_{min}, are defined as follows:

$$t^* = \frac{t}{T} \text{ or } t^* = \frac{i}{N}; \quad T_m^* = \frac{T_m}{T}; \tau^* = \frac{\tau}{T}; S^* = \frac{S}{S_{\max}}; \quad S_{\min}^* = \frac{S_{\min}}{S_{\max}}, \tag{2}$$

where T is the time interval within which the calculations are made; i and N stands for t and T in discrete measurement procedure.
The relative load time characteristics: T_m^* and τ^* can be expressed through the relative load time function $f(t^*)$:

$$T_m{}^* = \frac{\int_0^1 S_{\max} f(t^*)dt^*}{S_{\max}} = \int_0^1 f(t^*)dt^* \; ; \tau^* = \frac{\int_0^1 (S_{\max} f(t^*))^2 dt^*}{S_{\max}{}^2} = \int_0^1 f^2(t^*)dt^* \; ; f(t^*) = \frac{S(t^*)}{S_{\max}}, \quad (3)$$

$f(t^*)$ changes within the limits $1 \geq f(t^*) \geq 0$ (see (Fig.1).

When expression $\int_0^1 S_{\max} f(t^*)dt^*$ instead of S_{max}, is related to another value, (e.g. $k_S S_{max}$), then we will have

$$T_m^{*r} = \frac{\int_0^1 S_{\max} f(t^*)dt^*}{k_S S_{\max}} = \frac{\int_0^1 f(t^*)dt^*}{k_S} = \frac{T_m^*}{k_S}; \quad \tau^{*r} = \frac{\int_0^1 (S_{\max} f(t^*))^2 dt^*}{k_S^2 S_{\max}^2} = \frac{\int_0^1 f(t^*)dt^*}{k_S^2} = \frac{\tau^*}{k_S^2}. \quad (4)$$

To approach solving the question, we must consider the graph of load duration curve (LDC) in general, which is shown in Fig.1. The area below load duration curve can be divided in two parts: the lower part will be called LDC-base and the upper one – LDC-delta . It can be seen that

$$f(t^*) = S_{\min}^* + f_\Delta(t^*) \quad (5)$$

and that the maximum load time is

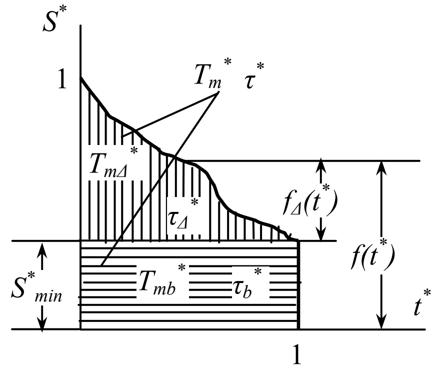

Fig.1. The decomposed graph of load duration curve

S_{max} – maximum load in time interval T; $T_m{}^*$, τ^* - relative values of MLT and UTL for entire LDC grapf; $T_{mb}{}^*$, $\tau_b{}^*$ – relative values of MLT- base, UTL – base (for base part of LDC graph); the same: $T_{m\Delta}{}^*$, $\tau_\Delta{}^*$ - for MLT- delta, UTL – delta (for the upper part of LDC graph); S^*, $S_{min}{}^*$, $S_{max}{}^*$ – relative values of S, S_{min}, S_{max}.

$$T_m^* = \int_0^1 (S_{\min}^* + f_\Delta(t^*))dt^* = S_{\min}^* + T_{m\Delta}^* = T_{mb}^* + T_{m\Delta}^*. \quad (6)$$

MLT- base ($T_{mb}{}^*$) and MLT- delta ($T_{m\Delta}{}^*$) are correspondingly:

$$T_{mb}^* = S_{\min}^* ; \quad T_{m\Delta}^* = \int_0^1 f_\Delta(t^*)dt^* . \quad (7)$$

But the utilization time of power losses will be

$$\tau^* = \int_0^1 (S^*_{\min} + f_\Delta(t^*))^2 dt^* = S^{*2}_{\min} + 2S^*_{\min} T^*_{m\Delta} + \tau^*_\Delta , \qquad (8)$$

where τ_Δ^* stands for UTL-delta (see Fig.1). Applying above considered decomposition of load duration curve, the more precise determination of UTL can be received as compared with Kazevich formula [1]. More detail are in other yet unpublished paper.
Yet this method of LDC graph decomposition is applied in this paper for more precise calculation of UTL using maximum load time MLT as well as for determination of UTL after load graph.

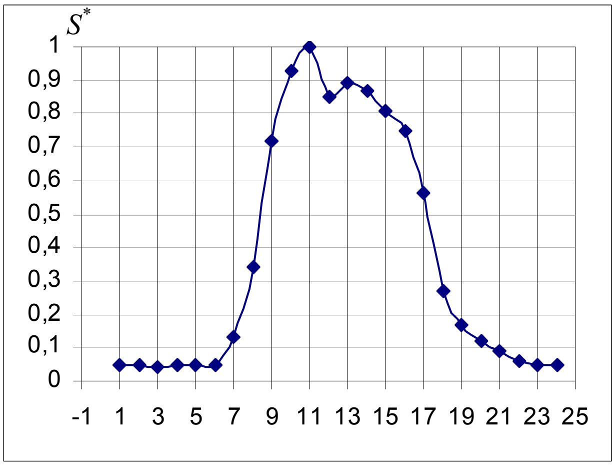

Fig.2. Daily load graph of a printing

In Fig.2, load curve of a printing house at winter time day is presented, after data rendered by the Institute of Physics and Energetics of Latvian Academy of Sciences. It can be seen that load is changing swiftly. And the question appears, how it is better to consider each load graph element: as a column with triangle top (Fig.3a) or a column with horizontal top (Fig.3b). To solve this question, it is necessary that MLT of both columns are equal. This can take place when

$$T^{*r}_{m\Delta} = T^{*r}_{m\Pi} = 0{,}5 . \qquad (9)$$

The reduced UTL for right triangle τ_Δ^* and for rectangle $\tau_{\square}^*$ are:

$$\tau^{*r}_\Delta = \int_0^1 t^{*2} dt = \frac{1}{3}; \qquad \tau^{*r}_\Pi = \int_0^1 0{,}5^2 dt^* = 0{,}25 . \qquad (10)$$

From (8), observing (3) – (7); (9); (10), we receive the UTL for load graph element number i with triangle top and for load graph element number i with rectangle top:

$$\tau^*_{\Delta i} = S^*_{i-1}(S^*_{i-1} + \Delta S^*_i) + \frac{1}{3}\Delta S^{*2}_i ; \quad \tau^*_{\Pi i} = S^*_{i-1}(S^*_{i-1} + \Delta S^*_i) + 0{,}25\Delta S^{*2}_i , \qquad (11)$$

the increment ΔS_i^* (Fig.3) is:

$$\Delta S_i^* = S_i^* - S_{i-1}^*; \quad \Delta S_1^* = S_1^* - S_N^* \quad \Delta S_N^* = S_N^* - S_{N-1}^* \tag{12}$$

where i and N – current and total number of measurements. Such an expression for ΔS_1^* is because load graph has an uninterrupted periodical character. Just for this reason

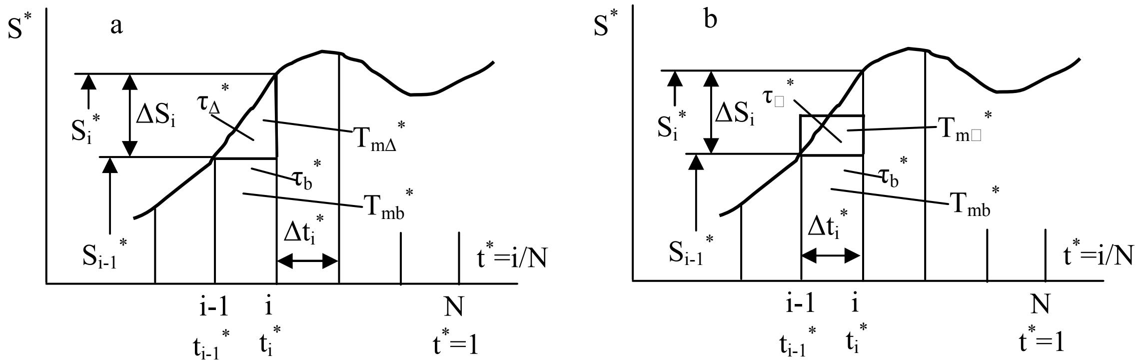

Fig.3. LDC graph decomposition in elements of time intervals Δt^* and each column in base part and upper part; a – upper part graph element is reduced to right triangle; b – upper part of graph reduced to rectangle

usually $S_1^*=S_N^*$; $\Delta S_i^*=0$ *and* $\tau_{\Delta 1}=S_1^{*2}$.

Now we can determine the relative difference between UTL of element i with rectangle top and of element with triangle top (in percents), where $\tau_{\Delta i}^*$ is considered as more accurate value. The results are shown in table 1.

$$\Delta\tau_i,\% = \frac{\tau_{\Pi i}^* - \tau_{\Delta i}^*}{\tau_{\Delta i}^*}100 = -\frac{0{,}0833\Delta S_i^{*2}}{S_i^*(S_i^* + \Delta S_i^*) + 0{,}3333\Delta S_i^{*2}}100 \tag{13}$$

The relative difference for entire load graph is:

$$\Delta\tau,\% = \frac{\sum_1^N(\tau_{\Pi i}^* - \tau_{\Delta i}^*)}{\sum_1^N \tau_{\Delta i}^*} = -\frac{0{,}0833\sum_1^N \Delta S_i^{*2}}{\sum_1^N S_i^*(S_i^* + \Delta S_i^*) + 0{,}3333\Delta S_i^{*2}}100 \tag{14}$$

This difference (error) $\Delta\tau^*$, *%* was calculated for three customers with explicit load curve inconsistency: a farm of unspecified occupation in summer $\Delta\tau^*$=0,5 %; a timber frame without drying room in winter $\Delta\tau^*$*=1 %*; printing house in winter (Fig.2) $\Delta\tau^*$*=0,5 %.* For smoothly changing load curve the error will be still less. The consideration shows that the difference is small. The method of load graph element with triangle top can be taken as more accurate one because triangle hypotenuse more closely fits to load curve line segment (see Fig.2;3); applying this method, the measurements can be less frequent.

Table 1

Values of $\Delta\tau_i$, % after expression (14)

S_i^*	ΔS_i^*, %					
	0,1	0,2	0,3	0,5	0,7	1
0,1	-3,57	-7,69	-10,71	-14,53	-16,78	-18,79
0,3	-0,68	-2,04	-3,57	-6,44	-8,81	-11,52
0,5	-0,27	-0,92	-1,74	-3,57	-5,35	-7,69

0,7	-0,14	-0,52	-1,03	-2,26	-3,57	-5,47
1	-0,08	-0,27	-0,56	-1,52	-2,19	-3,57

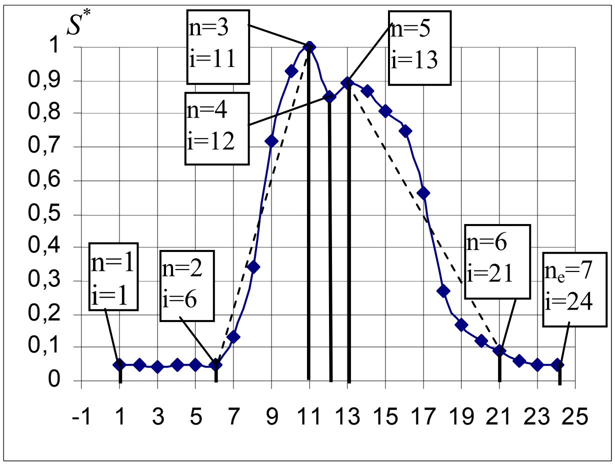

Fig.4. UTL determination on the base of decomposed load graph

Just for this reason, the method of UTL estimation, which is based on load time curve bearing points: the bending points and the flex points, can be proposed. The method renders the possibility to estimate UTL directly from load graph avoiding building the load duration curve. In Fig.4, the bending points are n_3, n_4 and n_5; the flex points – n_2 and n_6. The load graph is split on 7 columns contained between adjacent bearing points: the 1st column ($n=7$)–($n=1$); the 2nd one ($n=1$)- ($n=2$); the 3rd ($n=2$)–($n=3$) ... the 7th ($n=6$)–($n=7$). The UTL τ_n^* of each number n column, calculated analogically to (8) as well as MLT T_{mun}^*, UTL τ_{un}^* of the column upper part (upper part is with subscript "u") and UTL of entire graph τ^* are:

$$\tau_n^* = (S^*_{\min n} + 2S^*_{\min n}T^*_{mu\,n} + \tau^*_{un})(t^*_n - t^*_{n-1});$$

$$T^*_{mun} = k_n^{(Tm)}\Delta S_n^*;\ \tau^*_{un} = k_n^{(t)}\Delta S_n^{*2} \qquad (15)$$

$$\tau^* = \sum_{n=1}^{n=n_e}\tau_n^*$$

where S_{minn}^* - the less S^* value of two bearing points of the n^{th} column; t^* - see (2); ΔS_n^*; $k_n^{(Tm)}$; $k_n^{(\tau)}$ – see table 2. Choosing bearing points the attention must be paid that by double-sided digression of the load curve from hypotenuse (Fig.5a) the load curve crosses hypotenuse approximately in its middle point. The value of $k_n^{(Tm)}$ and $k_n^{(\tau)}$ depends on the degree the load curve of the upper part of actual graph column digresses from straight line, that is, it depends on a ratio h/λ (Fig.5; table 2). Of course, this dependence is not strict because the load curve within its column can not be so nice as it is in Fig.5.

Table 2

Quantities for formulas (15)

Fig.	ΔS_n^*	λ	h/λ	$k^{(Tm)}_n$	$k^{(\tau m)}_n$
5a	$S_n^*-S_{n-1}^*$	$S_n^*-S_{n-1}^*$	0; 075; 0,15	0,5; 0,5; 0,5	1/3; 0,36; 0,4
5b	$S_n^*-S_{n-1}^*$	$S_n^*-S_{n-1}^*$	0; 0,16; 0,32	0,5; 0,6; 0,7	1/3; 0,45; 0,48
5c	$S_n^*-S_{n-1}^*$	$S_n^*-S_{n-1}^*$	0; 0,16; 0,32	0,5; 0,4; 0,3	1/3; 0,25; 0,18
5d	h	$t_n^*-t_{n-1}^*$ or $(i_n-i_{n-1})/N$	0; 0,15; 0,3	0; 0,095; 0,01	0; 0,01; 0,045
5e	$-h$	$t_n^*-t_{n-1}^*$ or $(i_n-i_{n-1})/N$	0; 0,15; 0,3	0; 0,095; 0,01	0; 0,01; 0,045

The actual shapes of column upper parts will differ from those the coefficients $k_n^{(Tm)}$ and $k_n^{(\tau)}$ were calculated for and measurements of h and λ can be only approximate, however, taking into account that the upper parts constitute only small part of the column, these inaccuracies and deviations do not play a significant role. In table 2 only three values of ratio h/λ are given, bearing in mind that for any other value of h/λ the interpolation can be used.

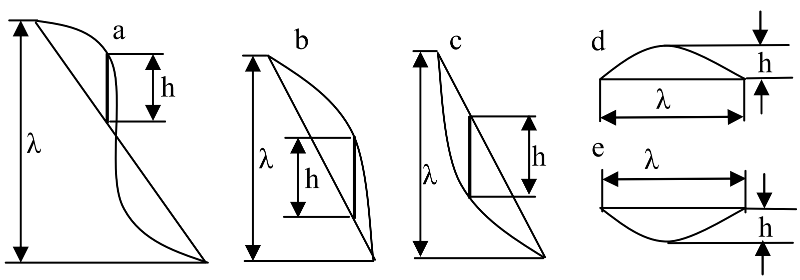

Fig.5. Quantities of load graph column upper

For rough estimation one can assume $h=0$ and then calculations become simple enough.
As an example, the worst case was taken when load curve goes strongly up and down: the UTL of load graph Fig.4 was calculated; by rough calculation τ^*=0,239, whereas accurate procedure gives the result 0,27 while the real number is 0,269.

Conclusions

1. Applying load duration graph decomposition more precise determination of UTL can be achieved.
2. UTL calculated by method of the elements with rectangle top differs only slightly from UTL calculated by more accurate method of elements with triangle top provided the measurement number is not less then 24 in considered time interval.
3. Applying method of decomposition of load graph into columns, the UTL can be estimated with sufficient precision basing directly on load graph picture, avoiding load duration curve building.

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Survilo J. Maksimālo zudumu laika aprēķins pēc slodzes grafika.
Maksimālo zudumu laiks (MZL) tiek lietots, nosakot enerģijas zudumus tīklos. Jo precīzāk ir noteikts MZL, jo precīzāk var aprēķināt enerģijas zudumus. Izmantojot MZL aprēķinam maksimālās slodzes laiku, labāku rezultātu var iegūt, sadalot slodzes ilguma grafiku (SIG) divās daļās: bāzes daļā un delta daļā. Ņemot vērā, ka delta daļa aizņem SIG mazāku laukumu, mērķis ir sasniegts, jo kļūdu var ieviest tikai delta daļas aprēķina neprecizitāte. Uz šīs metodes pamata var rēķināt MZL tieši no slodzes laika grafika un sasniegt tādu pašu precizitāti kā ar klasisko metodi, izmantojot aprēķinam mazāku mērījumu skaitu. Vēl, modificējot šo metodi, ir iespējams vērtēt MZL tieši no slodzes laika grafika attēla, balstoties uz tā nesošajiem punktiem, kuri ir slodzes laika līknes vietējie ekstrēmumi un lieces punkti. Slodzes laika grafiks tiek sadalīts stabiņos, katrs stabiņš ietilpst starp diviem blakus esošiem nesošajiem punktiem. Tiek aprēķināts katra stabiņa MZL. Visu stabiņu MZL summa ir meklējamais rezultāts. Rēķinot stabiņa MZL, ņem vērā minimālo slodzes vērtību stabiņa robežās, kā arī stabiņa augšējās daļas maksimālo slodzes laiku un MZL. Abi pēdējie lielumi ir atkarīgi no slodzes līknes novirzīšanās no taisnas līnijas stabiņa robežās.

Survilo J., On calculation of the time of maximum losses by load graph.
Utilization time of maximum power losses (UTL) has been applied for determination of energy losses in power grids. The UTL is a parameter allowing for accurate estimation of energy losses. Using the maximum load time for UTL determination, better results can be achieved by decomposing the load duration graph (LDG) into two parts: the base and the delta ones. Bearing in mind that the latter occupies a smaller area of the entire LDG, the goal is achieved, since the errors can be caused only by the inaccuracy of delta part calculation. Based on this method it is possible to calculate UTL directly from the load graph and to achieve the same accuracy as with the classical method and with a smaller number of load measurements needed. By modifying this method once again, we can estimate UTL from the load graph based on its bearing points which are bending and flex points of the load time curve. The load time graph is decomposed into columns, each of them being contained between two neighboring bearing points. The UTL of each column is calculated to obtain the total UTL, which is the sought-for value. The UTL of a column takes into account the minimum load value within the column, the maximum load time and the UTL of its upper part; both of the last quantities depending on the degree of the load curve diversion from a straight line.

Сурвило И., Определение времени максимальных потерь по графику нагрузки.
Время максимальных потерь (ВМП) применяется при определении потерь энергии в сетях. Чем точнее определено ВМП, тем с меньшей погрешностью могут быть рассчитаны потери энергии. Используя при расчете ВМП время максимальной нагрузки более точный результат возможно получить разложив график длительности нагрузки(ГДН) на две части: на базовую часть и на дельта часть. Принимая во внимание, что дельта часть занимает меньшую площадь ГДН, цель достигнута, так как ошибку может внести только неточность расчета базовой части. На основе этого метода возможно рассчитывать ВМП непосредственно по графику нагрузки и получить такую же точность, как используя классический метод, с меньшим количеством замеров нагрузки. Еще модифицируя этот метод, ВМП может быть оценен по картине графика нагрузки, опираясь на несущие точки, которыми являются местные экстремумы и точки перегиба кривой нагрузки. Временной график нагрузки разбивается на столбцы. Каждый столбец заключен

между двумя соседними несущими точками. Рассчитывается ВМП каждого столбца. Сумма ВМП всех столбцов есть искомый результат. Рассчитывая ВМП столбца, принимается во внимание минимальная нагрузка в пределах столбца а также время максимальной нагрузки и ВМП верхней части столбца. Две последние величины зависят от степени отклонения кривой нагрузки в пределах столбца от прямой линии.