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Pareto - ABC Analysis of High Voltage Single Core Cable Temperature

***Abstract**. The paper presents the "Pareto Principle"used for the analysis of a multi-parameter temperature field in a single phase high voltage cable core of* 110kV. *The study makes use of a multi-criteria Pareto model and ABC charts to determine the qualitative and quantitative impact of some specific parameters on the temperature of the cable core.*

Streszczenie.** W pracy przedstawiono „zasadę PARETO" dla analizy wielo-parametrowej temperatury rdzenia kabla wysokiego napięcia* 110kV *pracującego w układzie pojedynczym. W analizie wykorzystano wielo-kryterialny model PARETO oraz wykresy ABC w celu ilościowego i jakościowego zidentyfikowania wpływu określonych parametrów na temperaturę rdzenia kabla.* (Pareto-ABC analiza temperatury żyły kabla wysokiego napięcia).***

Keywords: Pareto principle, *ABC* charts, temperature field, temperature core,110kV cables, *FEM*.
Słowa kluczowe: Zasada PARETO, wykresy *ABC*, pole temperatury, temperatura dopuszczalna, kable 110kV, *MES*.

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Introduction

The creator of the "Pareto principle" (1887) was a professor at the University of Lausanne, Vilfredo Pareto. In examining the distribution of income in Italy he discovered that 80% of the assets were owned by 20% of the entire population. Further studies confirmed the presence of this rule in many areas of life, and were later transferred to certain technical applications [1,2,3,4,5,6,7].

This principle, also called the 80-20 rule, has shown correctness, for instance, in the following events presented in Figure 1:

- 80% of a company's sales come from 20% of its products,
- 80% of decisions are determined by 20% of available information,
- 80% of complaints in supermarkets come from 20% of their customers,
- 80% of shortcomings are the result of 20% of the causes.

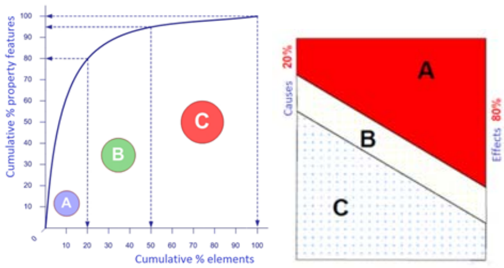

Fig. 1. Visual representation of the *ABC* analysis results using Lorenz curve

In summary, it can be stated that a small number of people, causes or circumstances are responsible for most of the tasks of amending, eliminating or indicating these causes. In this way it is possible to improve the situation or identify the 20% of elements that have a decisive influence on the analyzed phenomenon and constituting 80% of a given characteristic.

An example of analysis based on the "Pareto principle" is the one carried out concerning breakdowns of cars older than 11 years in Germany. The results of the analysis indicated the main causes of breakdowns occurring in the population of 1000 cars.

A Pareto – Lorenz [1] chart of the car breakdowns is shown in Figure 2.

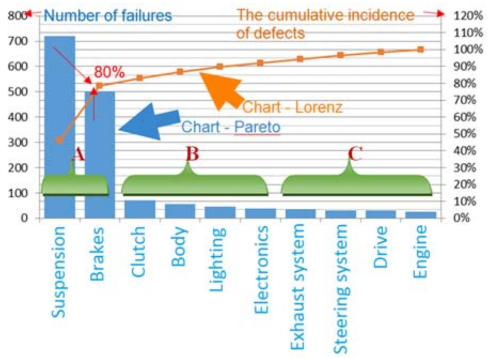

Fig. 2. Pareto - Lorenz chart of faults in 1000 examined cars

In order to develop the chart the cumulative numbers and cumulative incidence of breakdowns were determined. Using the chart, we find that 80% of the total number of breakdowns results from 20% of the causes i .e. 80% of failures are due to suspension and brake failures.

The numbers 80 and 20 are some kind of approximation of the cause and effect analysis. Further development of the "Pareto principle" is the *ABC* analysis which organizes and categorizes elements of individual sets. Analyzing both Fig. 1 and 2 we can group the causes of car breakdowns into categories *A* , *B* and *C*. Subset *A* will include from 5% to 20% of all items that constitute the main causes of failures, i .e. suspension and brakes. Subset *B* is the average level of the causes, ie. clutch, body type, lighting, electronics. Subset *C* contains marginal causes, such as exhaust, steering, propulsion, and engine). This analysis allows car designers to eliminate the root causes of damage and increase car's reliability. This is essential in a competitive market.

The procedure for the *ABC* method used in the example above includes the following steps:

- selection of population and ordering criterion (cars, failures),
- data collection,
- ordering the population by decreasing value level of participation,
- calculation of the cumulative share, i .e. increasing number of total faults in the population,
- creation of an *ABC* chart,
- division of the population into subsets *A* , *B* and *C*,
- analysis of the results.

This paper deals with the application of the "Pareto principle" and the resulting *ABC* charts to solving technical problems. The analysis presented above shows the applicability of the principle to assess car failures of a strictly defined car population. As a result, conclusions concerning the fundamental causes of car failures were made. Below, possibilities of applying the principle to energy issues are discussed.

Thus, further on we present thermal analysis of energy systems in the form of high voltage cable operating at 110[kV]. We discuss and analyze the impact of the following parameters on the temperature of the main cable core: its depth in the ground, thermal conductivity of the ground, the materials used for the construction of the current loaded cable, temperature and wind speed over the surface of the ground, etc.

Failures of high voltage cable systems (110[kV]) cause power shortages not only for industrial customers but also in residential buildings, which results in significant financial losses for producers and power line operators. The temperature of the cable core exerts the most important impact on the reliability of the system. The core's temperature should not exceed 90 degrees Celsius.

The cable temperature is affected by many factors [9,10,11,12], which include:

- thermal conductivity of the ground where the cable system is laid,
- temperature of the air above the ground,
- convective heat transfer coefficient over the surface of the ground (wind speed [19]),
- resistivity and thermal conductivity of the cable core,
- carrying capacity of the cable,
- thermal conductivity of insulation,
- geometry of the cable system,
- type and thickness of the individual layers of the cable,
- the depth of cable placement, etc.

To determine basic parameters that exert critical influence on the temperature of the cable core, and their analysis is a primary objective of this paper. Both the "Pareto principle" and the *ABC* analysis have been used here to deal with the above problems.

Construction of the HV cable

Cables are built of single or multi-core units with isolated conductors and tight outer sheath adapted to be laid in the ground or in the water. Cables are also used in buildings and overhead lines. In this analysis we are going to focus on high voltage cables whose main conductor is covered by insulation and protective wrapping, and a metal tape forming a screen, grounded at one or both ends of the cable. The screen, in some cases, constitutes an additional source of heat from 10 to 30 percent of the value compared to the losses in the main conductor. A detailed structure of a copper cable is shown in Figure 3. A typical high voltage cable consists of the following layers:

1. conductor wires (copper or aluminum), 2. semi-conductive insulation of polyethylene XLPE, 3. insulation of polyethylene XLPE shell [13], 4 semi-conductive screen (insulating layer), 5. semi-conductive screen, 6. screen, 7. tape, 8. inner shell, 9. longitudinally applied tape with copolymer, 10. external shell, 11. outer sheath (fire-resistant), 12. outer graphite coating.

Directly around the compacted wires of copper or aluminum, there is an inner conductive layer manufactured in a single technological operation together with an overlaying insulation and outer conductive layer. The screen area made of copper wire (*Cu*) is manufactured by depositing waterproof material swelling longitudinally which, in case of possible sheath damage, prevents the penetration of water into the interior of the cable. The outer sheath is made of polyethylene resistant to abrasion. Its transverse water tightness is ensured by coated aluminum tape underneath the sheath. The tape is inseparably combined with the polyethylene (*PE*).

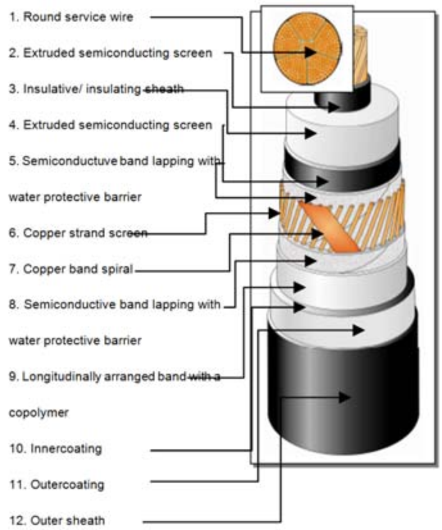

Fig. 3. Construction of copper cable 64/110[kV] manufactured by TELE -FONIKA Kable, LTD [13]

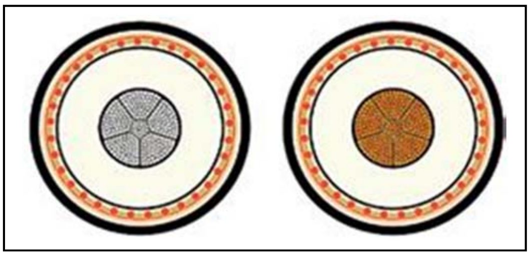

Fig. 4. Cross section of Milliken design conductor (with Al and Cu core)[14]

At approximately constant electrical and dielectric properties of the cable, an increased resistance to the maximum admissible temperature of the cable core is tantamount to higher acceptable load in continuous cable operation or in the event of a short circuit.

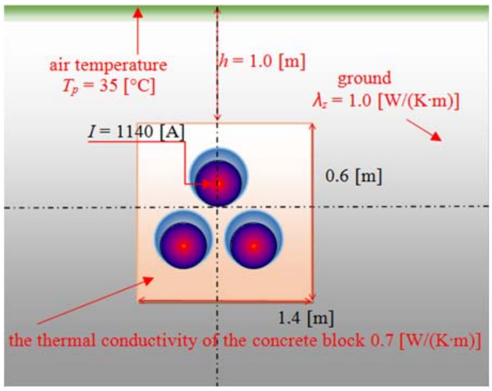

Fig. 5. Distribution of the cable system in concrete lagging at the depth of 1[m]

Proper use of the cable requires appropriate laying of the cable in the ground. The figures below show the arrangement specified by the manufacturer. Figure 5 shows the arrangement of the cable in an air lagging in a block of concrete, whereas Figure 6 illustrates cable deployment directly in the ground.

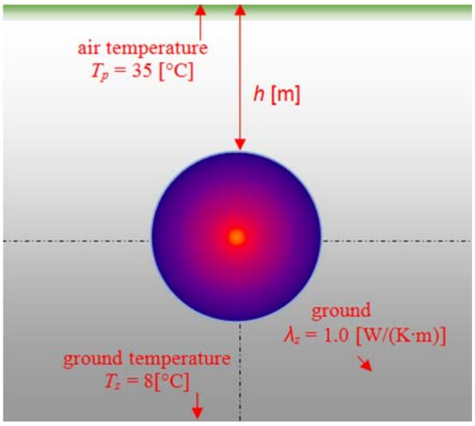

Fig. 6. Placement of HV cable without a protective coating *h* – distance from the earth's surface

To choose the right cable dedicated software is used to simulate the operation of the cable system [15].

In the further part of the paper we discuss the use of the Pareto principle to analyze the impact of the depth of the cable laid in the ground, thermal conductivity of the ground, current load, and other parameters on the temperature of a single phase conductor cable. (Fig. 6)[16,17]. Analysis of three-phase current cable (Fig. 5) will be presented in the next work.

Numerical model of the system

The main tool used in this research work is the simulation program NISA Suite of FEA Software [15]. For calculation NISA/HEAT TRANSFER was used [18]. The program is based on the finite element method (FEM) [19].

When we study the distribution of temperature field in high-voltage power cables we have to take into account not only Joule's heat resulting from the flow of an electric current, but also the heat emitted as a result of dielectric loss or losses on magnetic hysteresis, and sometimes also the heat given off due to mechanical friction.

However, most of the thermal problems are closely associated with the phenomenon of heat conduction in solid bodies. The solution of such issues can usually be reduced to finding the temperature field $T(x,y)$ in a specific area, that is, to solving partial differential equations of the second order with appropriate boundary conditions.

For a two-dimensional homogeneous and isotropic environment, the heat conduction equation in the steady state takes the form of [20,21]:

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}=-\frac{g}{\lambda} \tag{1}$$

where $g = j^2 \cdot \rho$[W /m^3] is rate of heat production the core of the cable , j[A /m^2] is current density, ρ[Ω·m] - resistivity, and λ[W /m·K)] the thermal conductivity of individual system components.

The boundary conditions adopted for the solution of equation (1) shown in Figure 7 are as follows:

- inhomogeneous boundary condition of the first kind (Dirichlet's) on the lower edges of the analyzed area (constant temperature of the ground assumed $T_0 = 8$[^{0}C]),

$$T\big|_s = T_o \tag{2}$$

- inhomogeneous boundary condition of the third kind on the earth's surface corresponding to the exchange of heat over the surface of the earth, according to Newton's law,

$$\frac{\partial T}{\partial n}\Big|s = -\frac{\varepsilon}{\lambda}(T_s - T_p) \tag{3}$$

where ε[W /(m·K)] is the convective heat transfer coefficient describing wind speed over the surface of the earth [19]), T_s- surface temperature of the analyzed area, T_p air temperature over the surface of the earth.

- over the vertical of the analyzed area (Fig. 7), the same condition for the heat flux continuity must be fulfilled.

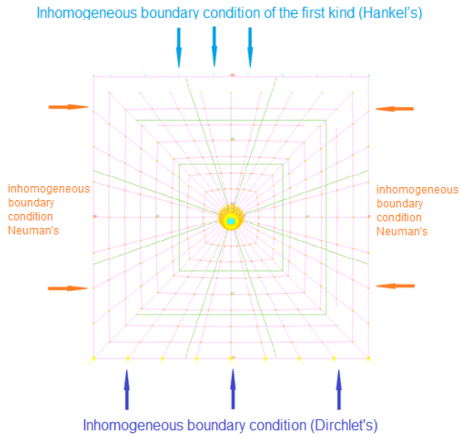

Fig. 7. The geometric model of grid distribution and the finite element nodes for a single core cable laid directly in the ground with the boundary conditions

The Pareto Rule and ABC charts for a single core cable laid in the ground

In this work it is assumed that the temperature of the HV cable core depends on 7 parameters (discussed above). Thus, the function that describes the cable core temperature can be defined as follows:

$$T_r = f(\lambda_z, T_p, I, \rho_{Cu}, \varepsilon, \lambda_d, \lambda_{Cu}) \tag{4}$$

where: T_r[^{0}C] - core temperature, λ_z[W/(m·K)] - thermal conductivity of the ground, T_p[^{0}C] - air temperature over the surface of the ground, I[A] - cable core current, ρ_{Cu}[Ω·m] - copper resistivity, ε[W/(m^2·K)] - convective heat transfer coefficient over the surface of the ground, λ_d[W/(m·K)] - thermal dielectric conductivity, λ_{Cu}[W/(m·K)] - copper (cable core) thermal conductivity.

The following example shows temperature graphs of the cable core depending on the depth of the cable laid in the ground h (Fig. 8), air temperature T_p (Fig. 9) and the thermal conductivity of the ground (Fig. 10). The remaining parameters, as indicated in the figure, are assumed constant.

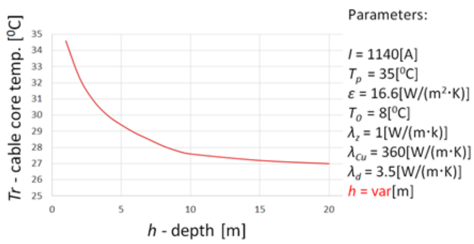

Fig. 8. Temperature chart of the cable core T_r dependent on the depth of its location

Analyzing the above chart, we should note a relative stability of the cable core temperature at depths greater than 10 meters from the ground surface.

The dependence of the core temperature on the variations of air temperature T_p over the ground surface is illustrated in Fig. 9.

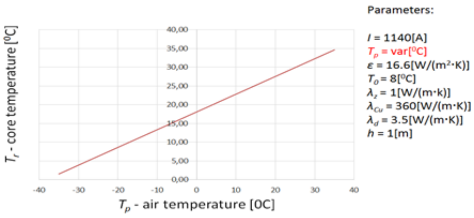

Fig. 9. Temperature chart of the cable core T_r dependent on the changes of air temperature T_p

In this case, we should note a linear dependence of the cable core temperature T_r on the air temperature over the surface of the ground T_p. The dependence of cable core temperature on changes of the thermal conductivity of the ground is shown in Fig. 10.

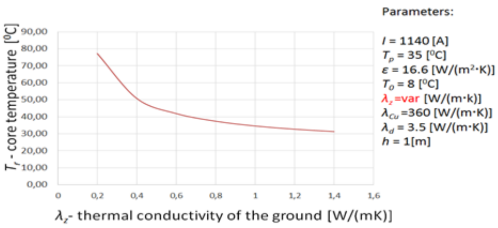

Fig. 10. Temperature chart of the cable core T_r dependent on the changes of the thermal conductivity of the ground λz

A significant impact of the low values of thermal conductivity of the ground λ_z in the range 0.2 - 0.4 on the cable core temperature T_r imposes a strict work regime due to the maximum permissible temperature of the core of Tr, max = 90[°C].

Now we systematize the discussed system and present some basic definitions explaining the use of the Pareto rule and the ABC chart. The preliminary analysis deals with a single high voltage cable laid in the ground at depths from 1 to 20 meters. The assumed parameter changes occurring in formula (4) have been adopted on the basis of changes in the physical conditions occurring in Poland as well as on the assumed changes in percentage of given data of physical quantities:

- according to the literature the thermal conductivity of the ground varies from 0.2[W/(m·K)] for dry soil to 1.4[W/(m·K)] for wet soil [13,14],
- in our paper we assume the changes in air temperature over the surface of the ground valid for Polish climatic conditions T_p from -30[^{0}C] to +30[^{0}C],
- rated load of the cable core adopted for the analysis is I = 1140[A]. The assumed changes of load current are from 912[A] to 1368[A],
- depending on the chemical composition of copper (technological process) the assumed resistivity changes are in the range from 1.57·10^{-8} [Ω·m] do 1.88·10^{-8} [Ω·m],
- assumed changes in the convective heat transfer coefficient over the surface of the ground are from 16.6 [W/(m^2·K)] - (still air) to 150[W/(m^2·K)] - wind speed 50[m/s] [21],
- thermal conductivity changes of the thickest dielectric layer No 3 (Fig. 3) are assumed depending on its thermal properties. The changes vary from 2[W/(m·K)] to 5[W/(m·K)] [13,14],
- changes in the thermal conductivity of the cable core are dependent on copper smelting technology and vary from 360[W/(m·K)] to 390[W/(m·K)].

The assumed ranges of parameter changes affecting the temperature of the cable core have been named *base change ranges* of the analyzed parameters.

Def. 1 Changes of basic parameters affecting the temperature distribution in the cable core resulting from varying physical conditions occurring in Polish conditions or assumed percentage changes resulting from the production technology are is called *base change ranges.*

Def. 2 Temperature distribution occurring in the *HV* cable core due to a very small gradient is characterized by the maximum temperature and is called *cable core temperature.*

Using the Pareto rule and ABC chart, a “Pareto - ABC optimal” analysis of the power system using the following dependences has been performed:

(5)
$$T_w = \frac{T_{\max} - T_{\min}}{T_{\max}}$$

where T_W relative (percentage) temperature value in the core, T_{max} - T_{min} - the difference between the maximum and minimum temperature in the core at the assumed changes of a given parameter,

(6)
$$T_s = \sum_k T_{k,w}$$

where T_s is the sum of relative temperature changes whereas k is the number of parameters present in formula,

(7)
$$S_k = \frac{T_{k,w}}{\sum_k T_{k,w}}$$

S_k element of the cumulative temperature value,

(8)
$$S = \sum_k S_k$$

where S is the relative cumulative temperature value in the cable core.

Table 1. The range of base parameter changes assumed for the temperature field simulation for a single conductor cable (at 1[m] depth)

No.	Parameter	unit	$(T_{max} - T_{min})/T_{max}$	percent	base value -min.	T_1[^{0}C]	base value-max.	T_2[^{0}C]
1	Air temperature	^{0}C	0,8820	47%	-30,00	3.81 T_{min}	30,00	32,28 T_{max}
2	Thermal conductivity of the ground	W /(m·K)	0,6116	80%	0,20	74,77 T_{max}	1,40	29,04 T_{min}
3	Long term cable load	A	0,2889	95%	912,00	27,27 T_{min}	1368,00	38,35 T_{max}
4	Copper resistivity	Ω·m	0,0713	99%	1,57E-08	30,87 T_{min}	1,88E-08	33,24 T_{max}
5	Thermal conductivity of the dielectric	W /(m·K)	0,0186	100%	2,00	32,71 T_{max}	5,00	32,10 T_{min}
6	Convective coefficient of heat exchange	W /(m^2·K)	0,0028	100%	16,60	32,28 T_{min}	50,00	32,37 T_{max}
7	Thermal conductivity of the core	W /(m·K)	0,0000	100%	360,00	32,28 T_{min}	390,00	32,28 T_{max}

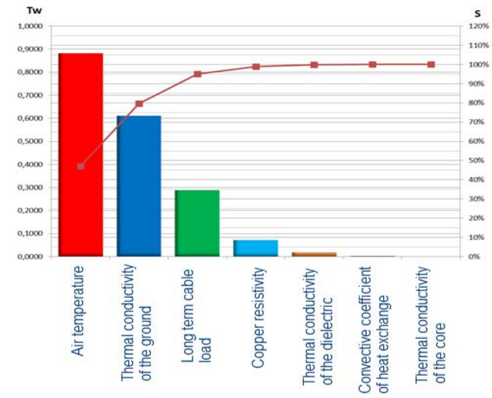

Fig. 11. ABC Chart for depth h = 1[m]

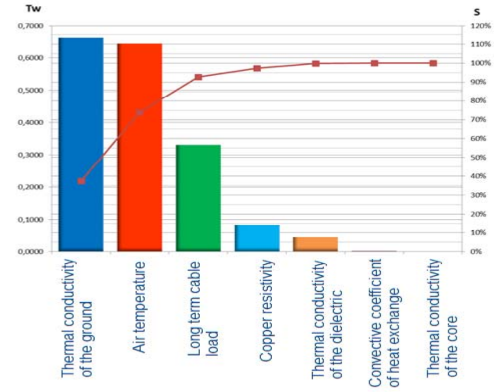

Fig. 12. ABC Chart for depth h = 2[m]

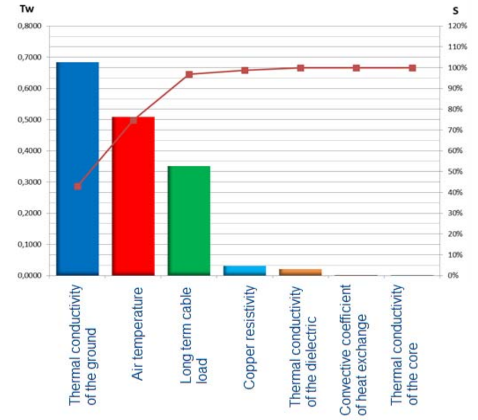

Fig. 13. ABC Chart for depth h = 3[m]

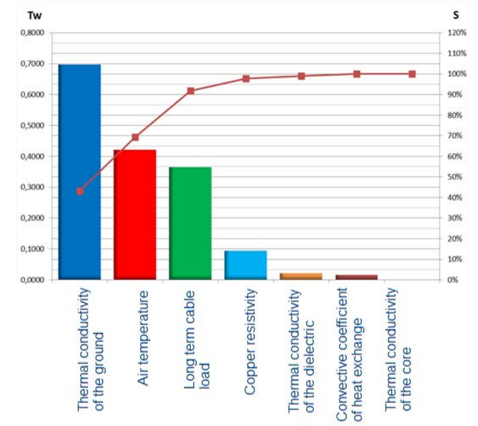

Fig. 14. ABC Chart for depth h = 4[m]

In the simulation tests a numerical model of single conductor cable system placed directly in the ground as shown in Figure 6 was used. In the calculations base change ranges presented in Table 1 were employed.
Using the calculations a number of ABC charts of various cable depths ranging from 1 to 20[m] were made, as shown in Figs 11-17.

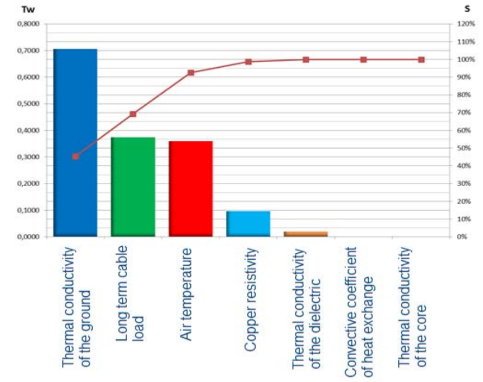

Fig. 15. ABC Chart for depth h = 5[m]

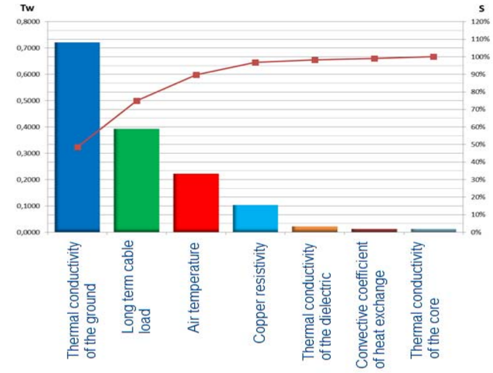

Fig. 16. ABC Chart for depth h = 10[m]

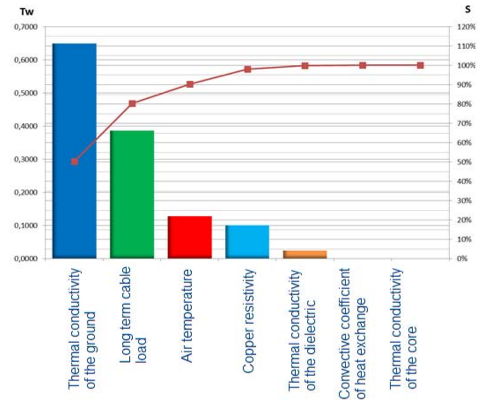

Fig. 17. ABC Chart for depth h = 20[m]

Analyzing Figs 11-17, it is possible to formulate basic conclusions regarding the structure of the ABC subsets. Subset A is composed of the following elements: thermal conductivity of the ground λ_z and the temperature of the ground above the earth's surface T_p $(A = \{\lambda_z, T_p\})$. Subset B contains the following: long term cable load I, copper resistivity ρ_{Cu} and thermal conductivity of dielectric $B = \{I, \rho_{Cu}, \lambda_d\}$. Finally, subset C contains the elements that exert a minimal effect on the temperature of the cable core, convective heat transfer coefficient above the earth's surface ε and thermal conductivity of the cable core λ_{Cu}, $C = \{\varepsilon, \lambda_{Cu}\}$.

However, at a depth of 20[m] the situation changes. Subset A contains ground heat conductivity λ_z and long-term load capacity of the cable I $(A = \{\lambda_z, I\})$, subset B is composed of air temperature T_p, copper resistivity ρ_{Cu} and thermal conductivity of dielectric λ_d $(B = \{Tp, \rho_{Cu}, \lambda_d\})$, whereas subset C contains convective heat transfer coefficient ε and thermal conductivity of the core λ_{Cu} $(C = \{\varepsilon, \lambda_{Cu}\})$.

Analyzing the ABC charts we should note the fundamental changes in the elements affecting the structure of subsets A and B. At depth h = 1[m] the greatest influence on the temperature in the cable core is exerted by the changes in air temperature, the value of thermal conductivity of the earth being second greatest. These are the elements of subset A . Analyzing the ABC chart at depth h = 3[m] we observe a change, here are the greatest influence is exerted by changes of thermal conductivity of the earth, whereas in the second place there are changes in air temperature. It is necessary to define the depth h, at which a transition from subset $\{T_p, \lambda_z\}$ to an ordered subset $\{\lambda_z, T_p\}$ is observed.

For this purpose, basing on the data presented in Table 2, we chart in Figure 18 the dependencies on the relative temperature changes $T_{w,p} = f(h)$ and $T_{w\lambda} = f(h)$, using the data given in Table 2 containing the relative temperature changes of a HV cable located at different depths below the earth's surface. The intersection point of these two functions gives us depth h, at which the conversion of subset elements occurs. The exact value of the depth was determined numerically and amounts to h = 1.89[m]

Table 2 Relative temperature change of cable core due to base parameter changes and depth of the laid cable

No.	Parameters	$(T_{max} - T_{min})/T_{max}$	$(T_{max} - T_{min})/T_{max}$	$(T_{max} - T_{min})/T_{max}$	$(T_{max} - T_{min})/T_{max}$	$(T_{max} - T_{min})/T_{max}$	$(T_{max} - T_{min})/T_{max}$	$(T_{max} - T_{min})/T_{max}$
1	Air temperature	8,8197E-01	6,4286E-01	5,0808E-01	4,2071E-01	3,5969E-01	2,2190E-01	1,2781E-01
2	Thermal conductivity of the ground	6,1161E-01	6,6136E-01	6,8435E-01	6,9711E-01	7,0554E-01	7,2141E-01	6,4937E-01
3	Long term cable load	2,8892E-01	3,3049E-01	3,5136E-01	3,6471E-01	3,7368E-01	3,9274E-01	3,8655E-01
4	Copper resistivity	7,1300E-02	8,3255E-02	8,5659E-02	9,3946E-02	9,6471E-02	1,0276E-01	1,0057E-01
5	Thermal conductivity of the dielectric	1,8649E-02	1,9514E-02	2,0232E-02	2,0671E-02	2,0232E-02	2,2206E-02	2,5427E-02
6	Convective coefficient of heat exchange	2,7804E-03	1,3029E-03	1,6725E-03	1,6512E-03	3,4977E-04	1,3139E-02	2,5471E-04
7	Thermal conductivity of the core	3,0978E-05	0,0000E+00	3,3646E-05	3,4399E-05	3,4988E-05	1,3139E-02	4,2461E-05
	Depth [m]	1	2	3	4	5	10	20

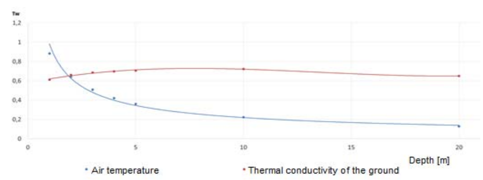

Fig. 18. Dependencies of relative temperature changes of the cable core in the function of its distance from the earth's surface $(T_{w,p}, \lambda_z)$. The intersection point determines the depth h = 1.89[m] at which the exchange of elements in subset A occurs

The function approximating the dependence of the changes in cable core temperature on depth h of its location and base changes in air temperature $T_{w,p}$ is given by the formula below:

(9) $$T_{w,p} = 0.9837h^{-0.652}$$

The function dependent on the thermal conductivity of the earth $\lambda_{w,z}$ is expressed by the formula:

(10) $$T_{w\lambda z} = 0.0001h^3 - 0.0041h^2 + 0.0447h + 0.5783$$

At greater depths of the cable the influence of air temperature T_p on cable core temperatures gets smaller and smaller to become at depth h = 4.42[m], equivalent to similar changes caused by long term cable load. There is an exchange of parameters between subsets A and B of the ABC chart ,namely $A = \{\lambda z, I\}$ i $B = \{T_p, \rho_{Cu}, \lambda_d\}$.

The function approximating the dependencies of the changes of cable core temperatures on its location depth h in the ground and its current load capacity is described by the following formula:

(11) $$T_{wi} = 0.0004h^3 - 0.0036h^2 + 0.04h + 0.2578$$

The dependence $T_{wp} = f(h)$ oraz $T_{wI} = f(h)$ is shown in Figure 19.

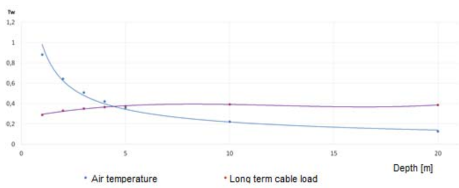

Fig. 19. Dependencies of relative temperature changes of the core on air temperature and long term cable load in the function of its distance from the earth's surface $(T_{w,p}, I)$

The intersection point gives us depth h = 4.42[m], at which the conversion of the elements subset A occurs.

Figure 20 presents the charts of relative changes in core temperature of the analyzed parameters depending on depth h of the cable in the ground.

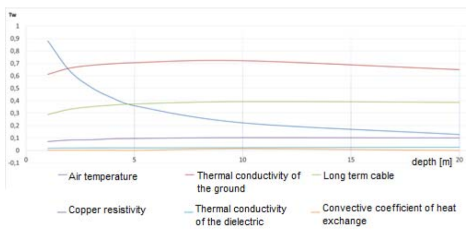

Fig. 20. Influence of parameters $\lambda_z, T_p, I, \rho_{Cu}, \varepsilon, \lambda_d, \lambda_{Cu}$ on relative changes in cable temperatures T_W

Comments and conclusions

In general, the research paper titled "Pareto-ABC analysis of high voltage single core cable temperature" presents a multi-parameter analysis of the temperature of high voltage cable cores operating in a single core system. In the paper we discussed the methodology concerning the analysis of the influence of basic parameters such as air temperature above the earth's surface T_p, thermal conductivity of ground λ_z, current load I, of depth h of the system in the ground on the temperature of a single core cable. The study made use of a multi-criteria Pareto model [1,2] and the ABC charts to determine the qualitative and quantitative impact of the parameters on core temperature. The research methodology has been also applied in the analysis of real three-phase systems that will be presented in the next paper.

The research results allow us to make the following conclusions:

- primary influence on the temperature distribution in the core of a single cable is exerted by the temperature of the air above the surface of the earth T_p, thermal conductivity of the ground λ_z, current load capacity of the system ,

- at a depth of 10[m] from the earth's surface the core temperature is constant and such parameters as T_p and λ_z have no substantial effect on the temperature changes of the core,

- in the analyzed system at the depth of 1.89[m] the following parameters exert essential influence on the temperature of the core: air temperature above the surface of the earth T_p, ground thermal conductivity λ_z at greater depths than 1.89[m] there is a dominant influence the thermal conductivity of the ground. At a depth of h = 4.42[m] there is a change in the elements of subsets A and B, namely, $A = \{\lambda_z, I\}$ i $B = \{T_p, \rho_{Cu}, \lambda_d\}$,

- minimal impact on the core temperature is exerted by the parameters describing the physical properties of the materials used for the construction of the cable as well as the coefficient of convective heat exchange ε, characterizing to some extent the wind speed above the earth's surface [21].

Basically the technology of laying high-voltage cables (110 [kV]) in the ground refers to a depth of up to 5[m]. However, in many cases (for example, for an intersection between a cable line with railway tracks) much greater depths of up to 20[m] are required. Taking into account the above standards, the simulation results presented here refer to the depths of up to 20[m].

The multi-criteria analysis of the impact of a variety of parameters on the temperature of high voltage cable core as well as the ABC criterion of their categorization can be applied to studies of other systems, such as energy assessments of building insulation or failure causes of turbines and engines.

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