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Self-organization and self-adaptation of computer networks in nonextensive approach

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Abstract

Contemporary computer networks fit into the category of complex systems. However, many models are still based on an idealistic paradigm of simple systems based on thermodynamic equilibrium. In order to understand and optimize the design of real networks, it is necessary to understand and describe their nonextensive operation aspects. Therefore, it is necessary to explain such concepts as self-organization, self-adaptation and matching load to finite resources.

Keywords: computer networks, nonextensive thermodynamics, self-organization, self-adaptation.

Samoorganizacja i samoadaptacja sieci komputerowych w ujęciu nieekstensywnym

Streszczenie

Współczesne sieci komputerowe wpisują się w kategorię systemów złożonych. Jednakże wiele sosowanych modeli sieci ciągle bazuje na idealistycznym paradygmacie systemów prostych opartym na termodynamice równowagowej. W celu zrozumienia i optymalizacji procesu projektowania rzeczywistych sieci komputerowych konieczne staje się zrozumienie i opisanie nieekstensywnych aspektów ich działania. Dlatego należy wyjaśnić takie pojęcia ja samoorganizacja, samoadaptacja, w systemie rozproszonym, dostosowanie obciążenia, równowagowy i nierównowagowy stan sieci komputerowej postrzeganej jako system. W artykule autorzy pokazują że samoadaptacja i samoorganizacja w sieci komputerowej ma charakter nieekstensywny, jak również analizują ich wpływ na wzajemne dopasowanie pomiędzy obciążeniem i ograniczonymi zasobami systemu rozproszonego. Analizowany jest również wpływ samoadaptacji i samoorganizacji na czas odpowiedzi systemu. Zaproponowany model pozwoli na doprecyzowanie i ulepszenie procesu projektowania i kontroli sieci komputerowych, który uwzględniać będzie zjawiska krótko i długoterminowe w nich zachodzące. Wpłynie to również na poprawę zarządzania sieciami realizowanego z wykorzystaniem sztucznej inteligencji, algorytmów genetycznych i logiki rozmytej.

Słowa kluczowe: sieci komputerowe, termodynamika nieekstensywna, samoorganizacja, samo adaptacja.

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1. Introduction

The research on computer networks have mainly focused on technical consideration in underload conditions. Computer networks can be regarded as distributed systems in the idealistic approach. George Coulouris says that the distributed system is a system whose hardware and software components are allocated in network nodes, they communicate and coordinate their actions only by sending messages [1]. The immanent features of this system are concurrency, the lack of global synchronization and independence of the failure of individual system components. This definition of the distributed system allows regarding it as a simple system of the following characteristics: algorithmic processing, linearity characteristics as a function of load, thermodynamic equilibrium, stationarity of processes, ergodicity, laminar deterministic flow, lack of overload and collapse of the system, static capacity planning, system resources independence processes, the normal distribution in time and space, additive statistics, guaranteed quality of service, etc. Regarding individual components as simple elements in the case of distributed systems is a great simplification.

Modern computer networks fit into a category of social-economic--technological systems where processing is interactive and self-organizing, and the main features are: non-linearity, thermodynamic disequilibrium, not extensiveness, nonstationarity of processes, sensitivity to congestion and infection, emergence, dynamic load balancing, scale free processes, fractional Brownian motion, exponential law, small worlds, preferential attach, nonextensive statistics, the lack of guaranteed quality of service, etc. These features enables us to treat real computer networks as complex systems. Furthermore, it appears that the working area of computer networks oscillates between a laminar and a turbulent flow, that is on the border of chaos [2]. The complex system, totally different from the simple system, is an emergent structure of mutually interacting elements. Processes taking place in this system are scale free, form short-term to long-term ones.

The challenge for modern engineering of computer networks is to equip them with self-adaptation mechanisms, as is the case of natural systems, which leads to state where the finite resources and the load are balanced. The basis for understanding the self-adaptive systems is to understand the self-organization mechanism. Without this understanding, it is not possible to design self-adaptation mechanisms properly. The convergence and scalability of computer networks coupled with the load mismatch to the available resources, leads to the loss of control, which is usually revealed in degradation of the response time and, ultimately, degradation of the quality of services [3].

This paper proposes a departure from modeling of real computer networks as simple systems. To understand the functioning of computer networks as nonextensive complex systems, it is necessary to clarify such concepts as self-organization, self-adaptation and matching the load to the finite resources. This paper presents the explanation of these issues.

2. Self-organization

The contemporary perspective on computer networks is dominated by percepting them as a collection of components (systems) independently connected in space and time components. Such a perception leads to the application of the network management and control algorithms which are implemented independently on each system node according to the paradigm of equilibrium thermodynamics: only a finite number of permitted states can appear in a computer network; all permitted states are equally probable; productivity of a computer network and its components is unlimited but its structure is closed; entropy is extensive; interactions among states have only a short-term character. An example is the motion, which was registered in a real local network, which connected 30 users.

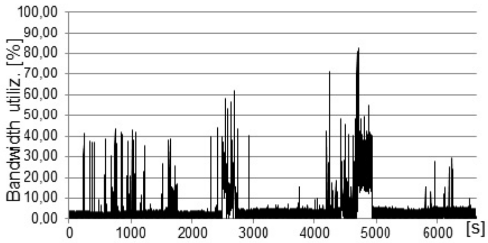

Fig. 1. The real traffic on the LAN. The percentage of bandwidth utilization
Rys. 1. Rzeczywisty ruch sieciowy. Procentowe wysycenie pasma

The estimated Hurst exponent H for this movement is 0.5484. For this movement the value of the exponent H> 0.5, which indicates that the series is persistent, keeping a positive correlation between the subsequent amendments of the series and indicating the existence of a trend. This undermines the assumptions, underlying the commonly used models, and forces us to look at the network as a system in terms of nonequilibrium thermodynamics.

The quintessence of the equilibrium thermodynamic is Boltzmann-Gibbs entropy and then Shannon entropy:

$$S_1(x) \equiv -\sum_i p_i \ln p_i, . \tag{1}$$

where the p_i are probabilities associated with microstates i of the system. Equilibrium thermodynamics, which is rather thermostatics, leads to idealization of perception of reality and finally, to the reductionist paradigm. The formula of equilibrium thermodynamics ignores spatial-temporal limitations of real systems, which leads to non-equilibrium thermodynamics, which means that in the system: there can be any number of permissible states; occurrence of the states is not equally-probable; performance of the system and its components is limited but the structure is open; entropy is not-extensive; interactions between states are arbitrarily ordered i.e. they have scale-free from short- to long-range dependence.

Non-equilibrium thermodynamics leads to more general non-extensive entropy, for example Tsallis entropy [3]

$$S_q = k\frac{1-\sum_{i=1}^{W} p_i^q}{q-1} \qquad \left(S_1 = S_{BG}; \sum_{i=1}^{W} p_i = 1; q \in R\right), \tag{2}$$

where W is the total number of configurations, q is the non-extensive entropic index, p_i^q is generalization of q-probability distributions in range $-\infty < q < +\infty$. The basis of non-extensive thermodynamic and q-algebra is q-logarithm defined as [4]:

$$\ln_q(x) \equiv \frac{x^{1-q}-1}{1-q} \quad for\ x \ge 0\ \ and\ \ q \ne 1 \tag{3}$$

When $q \to 1$ then the special equilibrium case of Tsallis's entropy becomes Shannon's entropy. A non-extensive q-algebra grew on Tsallis's entropy [5], [6]. It is based on q-operations which lead to generalizations of the classic algebra. From the point of view of our considerations, the most interesting is q-sum of two numbers x and y which is based on a not-extensive operator of sum $\oplus$q defined as:

$$x \oplus_q y = x + y + (1-q)xy \cdot \tag{4}$$

Equation (4) shows that q-sum contains an equilibrium, additive term $(x + y)$ and dynamic non-equilibrium term $(1-q)xy$ which symbolize non-extensivity and the sensitivity to initial conditions [7]:

$$\xi(t) \equiv \lim_{\Delta x(0)\to 0} \frac{\Delta x(t)}{\Delta x(0)} = \left[1+(1-q)\lambda_q t\right]^{\frac{1}{1-q}} \qquad (q \in \Re). \tag{5}$$

where λ_q is the generalized Lyapunov exponent. According to equation (5), a system is insensitive to initial conditions when

$$\lim_{\Delta x(0)\to 0} \frac{\Delta x(t)}{\Delta x(0)} = \exp(\lambda_1 t). \tag{6}$$

In the case of computer networks, q-algebra can be used to analyze the extensiveness on the flow level (see Figure 2a) as well as on the processes level in the nodes, which are a function of a flow.

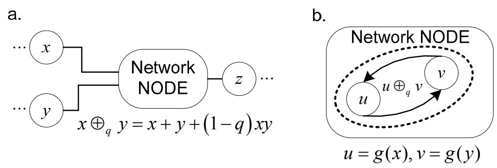

Fig. 2. Two aspects of nonextensivity in computer networks
Rys. 2. Dwa aspekty nie ekstensywności w sieciach komputerowych

In the case of thermodynamic equilibrium $q = 1$, therefore $\oplus_1 = +$. Taking into account (4), one can notice that in the case of q-sum, the commutative law $x \oplus_q y = y \oplus_q x$ and the associative law $x \oplus_q (y \oplus_q z) = (x \oplus_q y) \oplus_q z$ are valid, but the distributive law in relation to the usual multiplication $a(x \oplus_q y) \ne ax \oplus_q ay$ is not valid. However, the neutral element of the q-sum is zero, $x \oplus_q 0 = x$. Equation (4) has not only a mathematical aspect, but a physical one as well. From the mathematical point of view equation (4) indicates that q in a range $-\infty < q < 1$ leads to super-extensivity, i.e. $x \oplus_q y > x +$ y, whereas $1 < q < +\infty$ means sub-extensivity, i.e. $x \oplus_q y < x + y$. Thermodynamic equilibrium means $q = 1$ and additive features of systems. On the other hand, Equation (4) can be a basis for thermodynamic analysis of components structures and in consequence, of the whole system, where q modulates polarization and depth of feedback loops on the micro-level. Super-extensivity means positive feedback, sub-extensivity means negative feedback and additivity means lack of feedback loops. Thus, equation (4) allows defining non-extensive thermodynamics of structures of individual components and in consequence, non-extensivity of the whole system where interactions are scale-free, both inside components and between them. The basic properties of non-extensive components are described in detail in [8].

The analysis of the interaction of the network components shows that in the general case the structure of the thermodynamic system is dynamic and oscillates at the edge of chaos between globally simple (extensive), locally non-extensive (locally complex) and globally-complex (globally-non-extensive) one.

3. Logistic equation of arbitrary order

In the complex computer networks we can indicate three kinds of flows: laminar, reversible turbulent and irreversible turbulent. The Malthus equation refers to the laminar flow, but the logistic equation describes only one special case of homogeneous turbulent reversible flow. Non-extensive thermodynamics indicates [9] that the model of the complex system will be complete if phenomena in the system can be of arbitrary order, that is, they can be sub-extensive or super-extensive. Therefore, we proposed a general version of the logistic equation which refers to the whole family of systems [10]:

$$X = rN\left(1-\frac{N}{K}\right)^{f} = X_M\left(1-u\right)^{f} = \frac{1}{\sum_i \bar{S}_i\bar{V}_i + \bar{Z}}\left(1-u\right)^{f} = X_M G. \quad (7)$$

Equation (7) shows that the performance of a complex executive system is the product of the performance of a simple system X_M, and the deformation coefficient $G = (1\text{-}u)^{f}$, which modulates structure and processes of the non-degenerated systems. Parameter K denotes limited global resources of the system, and $u = N/K$ is the coefficient of the system's resource utilization, where $0 \leq u \leq 1$. Parameter f describes self-organization of the system as a result of feedback (sensitivity to initial conditions) and can have arbitrary (fractional) order in a range $-\infty < f < +\infty$. One denotes susceptibility of the structure to spatial - temporal deformations that lead to degradation of the simple system, but $G = (1\text{-}u)^{f}$ is the deformation factor.

In the general case of non-extensive complex systems, the service of each task can be characterized by microscopic parameters V_i, S_i , i and Z. V_i is the number of references (visits) to the i^{th} component of the system during the service of each task, where in general $0 \leq i < \infty$, and $0 \leq V_i < \infty$, S_i is the time of serving tasks by the system i^{th} component, where in the general case $0 < S_i < \infty$, and Z is the thinking time of a given process.

Moreover, it can be noticed that for f = 0, equation (7) corresponds with the Malthus equation, but for $f = 1$ it leads to the original logistic equation. On the other hand, the Malthus equation can be viewed as a special kind of demarcation line which divides the area of system performance X, vs. the number of tasks N, into two (above and below the demarcation line) diametrically different areas and different kinds of self-organizations. The first characteristic, super-extensive area, for $-\infty < f < 0$ and $0 < N < K$, is situated above the Malthus line and is self-managed only by the positive feedback. The second sub-extensive area is located below the demarcation line, $0 < f < +\infty$ and is related to the negative feedback.

The complex system is a fractal structure, where global parameters (at macroscopic-level) self-emerge at microscopic-level as a result of the feedback. The amplification parameter of the system with feedback r_f, is well known, particularly in electronic circuits and control theory, and on the basis of the Kirchhoff's second law in the amplitude domain is as follows [10]:

$$r_f = \frac{r}{1 \pm \beta r}, \quad (8)$$

where r is the coefficient of the system amplification without a feedback, and β is the coefficient of the feedback in the system. Comparing equations (7) and (8) we have:

$$\frac{1}{1 \pm \beta r} = \left(1-u\right)^{f}. \quad (9)$$

On the basis of equation (9) we can determine parameter f:

$$f = \frac{\log\left(\frac{1}{1 \pm \beta r}\right)}{\log\left(1-u\right)}. \quad (10)$$

Equation (10) indicates that f depends both on the coefficient of the real system's limited resources utilization u, and on the product βr. This means that in contrast to an ideal system, where V_i, S_i, i and Z are constant, in complex systems real self-organization processes are self-managed by variable V_i, S_i, i and Z, which in consequence leads to sensitivity of u and β to external and internal conditions.

Finally, taking into account equation (10) we can transform equation (7) to the following form [10], Fig. 3:

$$X = rN\left(1-\frac{N}{K}\right)^{\frac{\log\left(\frac{1}{1\pm\beta r}\right)}{\log\left(1-\frac{N}{K}\right)}} = rKu\left(1-u\right)^{\frac{\log\left(\frac{1}{1\pm\beta r}\right)}{\log(1-u)}}. \quad (11)$$

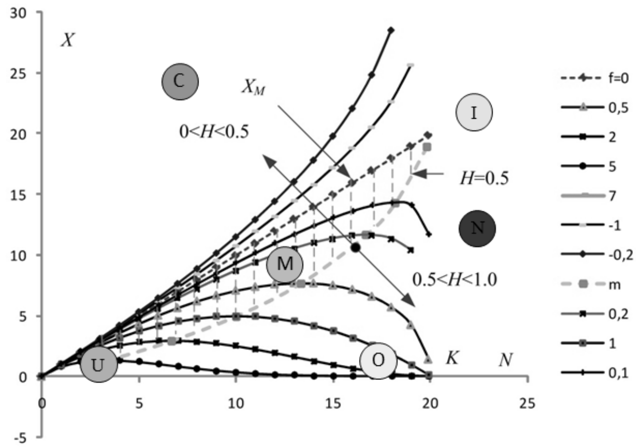

Fig. 3. Logistic equation of arbitrary order [8]
Rys. 3. Równanie logistyczne dowolnego rzędu [8]

Figure 3 is a graphic mapping of the logistic equation of an arbitrary order (11), on which the ideal case determined by Malthus equation is indicated as I and characteristic areas of work as N and C, where respectively N marks a non-catastrophic area, but C a catastrophic area of the computer network node (or the whole network). Moreover, U marks an under-load subarea of the computer network node (or the whole network), O marks an overload subarea of the computer network node (or the whole network), but M matching points between limited resources of the computer network node (or the whole network) and an realized communication task.

4. Influence of self-organization on matching between load and limited resources of complex systems and response time

Equation (11) indicates that the self-organization parameter of the arbitrary order f and the coefficient of the system's resource utilization u, for r = const. and K = const., inevitably lead to dynamics of the arbitrary order system which, on the basis of (4) can be defined as:

$$\frac{dX}{dN} = r\left[\left(1-\frac{N}{K}\right)^{f} - \frac{fN}{K}\left(1-\frac{N}{K}\right)^{f-1}\right] = r\left[\left(1-u\right)^{f}\left(1-\frac{fu}{\left(1-u\right)}\right)\right]. \quad (12)$$

From the control and management point of view, the area of a system's performance vs. the function of the number of tasks, located below the Malthus equation (I), $0 < f < +\infty$, which is divided by the optimal working point into two diametrically different zones [6] is very interesting. Coordinates of this point are X_m and N_m, where N_m means the optimal number of tasks, which is matched to limited resources of the system. When $N = N_m$, the system reaches the optimal performance $X = X_m$. Thus, from the point of view of energetic efficiency, coordinates X_m and N_m define the optimal working point of the complex system at the Hurst parameter $H = 0.5$.

The problem of artificial, human made complex systems, for example computer systems, is that they usually work far from the equilibrium point, which inevitable leads to the low energetic efficiency of the system. The matching point between the number of tasks and the system's limited resources, that is the point of the thermodynamic equilibrium, which separates two zones of the sub-extensive area can be determined on the basis of equation (7) as:

$$\frac{dX}{dN} = r\left[\left(1-\frac{N}{K}\right)^{f} - \frac{fN}{K}\left(1-\frac{N}{K}\right)^{f-1}\right] = 0. \tag{13}$$

Equation (13) makes it possible to calculate the coordinates of the matching point, N_m and X_m, respectively as:

$$N_m = \frac{K}{1+f} = \frac{K\log(1-u)}{\log\left(\frac{1-u}{1\pm\beta r}\right)}, \tag{14}$$

$$X_m = \frac{rK}{1+f}\left(\frac{f}{1+f}\right)^{f} = \frac{rK\log(1-u)}{\log\left(\frac{1-u}{1\pm\beta r}\right)}\left(\frac{\log\left(\frac{1}{1\pm\beta r}\right)}{\log\left(\frac{1-u}{1\pm\beta r}\right)}\right)^{\frac{\log\left(\frac{1}{1\pm\beta r}\right)}{\log(1-u)}}. \tag{15}$$

Taking into account equations (14) and (15) one can determine the trajectory of optimal working points of systems on the *X(N)* plane, at *r, K, f,* as parameters, Fig. 3.

5. Response time as a function of f and self-adaptation

Equations (14) and (15) describe sensitivity of the system's performance, or its components, and the response time of the system, or its components, and this way the quality of services on self-organization of the arbitrary order in the points of matching. Taking into account equation (15) we can determine the dependence between X_m and f in matching conditions at r and K as parameters, Fig. 4. Characteristics indicate how individual susceptibility of system or its components to self-organization, determined by f, influence the optimal performance in the matching point.

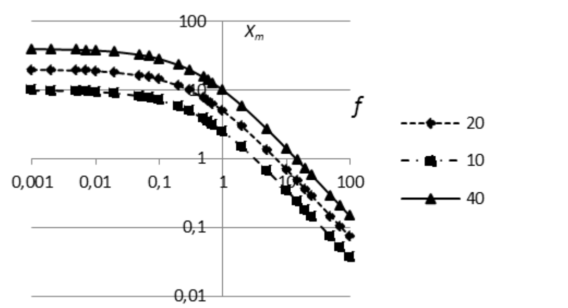

Fig. 4. Influence of f on *Xm* in the complex system, or its distributed components, in matching conditions, at r and K as parameters, where K = 10, 20 and 40

Rys. 4. Wpływ f na X_m w systemach złożonych, lub w jego rozproszonych komponentach, w warunkach dopasowania, gdzie r i K to parametry dla K = 10, 20 i 40

On the basis of equation (15) and Fig. 4 one can notice that the f increase leads to the decrease in X_m. In the ideal case (I) of the laminar flow described by the Malthus equation, when $f \to 0$ then $X_m \to X_M$ (equation (7)). In the range $1 < f < +\infty$ characteristics can be approximated by the power law dependence form $X_m \sim f^{-\gamma}$, where $\gamma \cong 1$.

The self-organization parameter of arbitrary order f influences not only performance but also the response time of the system or its components. In conditions mismatching, far from equilibrium, on the basis of equation (7) system can be characterized by the static response time described as:

$$R_c = \frac{N}{X} = \frac{N}{rN\left(1-\frac{N}{K}\right)^{f}} = \frac{R}{\left(1-\frac{N}{K}\right)^{f}} = \frac{R}{(1-u)^{f}}. \tag{16}$$

Equation (16) and Fig. 5 show that the response time in mismatching conditions R_c vs. f, at u as parameter, characterizes the unlimited growth, which leads to the degradation of the system. On the other hand, in matching conditions, taking into account equations (14) and (15), the response time can be described as:

$$R_m = \frac{N_m}{X_m} = \frac{1}{r}\left(\frac{f}{1+f}\right)^{-f} = \frac{R}{\left(\frac{f}{1+f}\right)^{f}}, \tag{17}$$

where R is the response time at $f = 0$. Equation (17) indicates that in equilibrium conditions R_m is insensitive to external conditions and depends only on parameter of the internal self-organization of arbitrary order f. In the special cases, when $f \to 0$, then $R_m \to R$, but when $f \to \infty$ then $R_m/R \to$ e, and self-stabilizes, Fig. 5, where e is the basis of natural logarithm.

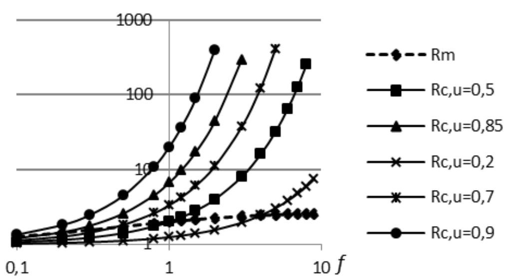

Fig. 5. In the thermodynamic equilibrium the response time of the complex distributed system R_m self-stabilizes and becomes independent from the self-organization parameter f

Rys. 5. W stanie równowagi termodynamicznej czas odpowiedzi rozproszonego systemu złożonego R_m samo stabilizuje się i staje się niezależny od współczynnika samoorganizacji f

6. Conclusions

So far, all models have assumed that self-organization and self-adaptation of computer networks have only the extensive nature. The paper shows that self-organization and self-adaptation have the nonextensive character. The proposed model of self-organization and self-adaptation will allow for more precise design and control of computer networks including processes that occur in them. It seems that this will improve network management with the use of artificial intelligence, genetic algorithms or fuzzy logic.

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INFORMACJE

XVII KONFERENCJA AUTOMATYKÓW RYTRO'2013
Charakterystyka prezentacji firmowych

W bloku prezentacji firmowych w I dniu Konferencji Automatyków przedstawione były następujące tematy.

- Pani Dyrektor Tatiana Perczak-Szanowska przedstawiła Program FAST, nowe narzędzie opracowane przez firmę WIKA.
- Pan Prezes Piotr Glinka przedstawił wybrane aplikacje, w których zastosowano produkty TURCK w regionie Polski południowej w okresie ostatniego roku.
- Pan Dyrektor Marek Wajszczyk zaprezentował film, prezentujący zakres produkcji, proces technologiczny i logistyczny w firmie TECHNOKABEL.
- Prezes firmy SKAMER-ACM pan Zygmunt Jarosz przedstawił dokonania i wyniki firmy w ostatnich kilku latach.
- Pan Michał Bereza, Product Manager w firmie Siemens, zaprezentował TIA Portal, który integruje wszystkie opcje, jakie są niezbędne dla projektanta urządzeń automatyki.
- Pan Dyrektor Tomasz Michalski przedstawił historię, potencjał produkcyjny i badawczy oraz przegląd produkcji firmy Pepperl Fuchs.
- Pan Profesor Piotr Kurytnik, członek delegacji Limatherm Sensor omawiał znaczenie sensorów w nowoczesnych systemach automatyki i pomiarów.
- Pan Prezes Marek Trutowski przedstawił historię, potencjał produkcyjny i badawczy oraz przegląd produktów firmy JUMO. W dalszej części prelekcji zaprezentował urządzenia z grupy JUMO safety M.
- Pan Rafał Rygielski zaprezentował inteligentną technologię bezprzewodową firmy Emerson, natomiast pan Krzysztof Rippel przedstawił przegląd produkcji firmy TopWorx.
- Pan Marek Tabaka, Key Investment Manager w firmie EATON Electric, zaprezentował firmę jako lidera w zakresie zarządzania energią oraz system SmartWire-DT.
- Pan Dyrektor Paweł Zmysłowski przedstawił historię, potencjał produkcyjny i badawczy oraz przegląd produktów firmy Danfoss.
- Pan Dyrektor Sławomir Kwiatosiński zaprezentował potencjał firmy ABB i rozwój firmy w Polsce, gdzie zlokalizowane są już 4 fabryki: w Łodzi, Przasnyszu, Aleksandrowie Łódzkim i Wrocławiu.

W drugim dniu Konferencji, na dwu równoległych sesjach, zostały zaprezentowane referaty techniczne dotyczące nowości w produktach firm Organizatorów.

W sesji I wygłoszono 6 referatów, o następującej problematyce.

- **LIMATHERM Sensor** – Grzałki elektryczne w ofercie Limatherm Sensor – budowa i dobór.
- **EATON Electric** – Jak rozwiązania kasetowe xEnergy z komunikacją SW-DT firmy Eaton rewolucjonizują zdalne lub automatyczne sterowanie silnikami i procesami produkcyjnymi.
- **TURCK** – Najciekawsze aplikacje automatyki i pomiarów w gazownictwie i energetyce.
- **EMERSON** – Bezpieczni z EMERSONEM.
- **WIKA Polska** – Przegląd urządzeń do testowania i kalibracji.
- **TECHNOKABEL -** Nowe konstrukcje kabli i przewodów do układów elektroniki i automatyki przemysłowej.

Po referatach odbyła się dyskusja, dotycząca aparatury kontrolno-pomiarowej i systemów sterowania. Nawiązywano do aktualnych potrzeb energetyki, m.in. charakteryzowano potrzeby związane są z zastosowaniem kabli i przewodów w aplikacjach związanych z odnawialnymi źródłami energii. Duże zainteresowanie wzbudził inteligentny system antyzalaniowy ISA-01, jego funkcje i zastosowanie.

W sesji II wygłoszono 6 referatów, o następującej problematyce.

- **DANFOSS Poland** – Przedstawiono dwa referaty: 1. Przetwornice częstotliwości Danfoss instalowane w trudnych warunkach środowiskowych, 2. Przetworniki ciśnienia i presostaty elektroniczne – nowości w ofercie Danfoss.
- **JUMO** – 1. System automatyki mTRON T; know-how JUMO w postaci nowoczesnej i elastycznej kompilacji sprzętu i oprogramowania, 2. Zapowiedzi nowości technologicznych w ofercie JUMO.
- **PEPPERL+FUCHS** – Nowoczesne rozwiązania na hali produkcyjnej.
- **SKAMER-ACM** – Pomiar wilgotności gazów. Technologie i ich zastosowania.
- **SIEMENS** – Nowości w aparaturze kontrolno-pomiarowej i w komunikacji przemysłowej firmy Siemens.
- **ABB** – 1. Nowy kompaktowy przepływomierz Coriolisa o wielkich możliwościach, 2. Nowe, energooszczędne zestawy napędowe od ABB - ACS850 z silnikiem reluktancyjnym.

Końcowym akcentem tej sesji również był blok dyskusyjny o tematyce napędów i instalacji elektrycznych. Dyskusja dotyczyła głównie przetwornic częstotliwości, zwłaszcza w układach pompowych i wentylatorowych.