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MACEDONIAN ACADEMY OF SCIENCES AND ARTS
ОДДЕЛЕНИЕ ЗА ТЕХНИЧКИ НАУКИ
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TAKI FITI, PRESIDENT OF THE MACEDONIAN ACADEMY OF SCIENCES AND ARTS

ON THE EVE OF THE GREAT JUBILEE - 50 YEARS OF THE MACEDONIAN ACADEMY OF SCIENCES AND ARTS 1967 – 2017

This year the Macedonian Academy of Sciences and Arts (MASA) marks and celebrates a great jubilee - 50 years of existence and work of our highest institution in the field of sciences and arts. Although on 22 February 2017 the 50th anniversary of the enactment of MASA in the Assembly of the Socialistic Republic of Macedonia was marked, and on October 10 it will be 50 years since the solemn establishment of MASA, we proudly emphasize that our roots, the roots of the Macedonian and Slavic cultural and spiritual continuity, are far back, in a time dimension which is measured in centuries. Because the mission of the Ss. Cyril and Methodius, the historical events that made Ohrid, with the famous Ohrid Literary School, already in the IX century to become the center of the Slavic educational and enlightening activity, which then spread throughout all Slavic countries, have fundamentally changed our contribution to the treasury of the European culture and civilization. And furthermore, centuries later, in the middle of the XIX century the Macedonian revival began, with a pleiad of our cultural and national activists. These processes at the beginning of the XX century resulted in the establishment of the Macedonian Scientific and Literary Fellowship in Saint Petersburg, led by Dimitrija Chupovski and Krste Petkov Misirkov, whose rich scientific, literary and cultural activities were a significant reflection of our spiritual continuity and identity, and an event that has marked the dawn of the Macedonian Academy of Sciences and Arts. This continuity will remain in the period between the two world wars, with a pleiad of artists in literature, art, music, philological, economic, legal and technical sciences. A few years after World War II, in 1949, in free Republic of Macedonia, the first state University of “Ss. Cyril and Methodius” was established, within which, in less than two decades, solid personnel resources were created which allowed rapid development of the higher education and scientific activity in our country. It was an event of great importance for the establishment of MASA as the highest institution in the field of sciences and arts.

This millennium pace and continuity in the development of art and scientific thought in our region is an indication and evidence that we are not a nation without its own roots, without its own history, without its own culture, and that the attempts to deny our identity, language, name, no matter where they come from, are residual of the Balkan anachronisms, and essentially speaking, they are absurd and retrograde.

Immediately after the establishment of MASA followed a period of rapid development, diversification and enrichment of its scientific and research activities and artistic work. Almost two decades after the establishment MASA entered the phase of its maturity and has grown and has affirmed as the fundament of the Macedonian science, language, culture and history and as one of the pillars and symbols of the statehood of the Republic of Macedonia.

Today, MASA, according to its integral concept, structure and function, has all the necessary attributes of a modern national academy of European type, and of course, performs the three basic functions typical of the European national academies: creating communication space for confrontation of different views and opinions on important issues in the field of sciences and arts, scientific and research work and advisory role.

The scientific and research activities and artistic work, in fact, constitute the core of the activity of MASA. The number of completed scientific and research projects and projects in the field of arts within MASA is impressive - around 600 projects in the past 50 years. Some of these projects are long-term and are mainly related to the strategic issues of specific national interest, and significant is the number of fundamental and applied research in all fields of science and art represented in the Academy. MASA members in their scientific research increasingly incorporate the international dimension in the work - in the recent years more than 60% of the scientific papers have been published in international journals, most of which have been published in journals with impact factor; 50% of the papers that have been published in proceedings of scientific and professional meetings are related to meetings held abroad, etc. In addition, the works of our renowned writers and poets, members of MASA, are translated into foreign languages, and their work has found its place in world anthologies. Our prominent painters and sculptors of the older and the younger generation have created and create masterworks that are regularly exhibited at home and abroad. It should be particularly noted that our two research centers - Research Center for Energy and Sustainable Development and the Research Centre for Genetic Engineering and Biotechnology “Georgi D. Efremov”, that have gained high reputation in the region and beyond, continue to successfully maintain the attained position. The work of the other research centers also enhances, including the newly established ones, which have begun to work on significant international scientific and research projects.

In its half-century of existence and work MASA developed a rich publishing activity. Since its establishment until today around 700 titles have been published - monographs, results of scientific projects, proceedings from scientific meetings, music releases, facsimile and jubilee publications, joint publications with other academies and scientific institutions, publications of solemn meetings, special issues of the departments of MASA etc. A special contribution to the publishing activities of MASA provides the “Trifun Kostovski” Foundation that has been existing and working for 18 years.

MASA proactively follows the changes and the new trends in the scope of the advisory function of the modern European national economies, and in that context the obligations arising from the project SAPEA - Science Advice for Policy by European Academies, initiated by the European Commission in order to intensify the cooperation of the European academies within their advisory role. Through the publication of the results of our scientific and research work, their presentation to the wider scientific and professional public in the country, to the government officials, etc., MASA participates in the policy-making in the field of sciences and arts and in the overall development of the country. The maintenance of the independence of MASA in carrying out the advisory role is our highest priority and principle.

In the recent years MASA has developed extensive international cooperation that contributes to the affirmation of the Macedonian scientific and artistic work and to the increasing of the reputation of MASA and of the Republic of Macedonia in international scale. Today, our Academy cooperates with more than 30 foreign academies and scientific societies and is a member of 7 international associations of academies. In the recent years the cooperation with the academies from the neighboring countries has been intensified, as well as with the Leibniz Society of Sciences from Berlin, and also, within the so- called Berlin process (Joint Science Conference of Western Balkans Process / Berlin Process) the cooperation with the German National Academy of Sciences - Leopoldina, with the French Academy of Sciences, the academies of Southeast Europe and others.

Due to the results achieved in its work, MASA and its members have won a number of high national and international awards. In the past 50 years, MASA has won around 90 awards and recognitions - charters, plaques, certificates of appreciation, medals and decorations from national and international scientific, educational, artistic and other institutions. Particularly, it should be noted that MASA has been awarded with the high decoration Order of the Republic of Macedonia for the contribution to the development of the scientific and research activity and artistic creativity of importance to the development and affirmation of the Macedonian science and state, which is awarded by the President of the Republic of Macedonia, as well as the prestigious Samuel Mitja Rapoport award of the Leibniz Society of Sciences from Berlin, which, for the first time, has been awarded to MASA. Today, 22 members of MASA have the status of foreign, corresponding and honorary members, as well as holders of honorary PhDs at around 60 foreign academies, scientific societies and universities.

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The developmental trajectory of MASA unambiguously confirms that the Academy, in its 50 years of existence and work, faced with periods ofheights, but also periods of descents and turbulences that are most directly linked to the situation in the Macedonian society, i.e. with crisis periods of different nature - the dissolution of the former common state (SFR Yugoslavia), problems with the recognition of the international status of the country after its independence, the embargoes and the blockades of the country in the early transition years, the internal conflict in 2001 and the political crisis in the last two-three years. In such crises and tense periods the criticism for the Academy grew - that MASA is an institution closed in itself, that MASA stays away from the current issues and developments in the country, and so on. On the one hand, it is a result of the insufficient understanding of the social role of the Academy - MASA is the highest scientific institution, where hasty reactions of columnist 'type', with daily political features are not characteristic. On the contrary, MASA uses facts and arguments. The basic activity of MASA, the results achieved in the scientific research and the artistic work is our identification within the national and international professional and scientific community, and beyond, within our society. On the other hand, this criticism and perception of MASA has a real basis in the fact that MASA, as opposed to the huge opus of implemented scientific and research and artistic projects still insufficiently affirms the results of its scientific and artistic production to the public. It is our weakness that we must overcome in the future. Of course, we cannot and must not "turn a blind eye" to the other weaknesses and omissions which, at least from time to time, we have faced with over the past 50 years and which we will face with in the future - insufficient scientific criticism of the events in the field of sciences and arts, insufficient resistance to political influence etc. On the contrary, in the future, we will have to clearly identify the weaknesses and the oversights in our work and to find out the right approaches to overcome them.

Today we live in a world of great science. The strong development of sciences, the new technological model based on information and communication technologies, the new wave of entrepreneurial restructuring of economies and societies, the globalization of the world economic activity, opened new perspectives to the economic growth and the development of individual countries and of the world economy as a whole. However, these processes, by their nature, are contradictory. The latest global financial and economic crisis of 2007-2009 revealed the contradictions of the globalization and the discontent of the people from it - the uneven distribution of wealth and power among individual countries, destruction of the resources and the environment worldwide, exhaustion of power of the existing technology and development models. These processes resulted in other problems - refugee and migration crises, strengthening of the regional and national protectionism despite the efforts to liberalize the international trade, fencing of the countries with walls at the beginning of the new millennium, changes in the economic and technological power and of the geo-strategic position and importance of entire regions and continents, etc. Nevertheless, one thing is a fact - societies that aspire to grow into societies and knowledge-based economies more easily deal with all the above mentioned problems, challenges and risks of the modern world. Of course, moving towards a development knowledge- based model assumes large investments of resources in education, science, research and development and in culture, simultaneously accompanied by well-conceived and devised strategies on development of these crucial areas of the human spirit and civilizational endurance. Hence, this fact, undoubtedly, emphasizes the special significance of the national academies of sciences and arts in achieving this objective.

In the recent years the Republic of Macedonia has been facing with the most difficult political and social crisis in the period after its independence. We are facing a crisis of the institutions, breach of the principles of the rule of law, the phenomenon of "captured state", a decline in the process of democratization of the society and falling behind on the road to the Euro-Atlantic integration processes. The problems that are now in the focus of our reality will require major reforms, much knowledge, energy and political will to overcome them. In this sense, and in this context, the role of MASA and of the overall scientific potential of the country in overcoming the crisis is also particularly important.

The above summarized evaluations and considerations about the development of MASA in the past 50 years, about the achievements in the realization of its basic activity, about the problems it faced and faces with, about the major challenges arising from the new age and which are determined with the changes in the international and national environment, they alone define the main priorities of our Academy in the forthcoming period:

- Our long-term goals are contained in the mission and vision of MASA as the highest institution in the field of sciences and arts. The mission of MASA is through the development of the basic functions that are characteristic for all modern national academies of European type, to give its full contribution to the inclusion of the Macedonian science and art in the modern European and world trends, and our vision is the Republic of Macedonia to become an advanced society based on science and knowledge;
- In the forthcoming years the focus of the scientific and research activity and artistic work of MASA, in cooperation with the other scientific and research institutions in the country and with government experts, will be particularly focused on the elaboration of issues and topics that are most directly related to the sources of the current political and social crisis in the country in order to offer possible solutions, approaches and policies to overcome it;
- The issues related to the Euro-Atlantic integration processes of the Republic of Macedonia, their continuous and persistent scientific monitoring and elaboration and active participation of MASA members in the preparation for the accession negotiations with the EU will remain a high priority on the agenda of MASA. Our ultimate goal is the Republic of Macedonia to become a democratic, economically prosperous and multicultural European country.

- The increasing incorporation of the international dimension in the scientific and artistic work of MASA, through the cooperation with foreign academies, scientific societies and other scientific institutions, through application and work on scientific projects financed by the European funds and the funds of other international financial institutions, also remains our important priority.

Let us congratulate ourselves on the great jubilee - 50 years of the Macedonian Academy of Sciences and Arts.

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MODELING EPIDEMIC SPREADING IN MULTIPLEX GRAPHS

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Abstract: The network structure can heavily influence the dynamic processes that occur in a network. The epidemic spreading processes and how they are affected by the network structure is still a hot topic in the research community. However, not so much is known how the composition complexity of a graph can influence the spreading process. Moreover, having in mind that today's network are not isolated, i.e. we are often switching between different types of networks, in this work we are extending the SIS model for non-linear dynamical systems on multiplex graphs. Using the proposed model we show that the composition complexity of a network (i.e. graph) slows down the epidemic process. The more the layers in the network the more the network is immune to epidemics. The second result from the simulations shows that if nodes are static and do not change the layer or they are highly dynamic (they change the layer in each time step) the disease will spread with a slower rate.

Keywords: Epidemic spreading, Multiplex graphs, Dynamical process, Nonlinear systems

1 Introduction

Spreading processes are one of the most present phenomena that occur in complex and composite networks, represented by spread of viruses and information in social or computer networks [1-6]. In the literature there are several approaches that analyze the epidemic spreading. One is the heterogeneous mean-field approach were nodes are divided in different degree classes and are given the same dynamical properties within a class [2, 3, 7, 8]. This approach suffers from inaccuracy, thus, a more successful approach used a deterministic non-linear dynamic system (NDLS), see [9] and [10]. Using this kind of approach, one can construct the whole phase diagram of different infection models determining the critical properties.

With the proliferation of network science, the epidemic models developed by the scientific community incorporate the structure of the underlying network [2]. This kind of approach produced results giving the threshold for networks with exponentially bounded degree distribution. Such modeling has attracted considerable attention in spreading processes over communication systems [11-13] and online social communities [14], [15]. However, dynamical processes that happen in the today's networked world are never isolated. Often they are interwoven with other dynamic systems and processes. This is due to the fact that the social networks, technical-technological networks, biological and physical networks are usually interconnected by their nature. Thus, it is very grim to find an insulated complex network, whose processes do not depend on the dynamical processes that occur in some other network. For instance, a person may be influenced by some commercial ad in Facebook and later he might retweet the information on Twitter or by finding an interesting place to visit in Foursquare he might tell his friends or family about this place and go out the next time. Another example is the power grid and telecommunication network, where some defect or attack in the power grid might reflect the operation of the telecommunication network and vice-versa. Moreover, flight cancellation in the air traffic will certainly reflect the everyday operation on the railway and road traffic. Thus, the dynamics in the real networks is composite, as a consequence of the interconnection between different layers (networks) in a multiplex network. In order to analyze the spreading dynamics that might occur in these composite complex networks, first we need to represent their interdependence on graph level. A good mathematical apparatus for the analysis of dynamical processes in these composite systems are multiplex graphs (i.e. networks), introduced recently in [16] and overviewed in details in [17]. Multplex graphs are used to describe multilevel system, consisted of coupled layered networks, where each layer have different connections and features. Besides the interconnections inside one layer, another very important feature of these multiplex graphs is how the nodes in different layers are interconnected between each other. These interconnections between layers heavily affect the undergoing dynamical process in the multilevel systems.

The main goal of this work is to analyze the epidemic spreading in these composite multiplex graphs and to show how the different interconnection between layers influences the spreading dynamics.

The outline of the paper is the following. In Section 2 we give an introduction to the epidemic spreading modeling, as well as, we show two different models, i.e. discrete and stochastic analytically tractable model, which will be extended for multiplex graphs in Section 4. In Section 3 we define multiplex graphs and we model the interconnections between the layers using discrete-time Markov chains, whereas, in Section 4 we propose SIS and SI model for multiplex graphs. The results from the analysis are shown in Section 5 and Section 6 concludes this work.

2 Epidemic Spreading Model Definition

The main purpose of using models for epidemiological dynamical processes is to enable prediction of the epidemic size after a certain time period for a given initial system state and specific parameters of the underlying model. Depending on the states in which the nodes can be, there are several different epidemiological models, such as: SIR (Susceptible-Infected-Recovered), SIS (Susceptible-Infected-Susceptible) and SI (Susceptible-Infected). One of the existing approaches to analyze these models is the deterministic approach by which the spreading processes are mathematically defined based on the rate by which the nodes switch from one to another state [18], [19]. The downside of this approach is that it does not take into account the interconnection between the nodes, i.e. it does not consider the system of individuals as a complex network. The other approach is stochastic one and the key parameter for the epidemic spreading are the connections between the nodes. The system is considered as a complex network, and the switching rates are represented as probabilities for changing the state of the node, for each node separately [2], [20]. In the following we will describe the stochastic SIS and SI spreading models in a complex network.

Consider a population of N actors, connected in a complex network structure, which is represented by a simple, undirected, unweighted, connected and unipartite graph $G=(V, E)$ with node set V and edge set E. The graph can be represented by its adjacency matrix A, where $a_{ij}=1$ if $a_{ij}\in E$ and 0, otherwise. Each node can be in one of two possible states: susceptible (S) and infective (I). The nodes in the S state are healthy ones and upon contact with infective nodes may become infective and spread the disease. At time 0 there is non-empty finite set of nodes in state I and all other nodes are in the state S. The state of a node is represented by a state vector having 1 in the present state and zero in the other state, i.e. $\mathbf{s}_i(t) = [s_i^S(t)\; s_i^I(t)]^T$, for all $i \in \{1,\dots,N\}$. Defining the probability mass function (PMF) of node i at time t as $\mathbf{p}_i(t) = [p_i^S(t)\; p_i^I(t)]^T$ the evolution of the SIS model can be described as:

$$\begin{aligned} p_i{}^S(t+1) &= s_i^S(t)(1-f_i(t)) + \delta s_i{}^I(t) \\ p_i{}^I(t+1) &= s_i^S(t) f_i(t) + (1-\delta) s_i{}^I(t) \end{aligned} \tag{1}$$

And

$$\mathbf{s}_i{}^I(t+1) = MultiRealize[\mathbf{p}_i(t+1)] \tag{2}$$

where $MultiRealize[\cdot]$ is a random realization of $\mathbf{p}_i(t+1)$. The model parameter $0 \leq \delta \leq 1$ is the probability of curing, i.e. the probability that a node will change its state from I to S. In this work we consider only infection spreading through reactive process, i.e. in each time step there as many stochastic contagions as there are neighbors to a node [21-23]. However, the infection spreading can be also modelled using contact process, i.e. each time step involves single stochastic contagion per infective node [24-26]. For the reactive process the probability $f_i(t)$ that a susceptible node i receives infection from its infective neighbors, used in Eq. 1, is given by:

$$f_i(t) = 1 - \prod_{j=1}^{N}\left(1 - \beta a_{ij} s_j^i(t)\right), \quad (3)$$

where $0 \leq \beta \leq 1$ is the probability of disease transmission from an infective to a susceptible node.

The system defined with Eq. (1-3) is realistic, discrete and thus, it is suitable for our simulations presented in Section 5. However for analytical study, one has to use the Non-Linear Dynamical System (NLDS) as defined in [9], and later adopted to the SIS process as in [27]. Using a system of probabilistic equations the following set of difference equations are obtained for the probabilities of states S and I:

$$\begin{aligned} p_i^S(t+1) &= p_i^S(t)(1 - f_i(t)) + \delta p_i^I(t) \\ p_i^I(t+1) &= p_i^S(t) f_i(t) + (1-\delta) p_i^I(t) \end{aligned} \quad (4)$$

where:

$$f_i(t) = 1 - \prod_{j=1}^{N}\left(1 - \beta a_{ij} p_j^i(t)\right). \quad (5)$$

Using $p_i^S(t) + p_i^I(t) = 1$ and $x_i = p_i^I$, the following nonlinear dynamical system is obtained:

$$x_i(t+1) = (1 - x_i(t)) f_i(t) + (1-\delta) x_i(t) \quad (6)$$

This system has two globally asymptotic stable fixed points, one is the origin $x_i = 0$, given that $\beta < \frac{\delta}{\lambda_{1,A}}$ and the other represents the endemic state in the network, x_i^* for all *i*, where $\lambda_{1,A}$ is the largest eigenvalue of the adjacency matrix. For more details, see [9], [10] and [27].

3 Multiplex Graphs

A multiplex graph is defined as a graph with MxN nodes and M layers. For simplicity, one can assume only two layers (M=2) where $G_1=(V_1,E_1)$ and $G_2=(V_2,E_2)$ are simple and undirected graphs such that $V_1=\{v_1,\ldots,v_n\}$ and $V_2=\{u_1,\ldots,u_n\}$. A multiplex graph $(V,)$ is defined by $V=V_1 \cup V_2$ and $E=E_1 \cup E_2 \cup \{v_{1,1}\} \cup \ldots\{v_n,u_n\}$. We can consider $\mathbf{x}=[\mathbf{x_1},\ldots,\mathbf{x_n}]^T$ and $\mathbf{y}=[\mathbf{y_1},\ldots,\mathbf{y_n}]^T$ as n-dimensional vectors where $\mathbf{x_i}$ is a m-dimensional vector assigned to a node i in V_1 and $\mathbf{y_i}$ is a m-dimensional vector assigned to the same node i in V_2. Let A_1 and A_2 be the adjacency matrices associated to graphs G_1 and G_2, respectively, where $a_{ij}{}^1=1$ if $a_{ij}{}^1 \in E_1$ and 0 otherwise (similar definition follows for $a_{ij}{}^2$). Small toy example multiplex graph is given in Figure 1.

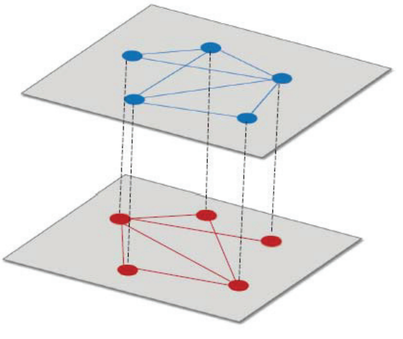

Figure 1: Small toy example multiplex graph

However, the interlinks between the two layers represent probabilities that a given node i will change its layer in time step t. The rationale is that a given actor in a network stays only for a certain time in one network and then switches to another network, meaning that nodes in each layer have to have self-loops representing the probability that the actor will stay in the same layer. This extension of the multiplex graphs can be explained for instance, in social networks, where people spend some time of their time with their colleagues, then they switch to their family and/or to their friends. Another example are the online social network, where users switch between Facebook, Twitter, Instagram, mobile communication, etc. and receive different information from different friends in their networks. Thus, the switching of a given node i between the layers can be represented by state-transition stochastic matrix L with dimension MxM, where M are the number of layers. Again for simplicity, we will consider that the multiplex graph has two layers (i.e. M=2) and the nodes' dynamics can be represented using homogeneous discrete time Markov chain and corresponding matrix $L = \begin{bmatrix} l_{11} & l_{12} \\ l_{21} & l_{22} \end{bmatrix}$ as in *Figure 2*, where $q_i^1(t)$ is the probability that the node i in time step t will be in layer *1* and $q_i^2(t)$ is the probability that i will be in layer 2.

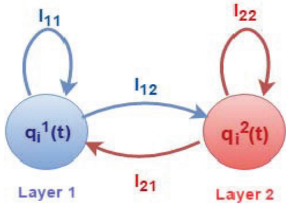

Figure 2: Interlayer switching Markov chain

It is obvious that it is easy to generalize the Markov chain to M states representing the M different layers and to make it heterogeneous, i.e. each node to have different dynamics according to which it will switch to a different layer. This would mean that in each time step the resulting network will be the intersection between the horizontal layers (i.e. the static configuration, giving the connections of the nodes in each layer) and the vertical nodes' dynamics. Another interesting observation is that one of the states in the Markov chain could represent an off state, i.e. a state in which the actor (i.e. the node) has no connections and communications with the other nodes in the network. The elements of the adjacency matrix in this off-layer will be zeroes. The analogy in real life is that sometimes the actor is isolated having no interactions with any other actor. However, in this work we will consider a simple 2x2 discrete time homogenous Markov chain without an off state. Having this assumption and that we are dealing with homogenous discrete Markov chains, using an initial stochastic matrix L one can obtain the probabilities $q_i(t)$ in each step t, as well as the stationary state of the Markov chain. However, we can lose index i, because we are concerning homogenous Markov chain for each node i. Thus, for a given initial status vector of the Markov chain **q**[0], with dimensions 1xl, the expected value of the status matrix in time step t in closed form is equal to:

$$E(q[k]) = E(q'[0])((L))^{t} \qquad (7)$$

The stationary vector **q**, when $t \rightarrow \infty$, will depend only on the structure of the Markov chain. This comes from the ergodicity and the stochasticity of the Markov chain matrix *L*:

$$lim_{t \rightarrow \infty} L^t = 1\pi' \tag{8}$$

where π is the left eigenvector which corresponds to the dominant eigenvalue and it is positive and normalized. From (1) and (2) we can easily obtain that:

$$lim_{t \rightarrow \infty} E(q^t[k] \| q[0]) = lim_{t \rightarrow \infty} E(q[0])([L])^t = q[0]1\pi' = 1\pi' = \pi' \tag{9}$$

Eq. (9) shows that each node will be in layer *l* with probability of π_l no matter the initial layer in which the node has been.
In the following section we will extend the SIS model by including the internal Markov chain in each node in the multiplex graph.

4 Epidemic Spreading Model on Multiplex Graphs

In this section we will extend the NLDS SIS model, as defined in Eq. (4) for multiplex graphs. Thus, each node besides a current state will have a current layer in the graph on which is currently active, see Section 3. The stochastic SIS model on Multiplex graph can be described using the following system of equations:

$$\begin{aligned} p_i^S(t+1) &= \sum_{l=1}^{M} p_i^S(t)\left(1 - f_i^l(t)\right) q_i^l(t) + \delta p_i^I \\ p_i^I(t+1) &= \sum_{l=1}^{M} p_i^S(t) f_i(t) q_i^l(t) + (1-\delta) p_i^I(t) \end{aligned} \tag{10}$$

where

$$f_i(t) = 1 - \prod_{j=1}^{N}\left(1 - \beta a_{ij} p_j^I(t) q_j^l(t)\right). \tag{11}$$

and the probability that a node i will be at a given layer is calculated using the probability vector q(t), given by:

$$q(t+1) = q(t)L$$

Again, using $p_i^S(t) + p_i^I(t) = 1$ and $x_i = p_i^I$, the following nonlinear dynamical system is obtained:

$$x_i(t+1) = (1 - x_i(t))\sum_{l=1}^{M} q_i^l(t) f_i^l(t) + (1-\delta)x_i(t) \tag{12}$$

The system in (12) can be further used for analytical study of the system dynamics in multiplex graphs, which is beyond the scope of this work. Furthermore, by substituting $\delta = 0$ (i.e. there is no curing probability), one can easily obtain the system equations for the SI model.

5 Numerical Results

In this section through simulations we show how the interconnection between the layers, i.e. the transition probabilities of the Markov chain influences the spreading in the network. We are using the model defined in Section 4, where $\delta = 0$ (i.e. there is no curing probability) and we set the probability of disease transmission to $= 0.02$. Our multiplex graph is consisted of two layers, where each layer is a small-world graph built using the Watts-Strogatz model [28] with 300 nodes, 900 edges and rewiring probability of 0.08. For the switching probability between the layers we have used the following state-transition matrix $L = \begin{bmatrix} 1-s & s \\ s & 1-s \end{bmatrix}$, where when s is closer to 1 it means that the nodes are switching their layer in almost every time step, whereas, when s is close to 0 it means that nodes are rarely changing their current layer. We will call s the switching parameter. The number of infected nodes at time step 0 are 6 randomly chosen nodes. The simulations were averaged on 20 example multiplex networks. In the first scenario, the initial layer of each node was also randomly chosen. The number of infected nodes as a function of the time steps and the switching parameter s for this scenario is shown in

Figure 3. The results show that in highly static (i.e. when s is 0) and highly dynamic multiplex networks (i.e. *s* is 1) the rate of the spreading is lower compared to the case when s is for instance equal to 0.05 or 0.95. In our simulations for this scenario the biggest spread after 100 time steps was obtained when *s*=0.65.

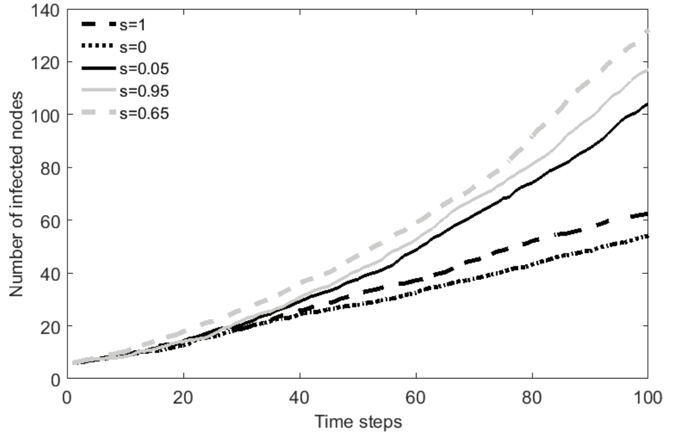

Figure 3: Number of infected nodes for different switching parameter

In the second scenario we compare the spreading in the multiplex networks with the spreading in one layer small-world network. As expected the spreading of the disease according to our model is reduced when nodes are switching their layer. The number of infected nodes in the multiplex graph (when *s*=0.25) is 50% less compared to the one layer graph (see Figure 4).

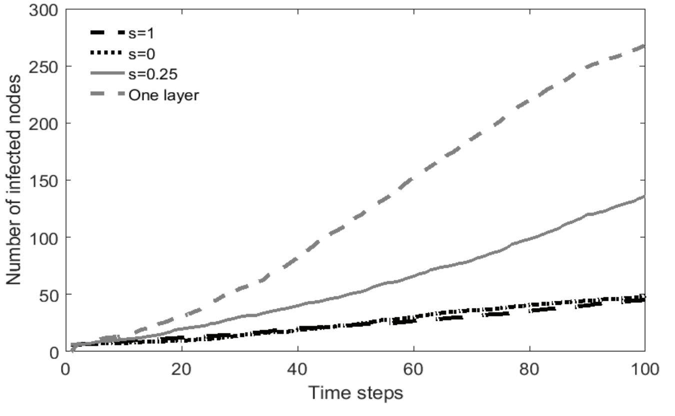

Figure 4: Comparing the spreading process in multiplex networks with single-layered networks

In order to compare the spreading process on multiplex graphs with different number of layers we have used state-transition matrix *L* with dimensions *MxM*, where each element l_{ij} was equal to *1/M*. In *Figure 5* we plot the obtained results for $M = 1,5$. The results show that the number of layers heavily influences the spreading dynamics, i.e. the more composite the network is, the less number of nodes are infected in a given time window.

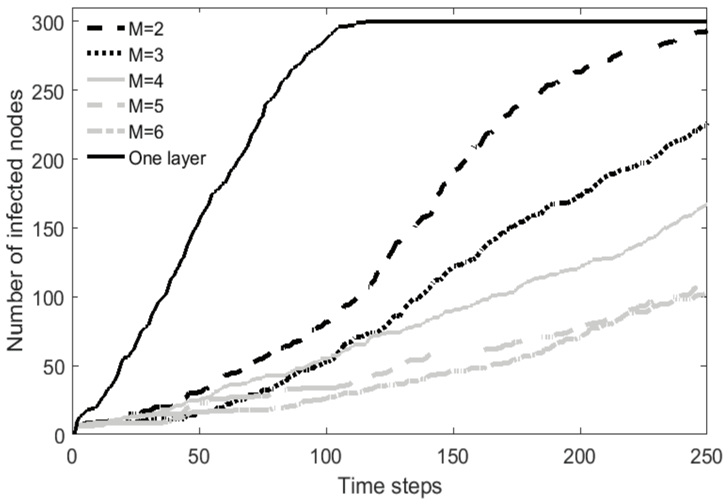

Figure 5: Spreading dynamics as a function of the number of layers in a multplex graph

6 Conclusion

In this paper we have extended the SIS model of infection spreading in multiplex networks, by introducing the switching probability of nodes in multiplex graphs. In this way, the behavior of a node (i.e. in which layer will be at each time step) is modeled with a discrete-time Markov chain. The proposed model and the numerical simulations lead us to the following main contributions of this work. The more composite the network is, the slower the spread is in the network. Moreover, in multiplex network with 2 layers, when the nodes are switching layer in each time step t, it will results in slower spreading rate. The same holds when nodes are staying in the same initial layer in each time step.

The extend model proposed for multiplex graphs is analytically tractable and can be used for further analytical study. The proposed nonlinear dynamical system for an analytically obtained critical value of $\frac{\beta}{\delta}$ will have two globally asymptotically stable fixed points, which are question for further research. Finally, in our future work we will include the off state and multiplex graphs with more than 2 layer in the analytical study as well as the numerical simulations.

References

1. M. E. J. Newman, Physical Review E 66, 016128 (2002).
2. R. Pastor-Satorras and A. Vespignani, Physical Review Letters 86, 3200 (2001).
3. R. Pastor-Satorras and A. Vespignani, Physical Review E 63, 066117 (2001).
4. V. M. Eguluz and K. Klemm, Physical Review Letters 89, 108701 (2002).
5. Y. Wang, D. Chakrabarti, C. Wang, and C. Faloutsos, In Proc. Symp. Reliable and Distributed Systems, Florence, Italy, Oct. 2003.
6. M. Draief, A. Ganesh and L. Massoulie, Threshold for virus spread on Networks, Ann. Appl. Probab. Volume 18, Number 2, 359{378 (2008).
7. M. Barthelemy, A. Barrat, R. Pastor-Satorras, and A. Vespignani, Phys. Rev. Lett. 92, 17870 (2004).
8. J. Gomez-Gardenes, V. Latora, Y. Moreno, and E. Profumo, Proc. Nat. Acad. Sci. USA 105, 1399-1404 (2008).
9. D. Chakrabarti, Y. Wang, C. Wang, J. Leskovec, and C. Faloutsos, Epidemic Thresholds in Real Networks, ACM Trans. Inf. Syst. secur. Vol. 10, 13, (2008)
10. S. Gomez, A. Arenas, J. Borge-Holthoefer, S. Meloni and Y. Moreno, Discrete-time Markov chain approach to contact-based disease spreading in complex networks, EPL 89, 38009 (2010).
11. J. Kleinberg, “Computing: the wireless epidemic.” Nature, vol. 449, no. 7160, pp. 287–8, Sep. 2007. [Online]. Available:
http://dx.doi.org/10.1038/449287a.
12. P. Wang, M. C. Gonzalez, C. A. Hidalgo, and A.-L. Barabasi, ´ “Understanding the spreading patterns of mobile phone viruses.” Science (New York, N.Y.), vol. 324, no. 5930, pp. 1071–6, May 2009. [Online]. Available:
http://www.sciencemag.org/ content/324/5930/1071.abstract.
13. M. Meisel, V. Pappas, and L. Zhang, “A taxonomy of biologically inspired research in computer networking,” Computer Networks, vol. 54, no. 6, pp. 901–916, Apr. 2010. [Online]. Available:
http://dl.acm.org/citation.cfm?id=1752615.1752711.

14. A. Guille, H. Hacid, C. Favre, and D. A. Zighed, “Information Diffusion in Online Social Networks: A Survey,” SIGMOD Rec., vol. 42, no. 2, pp. 17–28, Jul. 2013. [Online]. Available:
http://doi.acm.org/10.1145/2503792.2503797.
15. J. Borge-Holthoefer, R. A. Banos, S. Gonzalez-Bailon, and Y. Moreno, “Cascading behaviour in complex socio-technical networks,” Journal of Complex Networks, vol. 1, no. 1, pp. 3–24, Apr. 2013.
16. S. Gómez, A. D. Guilera, G. G. nes, C. J. P. Vicente, Y. Moreno and A. Arenas, “Diffusion dynamics on multiplex networks,” *Physical Review Letters*, vol. 110, pp. 028 701+, Jan. 2013.
17. S. Boccaletti, G. Bianconi, R. Criado, C.I. del Genio, J. Gómez-Gardeñes, M. Romance, I. Sendiña-Nadal, Z. Wang, M. Zanin, “The structure and dynamics of multilayer networks”, Physics Reports Volume 544, Issue 1, 1 November 2014, Pages 1–122.
18. T. Tassier: SIR Model of Epidemics, Journal of Mathematical Biology, 39 (6), 1999.
19. T.Tassier: Introduction to The Modelling of Epidemics – SIS Models, Duke University, 2005.
20. M. Bartelemy, A. Barrat, R. Pastor-Satorras, A. Vespignani: Velocity and Hierarchical Spread of Epidemic Outbreaks in Scale-free Networks, Physical review letters, vol. 92, no17 , 2004.
21. L. K. Gallos and P. Argyrakis, Absence of Kinetic Effects in Reaction-diusion processes in scale-free Networks, Phys. Rev. Lett., 92 (2004) 138301.
22. M. Catanzaro, M. Boguna and R. Pastor-Satorras, Diff usion-annihilation processes in complex networks, Phys. Rev. E, 71 (2005) 056104.
23. V. Colizza, R. Pastor-Satorras and A. Vespignani, Reaction-diffusion processes and metapopulation models in heterogeneous networks, Nature Physics, 3 (2007) 276.
24. J. Marro and R. Dickman, Nonequilibrium phase transitions in lattice models, (Cambridge University Press, Cambridge) 1999.
25. C. Castellano C. and R. Pastor-Satorras, Non-mean-field behavior of the contact process on scale-free networks, Phys. Rev. Lett., 96 (2006) 038701.
26. C. Castellano and R. Pastor-Satorras, Routes to thermo dynamic limit on scale-free networks, Phys. Rev. Lett., 100 (2008) 148701.
27. Daniel Smilkov and Ljupco Kocarev, The influence of the network topology on epidemic spreading, Phys. Rev. E 85, 016114 – Published 24 January 2012.
28. Duncan J. Watts and Steven H. Strogatz, Collective dynamics of 'small-world' networks, Nature 393, 440-442 (4 June 1998) | doi:10.1038/30918; Received 27 November 1997; Accepted 6 April 1998.

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SOUTH EAST EUROPEAN UNIVERSITY CAMPUS: SUSTAINABLE SMALL-SCALE POWER SUPPLY NETWORK AND REAL LABORATORY

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Abstract: South East European University (SEEU) is under realization of a Low Emission University Campus through the implementation of a Climate Action Plan (CAP) since 2011. The main goals of CAP are final carbon neutrality and energy efficiency. Distributed Energy Resources (DER) of SEEU campus with renewable energy sources (solar and biomass) and the energy management system (EMS) with implementation of smart technologies represent a sustainable small-scale power supply network (SEEU Microgrid) and hands-on laboratory to switch to a new sustainable paradigm. In this paper first of all are presented realization and investigations at this power supply network. Implementation of smart technologies will help to balance power generation to demand, to reduce the potential for blackouts and monitoring of power quality (PQ). This vision will enable also the realization of the objectives in terms of energy security and sustainability with economic and social impact. With the broad set of operational issues being addressed, SEEU is well suited also as a research and hands-on laboratory for energy sustainability. This Real Sustainable Energy Laboratory (RSEL) is very important university resource for education, research and link with industry. The case of collaboration with industry, for correction of power factor (PF), improvement of power quality (PQ) parameters and efficiency it is shown as well. The real laboratory provides foundation for research in the major features of global energy issues, sustainable energy technologies and their interactions with economy, the environment and policy. The summarized presentation of the university campus with integrated energy supply as a real sustainable laboratory and the different measured data with implementation of smart technologies verify of two hypotheses: Realization of CAP activities for decreasing the CO_2 emissions decreases energy consumption and second hypothesis: The integration of renewable electric energy resources increases the Power Quality (PQ) at small power supply network. At the same time, it is shown also the possibilities for balancing of power generation to demand, increasing power efficiency and security. Results of measurements with smart meters and high resolution PQ analyzers verify also very close relations of power factor, power consumption, efficiency and carbon neutrality.

Keywords: energy management sytem, power quality, smart technologies, bottom-up approach, energy strategy, demand response.

1. Introduction

Sustainable energy strategy (SES) for a small-scale power supply network can be of importance for realizing national strategies. This methodology in building general strategies represents a “bottom-up” approach.

A few years ago SEEU started to manage net carbon emission, enenergy efficiency and use of renewable energy sources. The aims of these activities are commitments on climate changes, sustainability, economic benefits and education. SEEU CAP [1] represents a ten year strategic plan for how the university campus will undertake the path to carbon neutrality. Moreover, a pilot sustainable initiative (pilot project) is a part of the CAP as well. Besides using renewable energy sources and implementation measures: continually measurement, monitoring and control, are also part of project for realization of microgrid concept. This will be a real laboratory for research and hands-on education of students and staff within the campus in the fields of energy efficiency, use of renewable energy sources and new technologies. For development of professional competences, SEEU academic teaching activities are based on triangle, teaching-innovation-research and is focused on development of institutional capacities. The goal is to enhance competences in the field of sustainable energy in general and small size energy systems in particular. The development of SEEU university staff and student's competences will be in accordance with energy research priorities (WBC-INCO Report 2012) and future labor market needs of Republic of Macedonia. The final goal is the realization sustainable energy strategy of the university.

The approach of model "paid-from –savings" using a sustainable program at a Universities [18] for academy is not enough. At Universities the awareness and responsibility for environment of academic communities, faculty, staff, students and community, it is of big importance which in the end represents a financial benefit also.

The national energy strategies consider the issues, such as legislation and regulatory changes, generation and transmission of energy, appliance efficiency standards, fuel standards, sustainability and many more. General principles for the functioning of the energy sector in the Strategy for Energy Development in the Republic of Macedonia until 2030 [2] are:

- Provision of energy security
- Improvement of energy efficiency
- Utilization of renewable energy sources
- Shift of the energy sector in Macedonia to market conditions
- Environmental protection, etc.

A combination of national and local strategic planning will result in action plans being successful and targets met. It is known that to build an energy strategy, one must focus on initiatives that will increase and diversify the energy supplies, including alternative and renewable energy, with a more efficient use of existing resources and, in general, a use of energy more efficiently [3]. Local action and planning is necessary to comply with the nation-wide energy strategies.

SES can be prepared at different levels: globally, regionally, locally, and as a small community strategy [4, 5]. Moreover, different sectors across the region or countries, public and private companies, and institutions can act and address energy challenges that they face as well. The actions required to realize the SES are different at different levels and with different size and impact. However, action can be taken successfully also in a small-scale power supply network based on SES of smaller communities, institutions, companies, buildings and houses, as a part of a general strategy. The bases of a general SES represents action taken to minimize demand for energy and cut unnecessary energy use as efficiently as possible. Additionally to use of renewable energy sources the use of fossil and other fuels should be in a cleaner and more efficient manner. Action taken in a small scale power supply network based on sustainable energy strategy for a small community represents a microgrid [6, 7].

2. The SEEU Concept as a Sustainable Small-Scale Power Supply Network

Education plays vital role in the efforts to move towards the goal of sustainability in society. While training initiatives have started to inform the campus community, most people are still unaware of their individual impact on the environment and have little knowledge of environmental issues in general. This lack of knowledge is a symptom of what society has forgotten his original relationship with the environment, and therefore only a big change in people's understanding of nature and the subsequently resulting interaction with the natural environment will lead to a sustainable relationship between humans and the earth. Education extends beyond the classroom at SEEU and other universities. In this case, at SEEU, outreach to campus and the surrounding community is an integral part of student education and sustainability. The idea behind the penetration of microgrids concept is to achieve total energy independence at SEEU and Small Scale University Campus grid as a Real Sustainable Energy Laboratory.

2.1 SEEU CAP

The methodological approach for the realization of a Low Emission Campus through the implementation of the CAP at SEEU foresees the analysis of the current energy consumption, greenhouse gases (GHG) emissions and the integrated planning for the implementation of environmental-friendly measures. Following the realization of the Greenhouse Gas Inventory (GGI), the CAP represents a powerful tool to reduce Universities carbon footprint, aimed at delineating strategies and a timeline for reducing greenhouse gas emissions. Furthermore, it allows pursuing the goals of integrating sustainability and climate action in all aspects of teaching, research, and community outreach. Universities can provide both practical and moral leadership to society's efforts to address climate change by showing real steps in reducing their own emissions.

After the publication of the GHG inventory, a representative building was selected in order to create a pilot sustainable initiative, aimed at showing the campus commitment towards energy efficiency and use of renewable sources. This will represent a sustainable model of low emission and high efficiency building as the model for the future realization of the eco-campus. [1]

Fuel substitution and better fuel diversity could also lead to improved sustainability of energy use. In addition, following the EU commitment to provide secure, competitive and sustainable energy as a driving force for the development of a low carbon economy. SEEU is determined to become a pioneer concerning practical implementation of intelligent Microgrid solution in the region. According to this concept, the achievement of Sustainable Energy Campus will become a reality within no more than 10 years. Figure 1 shows the basis of SES at SEEU.

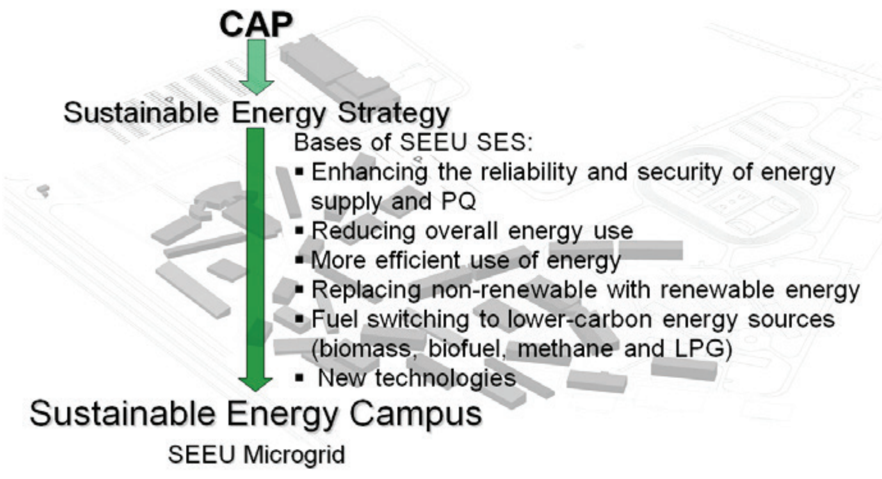

Figure 1: Basis of SEEU SES

Climate Action Plan after the number of reviews has undergone shifts during implementation. In figure 2 it is shown CAP Implementation Progress Time Schedule activities.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Baseline (tCO_2e)	5,085	5,230	5,191	5,242	5,295	5,348	5,401	5,455	5,510	5,565	5,621	5,677
CAP – subtotal (tCO_2e)	5,085	5,230	5,191	5,016	4,705	4,389	4,206	4,135	4,000	3,864	3,755	3,646
CAP implemented (tCO_2e)	5,085	5,230	5,016	4,705	4,389	4,206	4,135	4,000	3,864	3,755	3,646	3,420
Solar Thermal							33%	33%	34%			
Foundations Insulation								50%	50%			
Selective Collection						100%						
Lamps Replacement			50%	50%								
Photovoltaic				25%	25%					20%	20%	10%
SEEU Shuttles			50%	50%								
Videoconference			50%	50%								
Behavior Modification			50%	50%								
Carpool/Public Transport Policy					50%	50%						
Fuel Switch												Biomass
Cumulative Reduction			3%	10%	16%	19%	21%	23%	26%	28%	30%	35%
Annual Implementation Cost (€/y)			157,685	720,185	812,500	258,000	125,237	850,237	854,032	450,000	450,000	395,000
Cumulative Implementation Cost (€)			157,685	877,870	1,690,370	1,948,370	2,073,607	2,923,845	3,777,877	4,227,877	4,677,877	5,072,877

Figure 2: CAP Implementation Progress Time Schedule, Change in CAP Related to Fuel Switch

2.2 The Sustainable Initiative

Distributed Energy Resources (DER) of SEEU campus represents small-scale energy system. Research in Energy management of DER is a bottom-up approach for realization of sustainable energy strategy for energy systems. It includes energy efficiency, renewable energy and smart technologies and these are topics in teaching curriculums. As a further development, a microgrid evolves in an intelligent microgrid system. Specially developed tools will be incorporated in the microgrid infrastructure based on IT technology, intelligent measurement, virtual instrumentation and control and regulation with intention to create unique SCADA system. The concept is based on intelligent monitoring and control on electrical and non-electrical parameters [8].

Data acquisitions process of electric current and voltage are taken into consideration and compared according to the Power Quality Standard EN50160. The implemented concepts of an intelligent microgrid: monitoring, controlling, and managing, based on grid and IT resources, makes possible high power quality standards. Accordingly, a number of PQ standard problems, such as: continuity of service, energy outflows during demand peaks, variation in voltage (overvoltage, flicker and dips), magnitude, harmonic content in the waveforms, total harmonic distortion (THD), variations in the frequency, can be solved [9].

The DER concept can play an important role in transforming the conventional electricity transmission and distribution grid into a unified and interactive energy service network. On the other side, an intelligent microgrid will help to balance power generation to the demand. It will also enable to integrate alternative energy sources, such as biomass and solar plants.

In general, Small-scale University Campus Power Supply Network as a Real Sustainable Energy Laboratory will contribute to research and development of contemporary energy sector technologies that will tell us when the cheapest or cleanest power is available. This will allow us to change our energy consumption patterns to reduce our costs, our carbon footprint, and match our demand cycle to coincide with a smarter power grid infrastructure.

The installation of 100 kWp PV plant at SEEU campus has led to CO_2 emission reduction by 129 tCO2e/y and through energy-carrier switching measure (oil to biomass) within the centralized heating system CO_2 emission reduction corresponding to 626 tCO2e/y has been achieved. Planned and reached GHG Emission Reductions through CAP Implementation is presented in Figure 3.

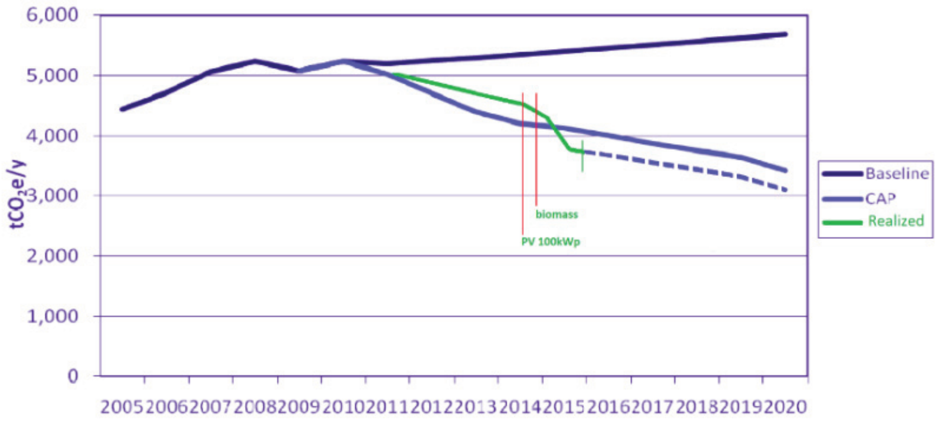

Figure 3: Planed and reached GHG Emission Reductions through CAP Implementation

SEEU Climate Action Plan, existing resources, IT infrastructure and research realized during the last six years represent bases and the background for realization of SEEU University Campus as a Real Sustainable Energy Laboratory.

3. SEEU University Campus as a Real Sustainable Energy Laboratory

The rapid increase in the amount of knowledge over time, and on the other side man's inability to absorb large amount of information initiates the need to find new methodologies for knowledge transfer. The interdisciplinary Sustainable Energy Laboratory recognizes the growing importance of computation as a methodology for tackling complex scientific and engineering problems. Combined with mathematical modeling and experimental observations, scientific computation enables engineers and scientists to solve problems that are otherwise intractable. This real sustainable energy laboratory provides a solid foundation for modeling, simulating, and solving complex problems. Providing a unified multidisciplinary teaching platform for hands-on learning in areas such as measurements, sustainable energy, control and communication will enhance engineering skill practices for engineering students at undergraduate, master and PhD study programs. SEEU Sustainable Energy Laboratory will provide competence: to design and construct experiment, as well as to analyze and interpret data, to formulate or design a system, process or program to meet desired needs, to function on multidisciplinary teams and to identify and solve engineering problems.

Higher Education Institutions in the Western Balkan Countries are currently not able to deal with the characteristic attribute such as fundamental research and training, and collaborative activities with industry partners in the field of energy (WBC-INCO Report 2012). Sustainable Energy Laboratory will focus on energy and provide links between local academia and industry. The Laboratory will be at disposal for university staff, but also commercially available for industry. For realization of R&D activities in the field of Sustainable Energy, existing infrastructure will be used: DER of SEEU campus, Sustainable Energy building (SEEU Building 304) and Sustainable Energy Laboratory as a part of a whole Real Sustainable Energy Laboratory of the University.

In the existing energy infrastructure of SEEU a 100 kW PV system was installed and moreover a shift of fuel for heating and cooling with a capacity of 1.6 MW, replacement of fuel oil with biomass was implemented and planned natural gas cogeneration - CHP. This energy infrastructure represents DER of SEEU campus.

Representative building was selected in order to create a pilot sustainable initiative, (Sustainable Energy building, SEEU Building 304), aimed to showing the commitment toward energy efficiency and renewable energy. This is real laboratory for research and hands-on education of staff and students in the fields of energy systems, use of renewable energy resources and new technologies. In this Sustainable Energy Building the following are installed: PV with capacity 5 kWp, power storage with capacity of 38 kWh, geothermal system with capacity of 20 kW, solar thermal system with capacity of 4 kW, fresh air ventilation system with efficiency of 97%, etc.

In Sustainable Energy Building is located Sustainable Energy Lab too for realization of specific measurements, analyses of measured data and monitoring of energy consumption and Power Quality of SEE University Campus Power Supply Network. For future research in close correlation with new curriculums and collaboration with industry, the laboratory is equipped with additional devices and instruments. The Lab will be at disposal for university staff and students. This Lab can help in development of policies, methods and knowledge needed for energy optimization, conservation, efficiency and security. The Laboratory will strengthen the role of university R&D in the field of sustainable energy and cooperation with industry, bridging the gap between academia and industry.

SEEU Energy Management System (EMS) will have to optimize the use of energy systematically, economically and ecologically from purchase to energy consumption and production. Examples of measured results of power consumption and production at SEEU Campus are shown in section 5 (Figures 13 -18).

In implementation of SEE EMS two types of measures will be differrentiated:

- Technical measures, for which investments are necessary
- Organizational measures, which integrate more efficient use of energy in the daily operations.

A particular measure of SEEU EMS is Demand Side Response. Optimization of the load does not result in energy saving, but depends on the existing power delivery contract with operators and can result in considerable cost savings (if the peak value is lower, power cost are reduced).

Demand response represents any active or preventative method to reduce, flatten or shift peak demand. Demand response includes all intentional modifications to consumption patterns of electricity of end-user customers that are intended to alter the timing, level of instantaneous demand, or the total electricity consumption [10]. Demand response refers to a wide range of actions which can be taken at the customer side of the electricity meter in response to particular conditions within the electricity system (such as peak period network congestion or high prices).

Dynamic Demand advance or delay appliance operating cycles by a few seconds to increase the diversity factor of the set of loads. The concept is that by monitoring the power, as well as their own control parameters, individual, intermittent loads would switch on or off at optimal moments to balance the overall system load with generation, reducing critical power mismatches. As this switching would only advance or delay the appliance operating cycle by a few seconds, it would be unnoticeable to the end user.

Reducing energy intensity, greenhouse gas emissions, and utilizing renewable energy is in accordance with standard ISO50001 Energy Management System.

In addition to decreased energy cost there will be additional advantages for SEEU:

- transparency of energy consumption
- promotion of renewable sources and energy savings
- environmental protection, image cultivation
- through continuous monitoring early detection and correction of significant changes
- increasing employees and students awareness relative to climate change and energy efficiency
- decreasing of maintenance costs

SEEU Energy Management System is based on intelligent metering, monitoring and control of electrical and non-electrical parameters. Implemented system will enable also real time power monitoring and reports according Power Quality Standard EN50160, EN 61000-2-4, NeQual, IEEE 519 and ITIC (CBEMA). Examples of measured results are shown in section 5 (Figures 20, 21 and Table1).

IT topology of SEEU Energy Management System and measurement infrastructure is presented in Figure 4.

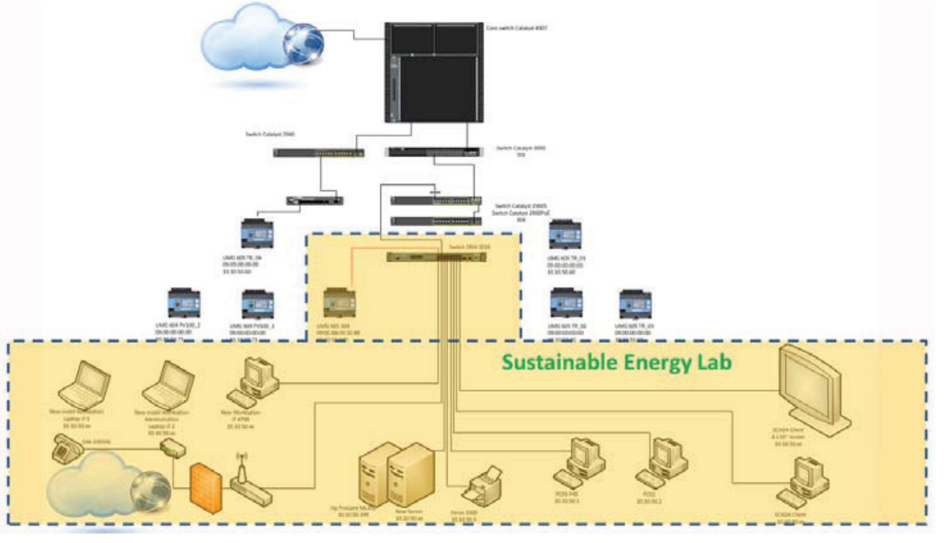

Figure 4: SEEU Energy Management System – IT and measurement infrastructure

Other non-electrical values (temperatures, fluids flow, pressure, and thermal energy flow) are also taken into consideration in the process of monitoring and regulation with intention to satisfy set up level according request by end users and SEEU policy. SEEU integrated EMS concept is presented in Figure 5. [8]

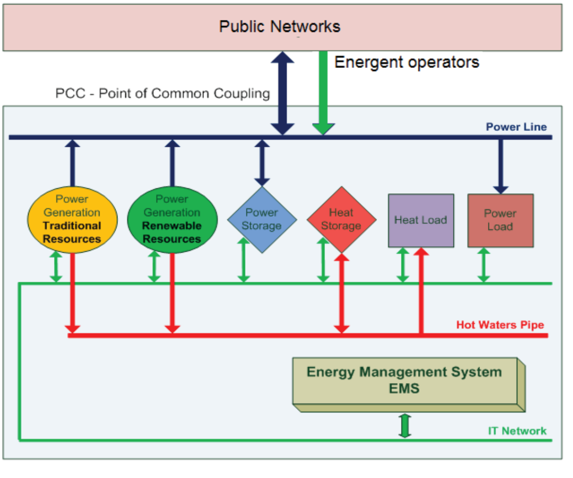

Figure 5: SEEU Integrated EMS Concept

Existing power, thermal and IT network and high level commitments of SEEU for energy sustainability, is a good basses in realization of Energy Monitoring and Demand Side Response in SEEU Campus project.
Content and capacities of SEEU Sustainable Energy initiative, SEEU Integrated Energy Concept are:

- Different types of energy sources, as Distributed Energy Resources (DER) are integrated in SEEU Energy System (local generators, micro turbines, renewable sources, biomass, geothermal, solar thermal and photovoltaic). Also as part of the system will be integrated energy accumulation devices with different respond time.
- Intelligent management system focused on production and consumption of energy
- Two way communications between energy resources with embedded intelligence and included intelligent metering.
- Communication net layer as infrastructure is above existing SEEU IT network
- Optimization between energy production and consumption based on consumer needs and production
- Optimal response to time of use tariff
- Decision Support System for energy planning
- Possible future upgrading of the system based on additional consumers as well as new sources and technological achievements.

SEEU Energy Management System (EMS) with the intelligent metering and computing resources will participate effectively in Power Management:

- Recording and data collection of the site's actual energy use.
- Automatic calculation of the SEEU's "baseline" energy use
- Ability to aggregate energy information from across multiple sites
- Immediate notification in the event
- Notification if power consumption or power quality parameters meet specific conditions.
- Energy analysis and planning.

Digital Energy Inventory are defined in levels based on SEEU Power Network infrastructure topology (tier 1 - Power stations, tier 2 - Master switch boxes, etc.) and definition of life, health and safety-driven loads, mission critical and non-critical loads and categorization of devices by purpose will be possible to identify high intensity loads. With design of

Digital Energy Inventory concept it is ready for further complete of all tiers and integration with SEEU Inventory Database.

Measurement devices provide indispensable information about sub-standard power quality and thus enable measures to be undertaken to resolve network problems. Ethernet (TCP/IP) is increasingly used as the backbone for data communication. Measurement devices with Ethernet/Modbus gateways ensure efficient systems with high transparency.

SEEU Electric network configuration with intelligent metering systems, distributed energy resources as an integrated concept with existing IT network (TCP / IP) is presented in Figure 6.

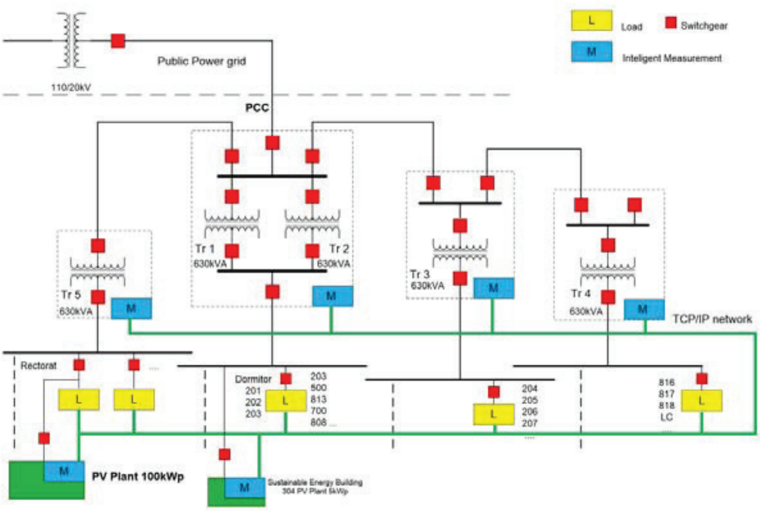

Figure 6: SEEU Electric network configuration with intelligent metering systems.

(SEEU campus in Tetovo with 197,000m^2 total surface – 29,000m^2 net building surface, administrative buildings, five student dorms, and teaching facilities).

In SEEU campus we deal with time variant loads. Time variant load problems appear in the engineering practice when the electrical properties of the installation deteriorate in time or random loading modeled as random processes is involved. Time variant electrical loads, fluctuating around their nominal point, cause fluctuations also of current and power. The mean of current and power differ in their nominal values, which results in a deflection of mean power input. The transformation to a time invariant equivalent circuit in many cases is a wrong approach. [14] The variances on the other hand contribute for the generation of disturbances in the power supply system.

4. Real electrical system as a time variant complex load

For consumers' of electric energy and industry optimum performance, namely cost-efficient power consumption is of primary interest. This applies in particular to Power Factor Correction and at same time including Power Quality equipment, which is justified only if it enables increased production or energy savings. Based on the analysis of the measured values of electrical parameters of time variant load in the presence of distortions, using a fast dynamic compensator with a response time in the order of the grid voltage period gives very good results in the correction of the Power Factor and improving the Power Quality of network. [14]

It is present a case of typical real industry electrical system as a time variant complex load and real measured electrical values used for solving problem of power factor and in the same time would improve Power Quality parameters and increase efficiency. This case represents the cooperation of the University and industry with use of Laboratory resources and successfully solving real problem of increasing efficiency and PQ. Results for both phenomena derive from a real industry system and are validated by measurements for three-phase system. Measurements are done during a day with a normal production. Measured data used to find solution for compensation of reactive and distortion power at real industry system in real production – hot plate mill which illustrated the application of ideas with real measured values. The most complex situation for compensation is under time variant loads that are at the same often nonlinear. The electrical loads that cannot be considered time invariant loads with their characteristics represent time variant loads or generally, time variant electric systems in the electrical network. The waveform of the electric current in these loads does not have periodicity due to the time invariant switching on and off. The time when these loads are switched on is longer than the period of the network voltage. By the Fourier transformation of this signal are obtained components of current with a frequency lower than the network frequency as well as intermodulation harmonics of current. Such load in the power network is usually a greater number of connected loads, linear and nonlinear, which are switched on and off randomly according needs of technological process.

In order to carry out the recording of the network parameters an advanced fast analyzer was used due to the complete defining of the behavior of the parameters of power. Power analyzer has the following characterristics: high Class A, accuracy of voltage measuring of 0.1%, analyzer recorder designed to record the wave function of the voltage and current inputs, sampling speed of each channel of 1024 samples during one cycle of 20ms, which guarantees recording of transients and other defects in the voltage with granulation of 19 microseconds, recording harmonic distortion up to 511 harmonic. The use of this analyzer guarantees that all fluctuations in the measured values will be registered, which will be taken into account in the dimensioning of the compensation.

Only an exact technical evaluation can guarantee real solution, through the use of contemporary and modern working methodology that involves four steps:

1. **Determining the Current Situation** - This step involves a review of single pole scheme, verbal communication and on-site inspection for the type of connected consumers, determining the correlation of the manufacturing process and factors with the consumption profile (dynamics and occurrence).
2. **Recording the parameters of the transformer with a fast analyzer** of the electricity quality for detection of the most subtle, rapid changes in the voltage and current that directly affect the solution.
3. **Analysis of the recorded results** with powerful software tool for reviewing the parameters in a time domain (effective and instant values) and frequency domain. The technical solution for compensation unites the first and the second step and clearly defines a solution.
4. **Simulation**

In the present case the transformer has a capacity of 1600kVA, with voltage levels of 6/0.4kV, Dy5 connection. The overall load of the transformer is composed of electro motors (9 in total) which represent large loads for the transformer at the moments of their connection. The transformer does not have a compensation system for the reactive power.

The motors switch on or change the direction of movement in time variant process, thus having accordingly large fluctuations of voltage and reactive power. The recording with the analyzer was done in the period of standard and nominal dynamics of the production within a period of 24 hours as a full working cycle. Because of the repeatability of the process, the results obtained with the measurement reflect the real picture of the transformer load. Figure 7 and Figure 8 presents the complete daily profile of the complex load that contains even the smallest time information to determine the operating parameters of the transformer.

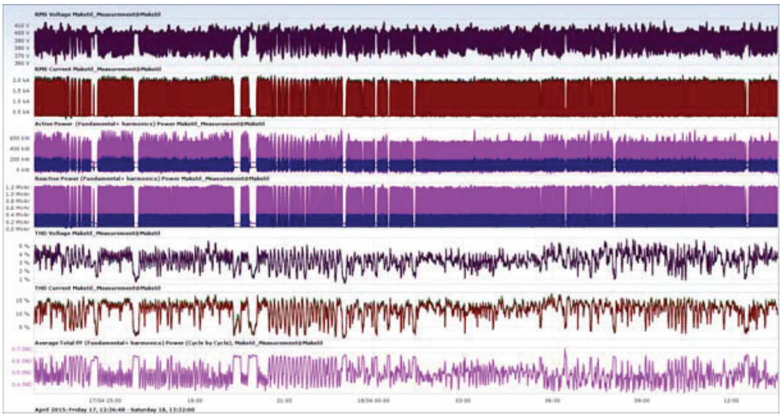

Figure 7: Operating voltage, current, power, harmonic distortion and power factor over the recording period

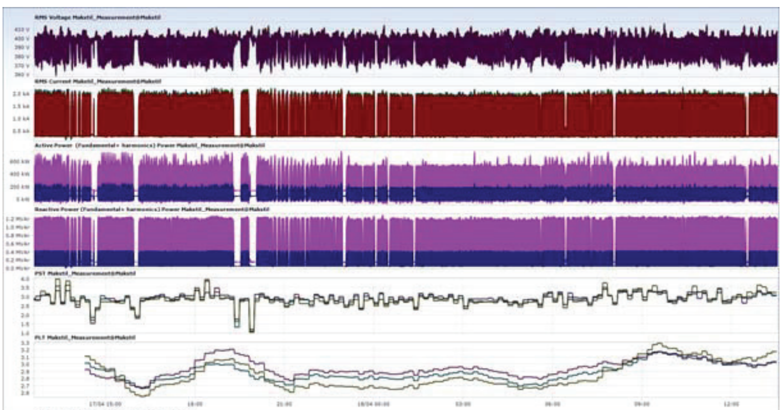

Figure 8: Operating voltage, current, power and flickers 10min (Pst) and 2h (Plt) for 24 hours

The initial information about the performed recording are as follows:

- As expected, the currents and voltages have rapid and dynamic changes that need to be further analyzed for a shorter period of time
- The voltage fluctuations are in the range of 370V-410V with current loads up to 2kA
- The active power of the individual changes is typically around 600kW, whereas additionally are taken over typically 1.2MVAr of reactive power
- Due to the inductive behavior of the consumers, the reactive power is very high, and the power factor is very poor (0.4-0.6)
- There is a harmonic distortion of the voltage and currents which should be further analyzed through a review of the frequency spectrum
- Due to the constant dynamic changes in the voltage, high values of the flickers occur for 10min and for 2h, Figure 8.

Due to more precise determination of the variations of voltage and current, the data are reviewed for one-hour periods. Reviews have been done of more detailed time profiles of the load, 5 minutes, 10 and 1 second. Figure 9 presents the time profile of 1 second. We notice variations in time frames of 200ms.

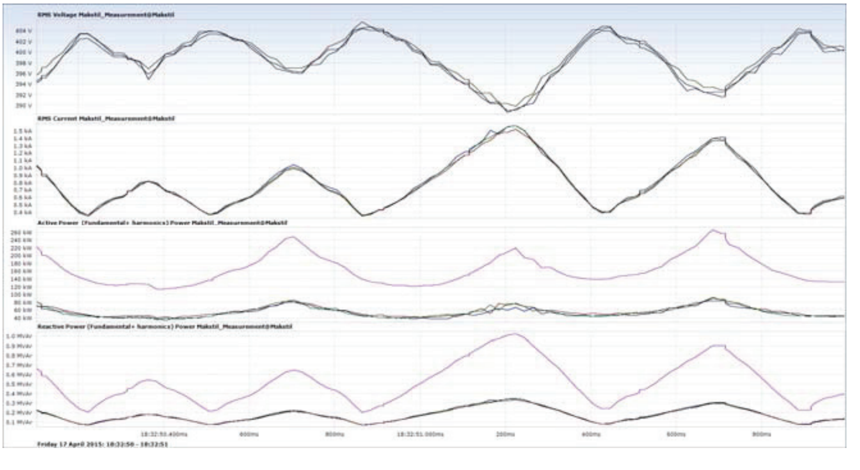

Figure 9: Operating voltages, currents and power (with and without harmonics) for a period of 1 second

The following Figure 10 presents the frequency range of the current and the voltage in absolute and percentage value.

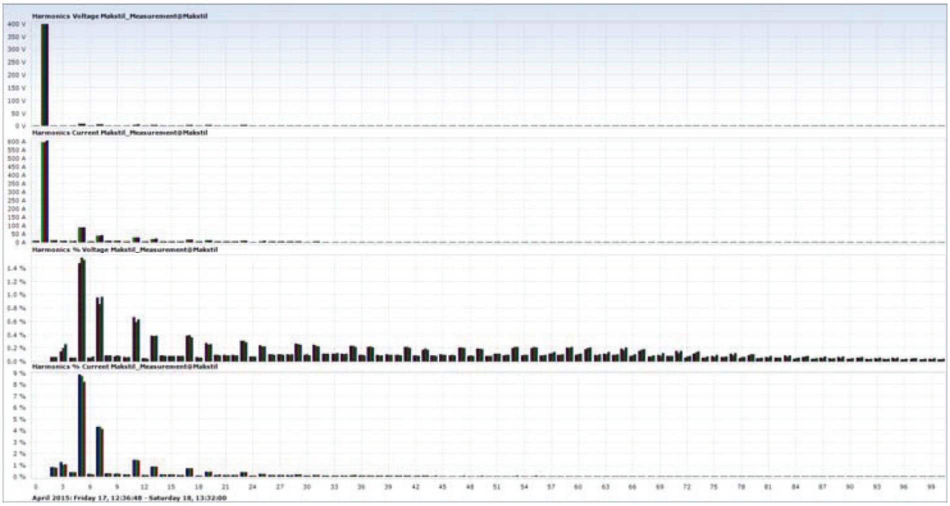

Figure 10: Harmonic analysis of the voltage and current

Given the determined current situation and the analysis of the previous step, the transformer compensation requires the following characteristics:

- Full compensation for one cycle: 5-20ms (for 50Hz systems)
- Total power of 1200kVAr
- Compensation in five steps of 240kVAr (1: 1: 1: 1: 1)
- Connecting to a computer with a software for monitoring the measured and management parameters in real time, modern solution, in accordance with the current regulations for compensation equipment
- 14% unadjusted filter with an iron core
- Electronic termination without generating of transients (termination at zero value of the current through the capacitors)

The proposed regulator has the response time which is up to ¾ of the cycle (15 ms). The compensation system is also a system to improve the electricity quality in real time in dynamic loads by: correction of the power factor to the ideal value of 1, saving electricity, improving voltage variation, reducing the flickers, filtration of the harmonics and reducing the electric shock. Using the compensation systems with a greater response time achieves reverse, negative effect.

In addition is the analysis of the effectiveness and the benefits of the proposed solution. The following Figure 11 and Figure 12 present the simulation of the appearance of the basic network parameters before and after the performed compensation with the proposed technical features.

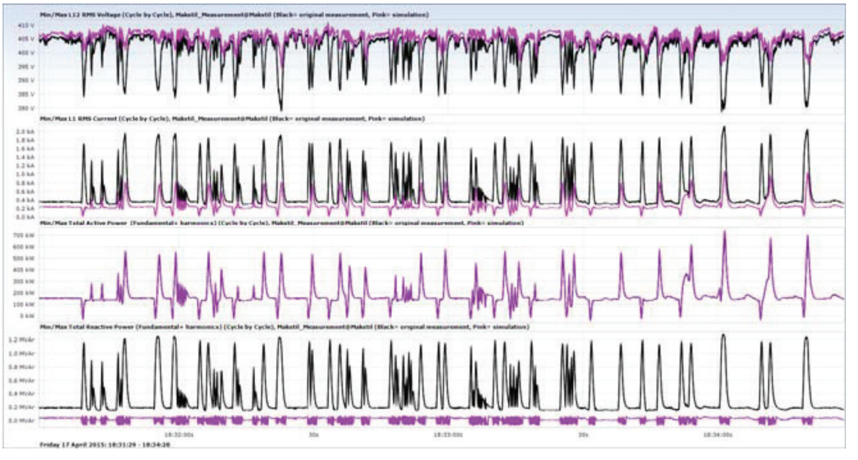

Figure 11: Network parameters before and after the performed compensation – the black color shows the original measurements, the purple color shows the simulation

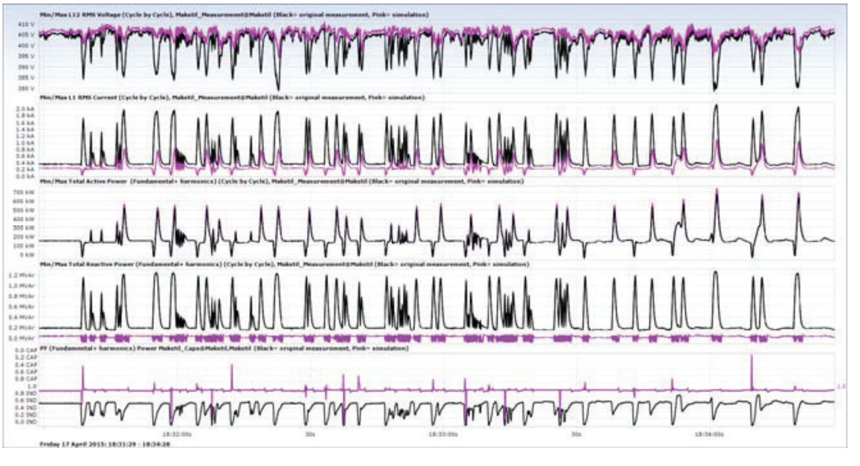

Figure 12: Network parameters before and after the performed compensation – the black color shows the original measurements, the purple color shows the simulation

The following are the technical benefits in the system before and after the compensation:

- The compensation system provides the reactive power for the needs of the consumers of the transformer. Thus, additional load with apparent power of 1000kVA can be connected to the transformer
- By setting the compensation, the effective value of the voltage of the secondary part will increase by 2.5 - 3%, thus, we can count on savings at this level by reducing the primary level of the transformer by 2.5%. Significant is the reducing of the fluctuations in the voltage in dynamic changes of the load.
- Significantly will be reduced the electricity shocks (60%) because the rapid compensation "provides" the initial current of the electric motors in the plant
- The lowest graph in Figure 12 presents the reactive power, which in this case would be completely eliminated, and the power factor is almost ideal to the value of approximately 1.

In the simulation process of this project the expertise of the world renowned manufacturer ELSPEC and their laboratory was also included.

5. Measurement results of Power Consumption, Production, and PQ at SEEU Campus

5.1. Power Consumption at SEEU Campus

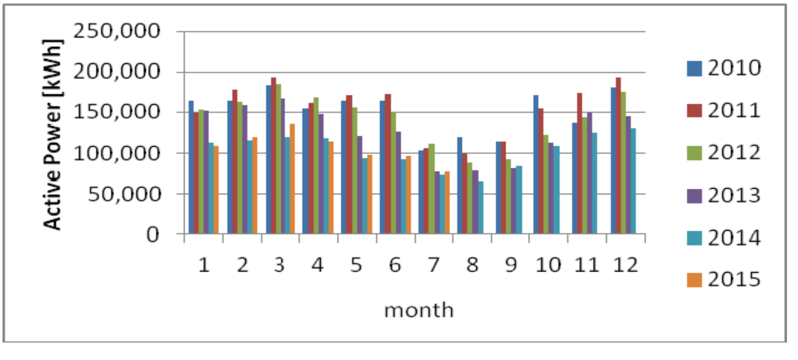

Figure 13: Annual consumption of active power delivered from public electric grid at SEEU Campus by month (2010 - 2014 and part of 2015 year)

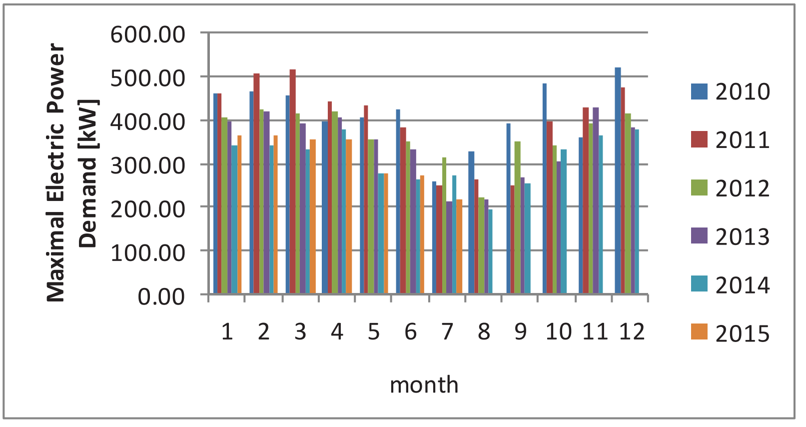

Figure 14: The annual Maximum Electric Power Demand at SEEU Campus by month (2010 – 2014 and part of 2015 year)

Consumption of power at SEEU Campus through the years is decreased as a result of: CAP activities for increasing of efficiency and savings and Power production of PV Plant (Figure13 and Figure14).

5.2. Power Production at SEEU Campus, PV Plant 100kWp

Location: 42°00’36”N 20°58’12”E and Elevation 484m
Average global irradiation per m^2: 1670 kWh/m^2 inclination 35°, 1570 kWh/m^2 inclination 10°

Total number of installed PV modules: 417, with Peak power of 230 Wp, Polycrystalline panels with total PV Peak Power 96 kWp with Inclination angle 10°, Azimuth angle 0°

Average annual energy yield 134,000 kW for 365 day total 4,265 h production and average annual specific energy yield 1401 kWh/kWp. Average daily specific energy yield is 3.84 kWh/kWp (Figure 15 and Figure 16).

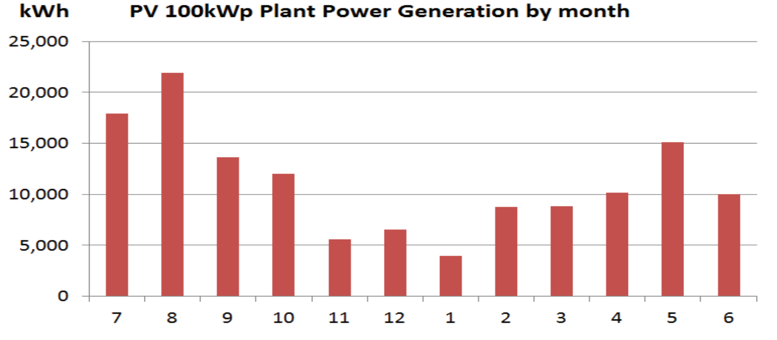

Figure 15: Average electric power production by months (PV 100kWp)

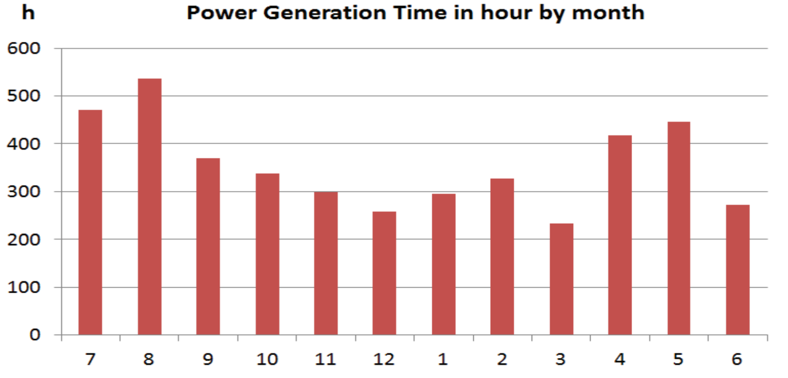

Figure 16: Average annual electric power production time by months (PV 100kWp)

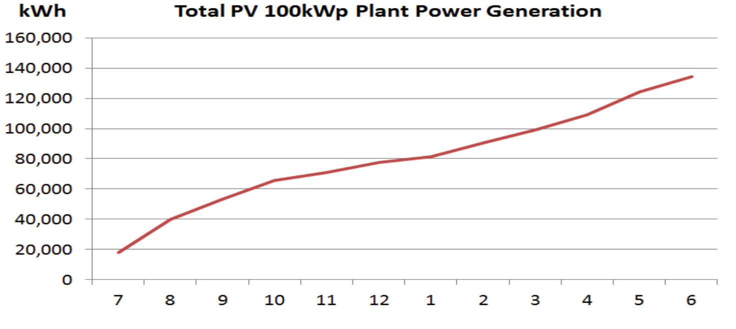

Figure 17: Cumulative annual average production of electric power by months (PV 100kWp)
(2014 - 134,478kWh for 365 day period, total 4,260 hour generation of electric power)

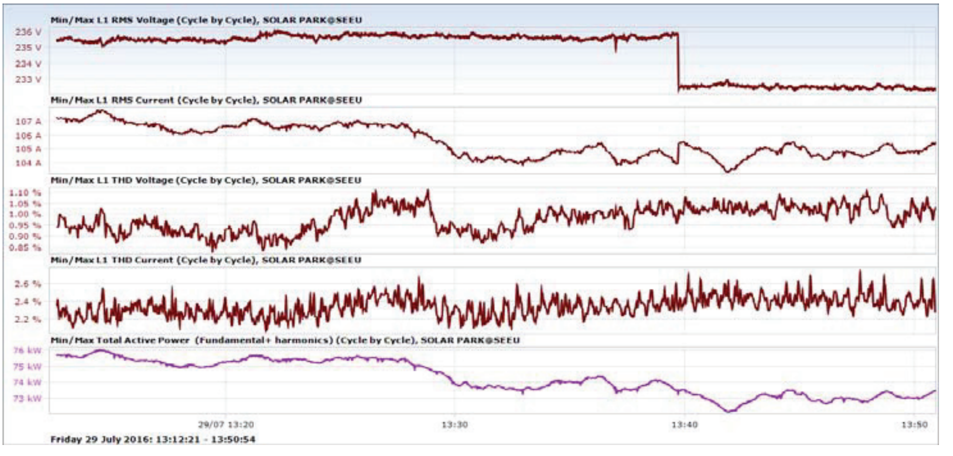

Figure 18: Voltage, current, production of electric power and THD of voltage and current at PCC of SEEU PV 100kWp plant (29 July 2016 at 13.12.21h

In figure 18 it is shown validity of declaration: The involvement of Renewable electric energy resources increases the Power Quality at Small Power Supply Network. Voltage THD and current THD values are lower than THD values of public supply network.

5.3. Example of Sum of Active Power at Power station TR_5 (24 hour profile)

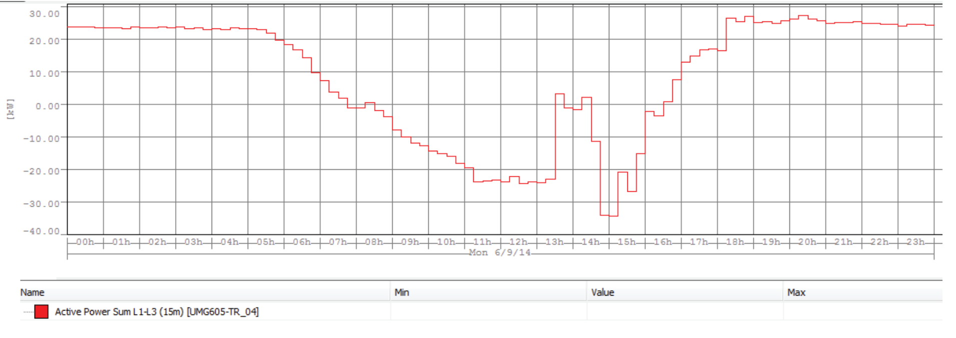

Figure 19: Measured Active Power Sum L1-L3 (granularity 15 minutes); point of measurement TR_05 for period 09.06.2014 (24h profile).

In Figure 19 it is shown the case of two way power flow, consumption and generation at power station TR-05.

5.4. Power Quality monitoring measurements

Power Quality monitoring has become a daily need in the field of electrical network management; the standards that are currently enforced represent minimum requirements that need to be fulfilled. The designed methodology aims to find solutions to the problems resulting from electrical power utilization and saving. The proposed designed solution is given as a digital system that enables Power Quality monitoring and electrical power consumption management. This acquisition system enables a real time simultaneous measurement of voltages and currents in a three-phase grid with high precision and sampling rate of 25 kS/s. Based on the simultaneous measured electrical values and the implemented algorithm, there will be a calculation of electrical values needed for analyzing and comparing of result with Power Quality accepted standards EN 50160. Therefore, the system continuously will acquire process and archive data in a form that will be appropriate for determining events and anomalies in the monitored electrical network system. This methodology for Power Quality monitoring is based on capabilities of smart instrumentation and contemporary IT. The potential, capabilities and values of this system includes: flexibility, modularity, upgradebility and low cost.

Sumary of PQ report according Report after EN 50160 2011:
Company: SEE University
Location: Building 304

Frequency +-1%	Passed
Frequency -6%/+4%	Passed
Voltage effective L1 - 1st Test	Passed
Voltage effective L1 - 2nd Test	Passed
Voltage effective L2 - 1st Test	Passed
Voltage effective L2 - 2nd Test	Passed
Voltage effective L3 - 1st Test	Passed
Voltage effective L3 - 2nd Test	Passed
THD U L1	Passed
THD U L2	Passed
THD U L3	Passed
Unbalance Voltage	Passed
Long term flicker L1	Passed
Long term flicker L2	Passed
Long term flicker L3	Passed
Harmonics voltage (rel.) L1	Passed
Harmonics voltage (rel.) L2	Passed
Harmonics voltage (rel.) L3	Passed

Power Quality of voltage at SEEU Campus for mentioned period is in compliance with EN 50160 2011.

Frequency +-1%

Lower limit	49.50Hz
Higher limit	50.50Hz
Percentage	99.50%

Min value	49.91Hz
Average value	50.00Hz
Max value	50.09Hz
Undercut	0.00%
Overcut	0.00%
Total out	0.00%
Result	Passed
Recording vacancy	48.67%

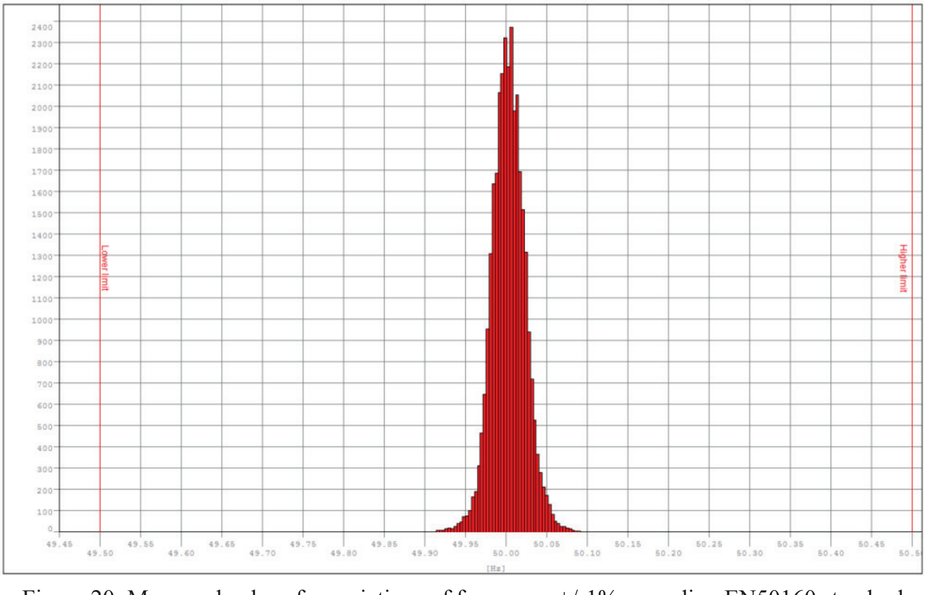

Figure 20: Measured values for variations of frequency +/-1% according EN50160 standard

Harmonics voltage L1

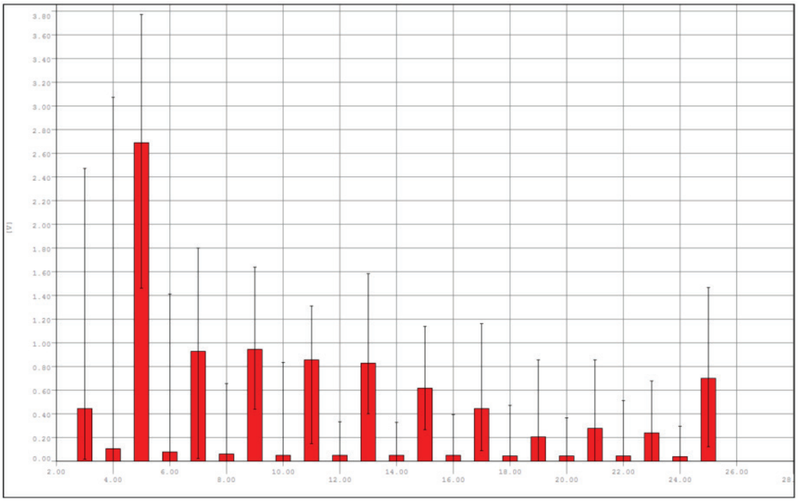

Figure 21: Measured values for harmonics of voltage for phase L1

3 deepest events

Starttime / Endtime	Length	Input	Eventtype	Limit	Min	Avg	Max
6/7/12 10:18:09 PM'479 / 6/7/12 10:18:09 PM'569	90.056ms	L2	Under voltage	195.50	134.89	152.05	190.62
6/7/12 10:18:09 PM'482 / 6/7/12 10:18:09 PM'562	79.955ms	L3	Under voltage	195.50	146.67	154.90	181.15
6/6/12 3:05:46 AM'212 / 6/6/12 3:05:46 AM'782	570.458ms	L3	Under voltage	195.50	173.08	174.68	190.81

Table 1: Under voltage events in period from 6/3/12 12:00 AM to 6/9/12 11:59 PM

In Table 1: it is shown that in period of 7 day /24 hours there are only three PQ event of under voltage for time duration <1s.

Conclusions

Local action and planning is necessary to complement nation-wide energy strategies. The realization Sustainable Energy Strategy of small scale power network can be of importance for building national Sustainable Energy Strategies. The SEEU concept represents a SES for small-scale power supply network.

SEEU small-scale power supply network is real laboratory for hands-on education and training of students in the campus in the fields of energy efficiency, use of renewable energy resources, and IT implementation for monitoring and control.

SEEU Energy Management System with intelligent metering and computing resources participates effectively in collecting and Recording data's, Monitoring, Power Management, and Energy analysis and planning.

Based on high granularity measurements and with classification of loads (as: Life, heath, and safety driven, Mission critical and Non-critical) by Energy inventory, it is shown that is possible to control Demand Side Demand Response at SEEU Campus and active participation of end users will reduce cost of energy supply and CO_2 emission.

Realization of CAP activities for decreasing the CO2 emissions decreases energy consumption. The involvement of Renewable electric energy resources increases the Power Quality at Small Power Supply Network. In the same time can be concluded that exist the possibilities for balancing of power generation to demand, increasing power efficiency and security. Results of measurements with smart meters and high resolution PQ analyzers verified also very close relations of Power Factor (PF), power consumption, efficiency and carbon neutrality. Complex industrial time variant load with rapid dynamic compensator of 17ms are achieved good results also for the rapid changes, occurred at dynamics of around 200-300ms (10-15 cycles). The proposed system for compensation of the time variant loads improves the electricity quality in real time at dynamic loads with: correction of the power factor to the nearly ideal value of 1, it makes electricity saving, reduces the flickers, performs filtration of the harmonics and reduces the electricity shocks in the network.

With implementation of Energy Smart Technologies, Small Size Power Network can participate in free energy market and coordinate Demand Side response with tariffs and time of day pricing as well, according energy market liberalization trends.

Acknowledgment

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References

[1] - South East European University Climate Action Plan, May 2011, Technical Working Group (SEEU, Institute for the Environment and Health), Alajdin Abazi, Murtezan Ismaili, Iljaz Iljazi, Darko Spirovski, Technical Working Group (Dappolonia, Sustainable Energy Unit) Marco Cremonini, Gianluca Cassulo, Alessandro Venturin

[2] - Strategy for Energy Development in the Republic of Macedonia until 2030, Skopje, 2010, Government of Republic of Macedonia, Ministry of Economy

[3] Strategy for Utilisation of Renewable Energy Sources in the Republic of Macedonia by 2020, Skopje, August 2010, Government of Republic of Macedonia, Ministry of Economy

[4] Sustainable Energy Strategy for Christchurch 2008-2018, Christchurch City Council, 2007

[5] The royal Academy of Engineering, Developing a Sustainable energy strategy, 2006

[6] B. Kroposki, T. Basso, R. DeBlasio, Microgrid Standards and Technologies, in Proc. 2008 IEEE Power and Energy Society General Meeting, Pittsburgh, Jul. 2008,

[7] C. Marnay, G. Venkataramanan, Microgrids in the Evolving Electricity Generation and Delivery Infrastructure, in Proc. IEEE Power Engineering Society General Meeting, Montréal, Jun. 2006.

[8]. A. Abazi, I. Ilazi, and D. Spirovski, From a Climate Action Plan (CAP) to a Microgrid: The SEEU Sustainability Concept Including Social Aspects, in Academicus International Scientific Journal, Nr. IV 2011, Albania.

[9] Bollen, Math H. J., Understanding Power Quality Problems: Voltage Sags and Interruptions, Wiley-IEEE Press, September 1999.

[10] I. Iljazi, A. Abazi, Energy Management and Demand Side Response in SEEU Campus, SDEWES, SEE2014.0201

[11] D. Spirovski, A. Abazi, I. Iljazi, M. Ismaili, G. Cassulo, A. Venturin, Realization of a low emission university campus trough the implementation of a Climate Action Plan, Procedia - Social and Behavioral Sciences, Vol. 46, pp 4695-4702, 2012, http://dx.doi.org/10.1016/j.sbspro.2012.06.321

[12] D.Spirovski, I.Iljazi, L.Eshtrefi, A.Abazi, From a Pilot Building to a Self Sustainable Energy Campus, SDEWES SDWS2012.0335

[13] I. Iljazi, D. Spirovski, L. Eshtrefi, A. Abazi, An Alternative Solution for Fuel Switching According to the SEEU CAP, SDEWES SDWS2012.0337

[14] I. Iljazi, A. Abazi, Z. Nikolovski, M. Markovic, Z. Krstevski, Power Factor Correction at Time Variant Load in Presence of Distortions, MakoCIGRE 2015, Ohrid

[15] Disterheft, A., Caeiro, S., Azeiteiro, U. M., & Filho, W. L. (2014). Sustainable universities – a study of critical success factors for participatory approaches. Journal of Cleaner Production, 106, 11–21. doi:10.1016/j.jclepro.2014.01.030

[16] Evans, J., Jones, R., Karvonen, A., Millard, L., & Wendler, J. (2015). Living labs and coproduction: university campuses as platforms for sustainnability science. Current Opinion in Environmental Sustainability, 16, 1–6. doi:10.1016/j.cosust.2015.06.005

[17] Larrán Jorge, M., Herrera Madueño, J., Calzado Cejas, M. Y., & Andrades Peña, F. J. (2014). An approach to the implementation of sustainability practices in Spanish universities. Journal of Cleaner Production, 106, 34–44. doi:10.1016/j.jclepro.2014.07.035

[18] Vahid Faghihi, Amir R. Hessami, David N. Ford, Sustainable campus improvement program design using energy efficiency and conservation, Journal of Cleaner Production, Volume 107, 16 November 2015, Pages 400–409

КАМПУС НА УНИВЕРЗИТЕТОТ НА ЈУГОИСТОЧНА ЕВРОПА: ОДРЖЛИВА МРЕЖА ЗА СНАБДУВАЊЕ СО ЕЛЕКТРИЧНА ЕНЕРГИЈА И ПРАКТИЧНА ЛАБОРАТОРИЈА

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Резиме

Универзитетот на Југоисточна Европа (УЈИЕ) е во фаза на реализација на Универзитетскиот кампус за ниски емисии преку имплементација на УЈИЕ Климатскиот акциски план (CAP) од 2011 година. Главните цели на CAP се финалната јаглеродна неутралност и енергетската ефикасност. Дистрибуираните енергетски ресурси (DER) на Кампусот на УЈИЕ со обновливи извори на енергија (соларна енергија и биомаса) и системот за управување со енергија (EMS) со имплементација на паметни технологии претставуваат одржлива мрежа за снабдување со електрична енергија, истовремено и практична лабораторија за преминување кон нова одржлива парадигма. Овој труд претставува заокружување на повеќегодишната реализација и истражувањата во енергетската мрежа за напојување во УЈИЕ. Имплементацијата на паметните технологии овозможува следење на квалитетот на електричната енергија (PQ), да се балансира производството на електрична енергија и да се намалат можните исклучувања. Оваа визија ќе овозможи и реализација на целите во однос на енергетската безбедност и одржливоста со економски и социјален ефект. Со широк спектар на оперативни прашања кои се опфатени, УЈИЕ е добро приспособен како истражувачка и практична лабораторија за енергетска одржливост. Оваа реална лабораторија за одржлива енергија (RSEL) е многу важен универзитетски ресурс за образование, истражување и за поврзаност со индустријата. Претставен е и случајот на соработка со индустријата, за корекција на факторот на моќност (PF), подобрување на параметрите за квалитет на електрична енергија (PQ) и ефикасноста. Оваа лабораторија обезбедува основа за истражување на главните карактеристики на глобалните енергетски прашања, технологиите за одржлива енергија и нивната интеракција со економијата, животната средина и регулативи.

Универзитетскиот кампус со интегрирано снабдување на енергија како реална одржлива лабораторија, различни мерени податоци со имплементација на паметни технологии верифицира две претпоставки: првата, реализацијата на активностите на CAP за намалување на емисиите на CO2 ја намалуваат и потрошувачката на енергија и, втората: интеграцијата на обновливите извори на електрична енергија го зголемува квалитетот на електричната енергија (PQ) во малите мрежи за напојување. Во исто време, се прикажани и можностите за балансирање на производството на електрична енергија со побарувачката, зголемувањето на енергетската ефикасност и безбедноста. Резултатите од мерењата со паметните мерачи и PQ-анализатори со висока резолуција ја потврдуваат и поврзаноста на факторот на моќноста, потрошувачката на енергија, ефикасноста и јаглеродната неутралност.

Клучни зборови: систем за управување со енергијата, квалитет на енергија, паметни технологии, „bottom-up“ пристап, енергетска стратегија, одговор на побарувачката.

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