The Investment Justification Estimate and Techno-economic and Ecological Aspects Analysis of the University Campus Microgrid

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Abstract—**The paper presents the plan and design of the idea of the microgrid at the Faculty of Technical Sciences in Novi Sad (FTN NS) in the university campus, which is based on the application of several different distributed energy sources. The main distributed energy sources used and planned for the distributed electricity generation in the microgrid "FTN NS" are the photovoltaic power plant with a nominal output of 9.6 kW, a photovoltaic power plant with a nominal output power of 16.3 kW, a wind power plant with a nominal output power of 2 kW, a cogeneration plant for combined heat and power production of the nominal output power of 10 kWe + 17.5 kWt, two electric vehicles of 4 kW and 2.5 kW power, and battery energy storage system with a total capacity of 36 kWh. The paper describes the main technical characteristics, the estimation of electricity generation and the estimation of the amount of non-polluted gaseous greenhouse effect for each distributed source of energy. In order to verify the justification of the application of the proposed microgrid concept, a detailed techno-economic and ecological analysis of the aspects of the application of distributed energy sources in the microgrid "FTN NS" was carried out in the paper.**

Index Terms—**distributed energy resources, distributed generation, microgrid, renewable energy sources, energy efficiency, techno-economic and ecological analysis**

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I. Introduction

HUMANITY is increasingly and intensively faced with global problems of dynamic increase in the consumption of electricity and heat, which is a consequence of the rapid increase of the human population on the planet Earth and its irrational and uneconomical relation to the limited capacities of fossil fuels, as well as the dynamic development different fields of industry and economy.

In addition, the standard way of planning and building traditional electricity systems requires a very long implementation period, which involves the implementation of various complicated processes and procedures, as well as the acquisition of licenses in the fields of construction, energy, mechanical engineering, ecology, law, etc.

In order to solve all of the above problems, especially global problems of increased energy consumption, greenhouse gas emissions (GHG), the concept of distributed electricity production based on the application of renewable energy sources has been developed.

Nowadays, one of the most effective and most efficient solutions that involves the application of the concept of renewable energy sources (RES) and energy efficiency (EE) are microgrids.

The microgrid (MG) represents a new concept in the field of clean energy technologies, which implies the application of different types of distributed energy sources (DESs) and distributed electricity production in the vicinity of electricity consumption [1]-[3].

The MG represents a small energy system based on the application of the following distributed energy technologies:

- distributed generators,
- systems and devices for storing electricity,
- systems and devices for interconnection, operation and control of MG and main distribution grid (MDG), and
- electricity consumers.

Distributed generators (photovoltaic panels, wind turbines, microturbines for combined heat and power production, hydroturbines, fuel cells, electric vehicles, etc.), their integration and application in MGs will result in increased reliability and security of power supply to consumers, improvement of power balance and frequency in the system reduction of power flows and power losses, and improvement of the quality of electricity in normal operation and cases of failure/outage in the energy system.

Energy storage systems (battery storage systems, energy and super capacitors, super magnets, flywheels, etc.) are an integral part of a MG that is used to store surplus produced electricity from distributed generators and its application in planned and/or unplanned situations (disconnection from the MDG and

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island mode of operation, disturbance of some of the distributed generators in MG, increased consumption, etc.).

Systems and devices in MGs for interconnecting, operating and controlling the MG and the MDG (power converters, power electronics, power transformers, controllers, etc.) are one of the key parts and factors for stable, reliable and safe operation and synchronization of MGs and MDGs in terms of voltage, frequency, active and reactive power flows. For the sake of better illustration, the look of the structure and architecture of a MG based on different types of DES is shown in Fig. 1.

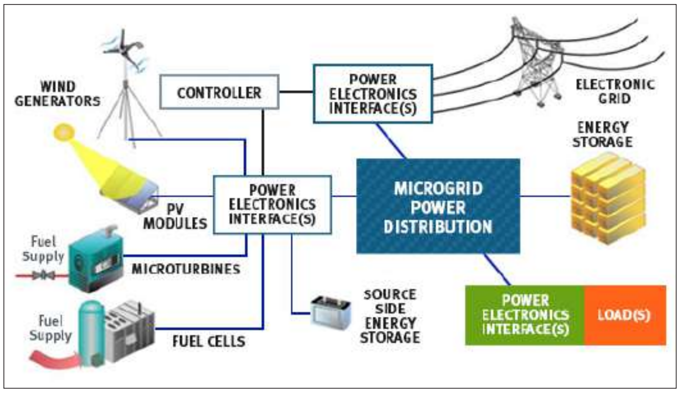

Fig. 1. Structure and architecture of the microgrid concept –an example [4].

The aim of this paper is to present the proposal of the conceptual plan and design of the MG based on the application of different DESs (in particular, two PV power plants, wind power plant, combined heat and power production plant, two electric vehicles, battery energy storage system, and electricity consumers) whose construction and realization is planned in the university campus at the Faculty of Technical Sciences Novi Sad (FTN NS), to process and analyze the main technical characteristics of the used and planned DES, with a special focus on the estimation of electricity production and the assessment of the avoidance of GHG emissions based on adequate technical, economic and ecologic analysis of the aspects the application of DES within the proposed MG. In addition, in order to better illustrate the principles of MG operation and distributed generation, the paper presents the potentials of RESs in the Republic of Serbia, as well as the classification of MGs.

II. Renewable Energy Potential In Serbia

The Republic of Serbia is located in Southeast Europe, in the central part of the Balkan Peninsula, with the territory which represents the shortest natural link between Eastern and Western Europe, northern and Southern Europe. Considering the latitude, relief, land layout and distance from the sea, the temperate climate (continental, moderate-continental and mountainous) is maintained in the Republic of Serbia with a uniformly distributed four seasons. Spatial distribution of climate parameters in the territory of the Republic of Serbia is a geographical position, relief and local influence, as a result of a combination of relief, the distribution of air pressure of larger proportions, the exposure of the terrain, the presence of river systems, vegetation, urbanization and other factors [5].

Based on a very suitable geographical location, there are more than significant potentials of different types of RESs in the Republic of Serbia. According to [6], the largest share in the total available technical potential of RESs has biomass energy of about 61.03% (3.448 million tonnes of oil equivalent (Mtoe)/year), hydropower 29.72% (1.667 Mtoe/year), solar energy 4.25% (0.240 Mtoe/year), geothermal energy 3.19% (0.180 Mtoe/year), while the share of wind energy is estimated at around 1.82% (0.103 Mtoe/year).

Total available technical potentials, used available technical potentials and unused available technical potentials of RESs in the Republic of Serbia are shown in Fig. 2.

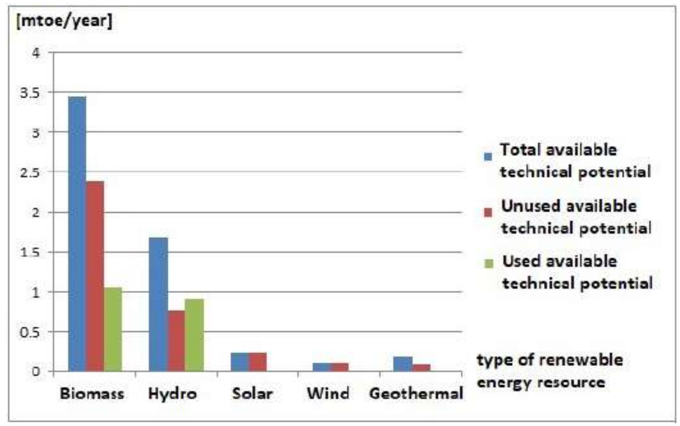

Fig. 2. Potential of RESs in Serbia.

A. Solar energy potential

Regarding the energy potential, the Republic of Serbia has a significant amount of solar energy that can be used for the production of heat and electricity. Compared to the average in other European countries, solar radiation on the territory of the Republic of Serbia is between 35 % and 40 %, with an annual number of hours of solar radiation between 1,500 and 2,200 hours.

The average daily intensity of solar radiation in the territory of Serbia on the horizontal surface in the winter period (January) is in the range between 1.1 kWh/m^2 and 1.7 kWh/m^2 in the north, and in the summer period (month July) between 5.9 and 6.6 kWh/m^2 in the south, while the average annual energy of solar radiation in the territory of Serbia is around 1,200 kWh/m^2 in the northwest, to about 1,550 kWh/m^2 in the southeast, and about 1,400 kWh/m^2 in the central parts [6]. For the purpose of better illustration, the map of the annual average of the daily energy of global solar radiation in the territory of the Republic of Serbia is shown in Fig. 3.

Regarding the energy potential of the territory of the Autonomous Province of Vojvodina of the Republic of Serbia, where the Faculty of Technical Sciences Novi Sad is located, there are significant solar power capacities.

The average daily energy of global radiation in the territory of Vojvodina for a flat surface during the winter period (December - January) ranges between 1.0 kWh/m^2 in the north, 1.45

kWh/m^2 in the south, and up to 3.55 kWh/m^2 (in March), and in the summer period between 5.70 kWh/m^2 in the north and 6.85 kWh/m^2 in the south (June-August), while the average annual energy of global radiation in the territory of the Autonomous Province of Vojvodina on the horizontal surface is 1.294 kWh/m^2 in the north, 1.335 kWh/ m^2 in the south, 1,281 kWh/m^2 in the west, and 1,294 kWh/m^2 in the east [9]. For the purpose of better illustration, the annual average of the daily energy of global solar radiation in the territory of the Autonomous Province of Vojvodina in the Republic of Serbia is shown in Fig. 4.

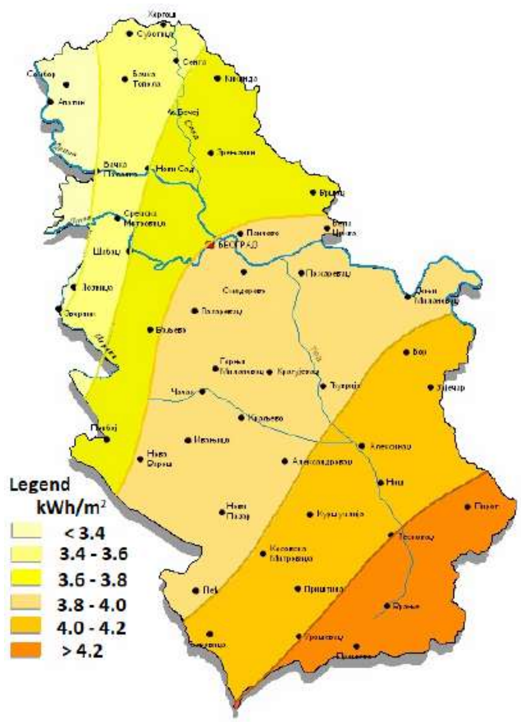

Fig. 3. Annual average daily energy of global solar radiation to the horizontal surface in Serbia [8].

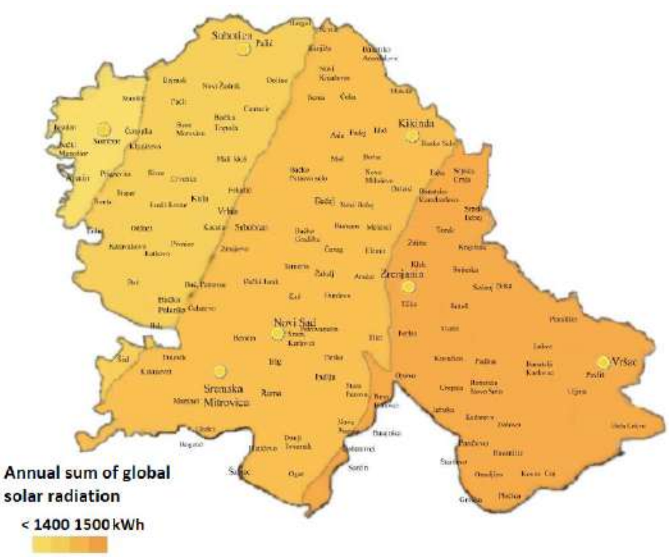

Fig. 4. Annual average daily energy of global solar radiation to the horizontal surface on the teritory of Serbia [9].

B. Wind energy potential

Regarding the energy potential, the Republic of Serbia has a significant amount of wind energy that can be used for electricity generation.

The largest wind power in the territory of the Republic of Serbia was measured and determined in the area of southern Banat, in eastern Serbia, on the eastern side of the mountain Kopaonik, in the area of the mountain Zlatibor, on the Pešter Plateau, as well as at the locations of mountain passes at altitudes above 800 m [8]. For the purpose of better illustration, the map of the average annual wind energy in the territory of Serbia at a height of 100 meters is shown in Fig. 5.

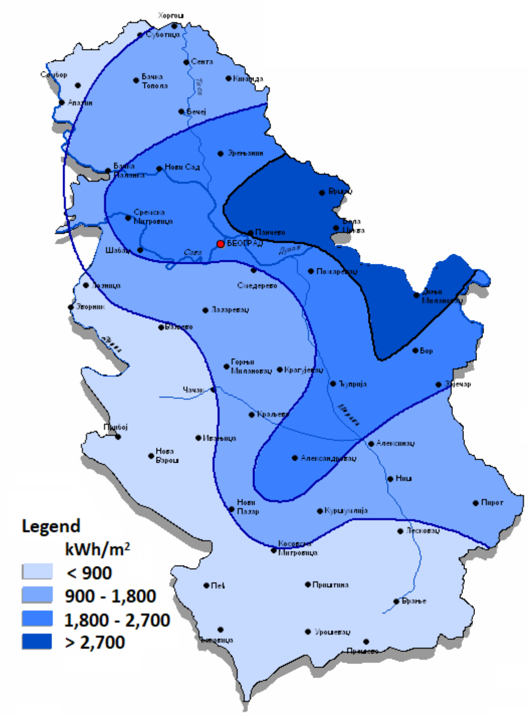

Fig. 5. Average annual wind energy in the teritory of Republic of Serbia [8].

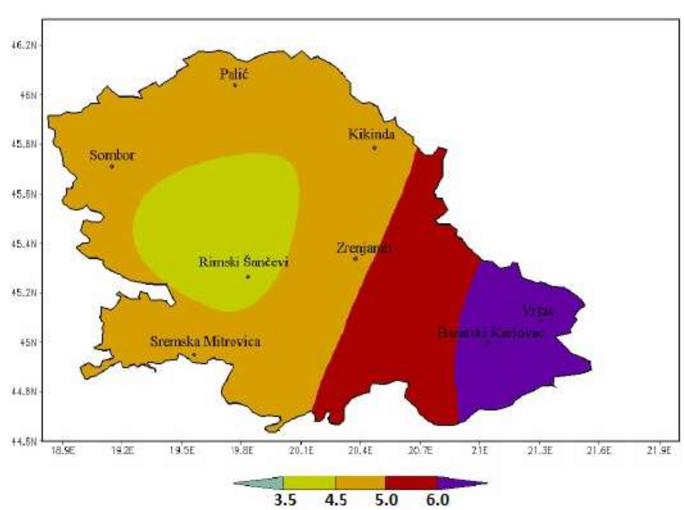

Fig. 6. Mean annual wind speed on the teritory of Vojvodina in m/ s at height of 100 m. [11].

Regarding the energy potential of the territory of the Autonomous Province of Vojvodina of the Republic of Serbia, where the Faculty of Technical Sciences Novi Sad is located, there are significant wind power capacities. According to [10], in most of the territory of Vojvodina, wind velocity was measured in the range from 3.5 m/s to 4.5 m/s in the area of Fruska Gora mountain, Vrsački Breg and southern Banat in the range 4.5 m/s to 6 m/ s, while on two locations on Vršački Breg plateau measured and determined wind speeds were more than 6 m/s. For the purpose of better illustration, mean annual wind speed in the territory of the Republic of Serbia is shown in Fig. 6.

III. Microgrid Classification

In terms of classification, MGs can be divided according to the following three main factors:

- operating mode,
- type of energy supply, and
- control mode.

For the sake of better understanding and illustration, the classification of the MG is shown in Fig. 7. A detailed description of the classification of the MG is given below.

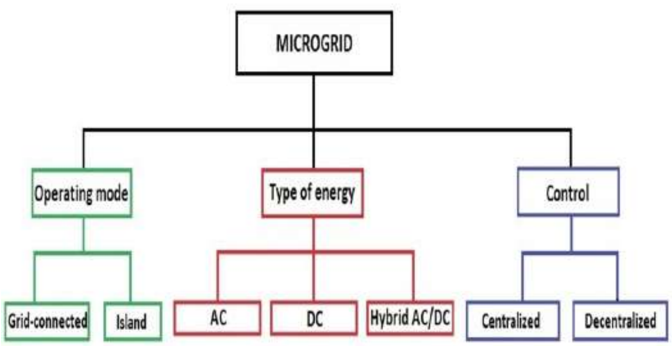

Fig. 7. Classification of the MG.

A. Microgrid operation modes

Regarding the mode of operation, MGs can be divided into two basic groups:

1. grid-connected mode, and
2. islanded mode.

The grid-connected mode represents the first and, in practice, the most common mode of operation of the MGs, in which the MG is connected to the MDG through the central switch, Point of Common Coupling (PCC) and the transformer. In a grid-connected mode, the MG is dependent on the MDG that defines and dictates the MDG requirements that must be met. In this regard, the main goal in the grid-connected mode of operation is to optimize the operation of the MG according to technical, economic and ecological criteria.

The technical criteria of the operation of the complete energy system of the MDG and MG include enabling and ensuring the stability of the main parameters within the defined (set) technical limits (voltage, frequency, flows of active and reactive power), economic labor criteria imply the achievement of a common profit through incentive measures for production electricity and heat from RESs, while economic criteria are aimed at reducing GHG emissions through the use of DES.

In the grid-connected mode of operation, between the MG and the MDG there is a exchange of active and reactive power and electricity exchange flows, in accordance with the given technical limits of voltage and frequency. Depending on the type of contract defined between the MG and the MDG, in grid-connected mode of operation completely produced and/or the surplus of produced electricity from the MG is delivered to the MDG. In the case that the electricity consumption in the MG is greater than the electricity generation in the MG, the amount of electricity that is missing in the MG is supplied from the MDG. The main role in the case of covering the maximum loads in the grid-connected mode of operation is provided by systems and devices for storing electricity in MGs, which represent a particularly effective and efficient techno-economic and ecological solution.

The islanded mode of operation is the second and, in practice, the type of mode of operation of the MG, in which the MG is excluded from the MDG. In the island mode, the MG is independent of the MDG and without interconnection works within the technical, economic and ecological limits in a stable, secure and reliable manner. In this regard, the main task of MGs in the island mode is to enable and secure the production of electricity that will fully meet the requirements of the electricity consumers. The main objective in the island mode is the stable, reliable and safe operation of the MG while maintaining the voltage and frequency within the defined (set) technical limits.

In the island mode of operation, in addition to designing the production capacity of DESs, the main role in covering the maximum load in the MG is provided by systems and devices for energy storage, which enable and provide the necessary reserve and power supply for consumers in case of planned/unplanned failure (outage) of production units in the MG. An example of the MG architecture in grid-connected and island mode is shown in Fig. 8.

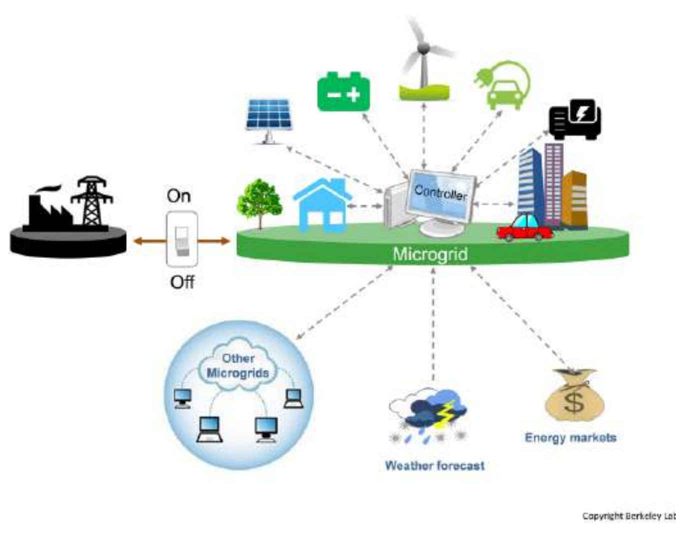

Fig. 8. Appearance of the MG and PCC with the MDG in grid-connected and island mode – an example [12].

B. Microgrid topology

In terms of the type of power supply system, MGs can be divided into three basic groups:

1. alternating current (AC) MG,
2. direct current (DC) MG, and
3. hybrid (AC/DC) MG.

The AC MG represents the first type of MG that is based on the application of different types of DESs, systems and devices for interconnection of the MG and MDG, and consumers of electricity. Given that AC MG is dominated mostly by AC DESs that produce AC electricity at their output (wind turbines, combined heat and power generation, diesel generators, etc.), in case of existence and use of DC DES (PV panels, fuel cells, energy storage systems, electric vehicles) AC/DC power converters are used in AC MGs. The main tasks of the DC/AC converters in AC MGs are focused on converting energy from DC DESs into AC energy to the AC bus and adjusting the AC power used by the AC consumers.

The DC MG represents second type of MG that is based on the application of different types of DESs, systems and devices for interconnection of MG and MDG, and DC consumers of electricity. Given that DC MGs are dominated mostly by DC DESs that produce DC electricity at their output (PV panels, electric vehicles, energy storage systems, fuel cells, etc.) in the case of the existence and use of AC DESs (wind turbines, combined heat and power production, diesel generators, etc.) in DC MGs are used AC/DC power converters. In DC MGs, the main tasks of the AC/DC power converter are focused on converting energy from AC DESs into DC energy on the DC bus and adjusting the DC power used by the DC consumers.

Regarding the principles of operation and control, AC and DC MGs are characterized by practically identical characteristics, with the only difference in terms of the applied energy inverter (DC/AC power converter in AC MGs, and AC/DC power converter in DC MGs).

Within basic types of MGs, the additional feature and techno-economic benefit is the fact that DC DES in DC MGs can be connected directly to the DC bus without the use of DC/DC power converters, while AC DES in AC MGs can be connected to AC bus without using AC/AC power converters. In this regard, an example of the appearance of the architecture of the AC MG (black line) and DC MG (green line) is shown in Fig. 9.

Hybrid MG represent the third type of MG that is based on the application of different types of DESs, systems and devices for interconnection of the MG and the MDG, as well as AC and DC electricity consumers. In terms of structure and architecture, hybrid MG represents a combination of a separate AC MG and separate DC MG that are interconnected in a hybrid AC/DC MG. Realization of the interconnection of AC MG and DC MG is done by means of a Bidirectional Interlink Converter (BIC) (AC/DC power power converter). In most cases of interconnection of AC MGs and DC MGs, in practice, a Back-to-Back (B2B) power converter is provided which provides and enables for the conversion of energy and the energy flow from the AC MG to the DC MG, and vice versa.

In terms of the type of concept, hybrid MGs can be implemented as AC hybrid MGs and as DC hybrid MGs. As with the case of standard (basic) types of MGs, DC DES in DC hybrid MGs can be connected directly to the DC bus without the use of DC/DC power converters, while AC DES in AC hybrid micro MGs can be connected to the AC bus without the use of AC/AC power converters, thus achieving a certain economic benefit. An example of the architecture of the hybrid AC/DC MG architecture is shown in Fig. 10.

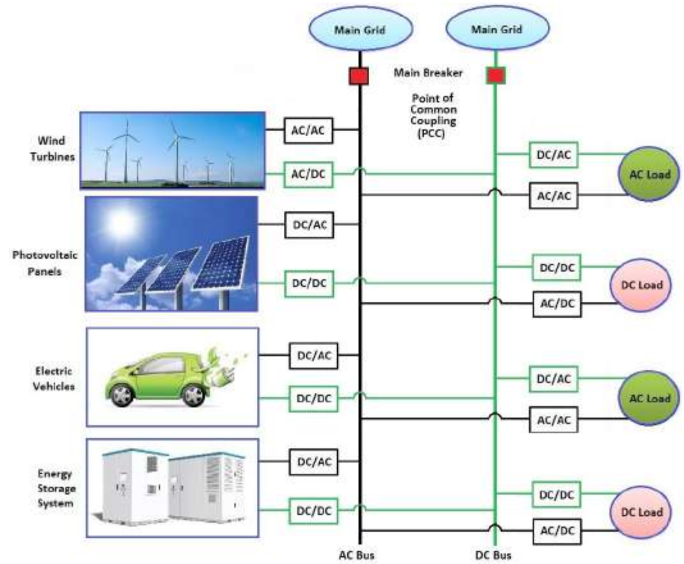

Fig. 9. An example of the architecture of an AC MG (black line) and an DC MG (green line).

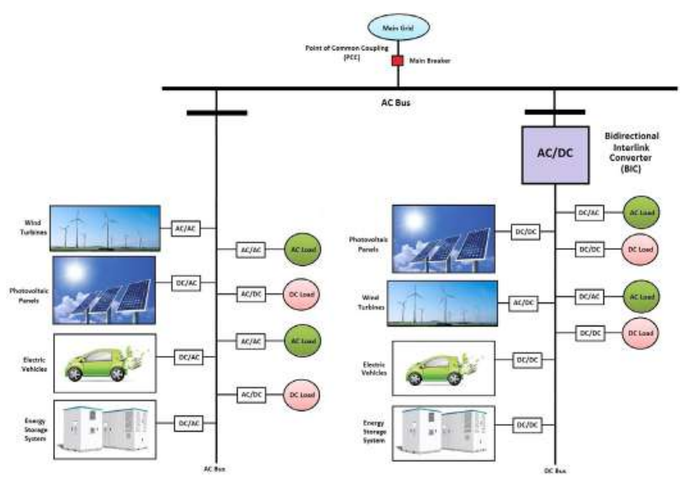

Fig. 10. An example of the architecture of hybrid AC/DC microgrid.

C. Microgrid control

In terms of control, MGs can be divided into two basic groups:

1. centralized, and
2. decentralized.

Centralized control represents the first type of MG control, in which the control of the complete energy system between the MG and the MDG, and the complete production of all DESs, is realized by one central control unit. In centralized control, the central control unit and main device used to connect, operate and control all types of DESs and MG in grid-connected mode and island mode, and which is responsible for the stability, reliability, security and protection of the complete energy system (MG and MDG) is microgrid central controller (MGCC).

MGCC represents the energy electronic device and the main interface between the MDG and the MG and other participants in the energy system (distribution system operator, market operator, power suppliers), whose main principle and goal of work are focused on maximizing the value of the MG (maintenance of voltage and frequency, active and reactive power), optimizing the operation of the MG, minimizing the operating costs of MG, respecting the prices in the open electricity market, demand and supply of distributed generators [1], [13]. Based on electricity prices in the electricity market and fuel prices, characteristics of production units in terms of GHG, technical requirements of the distribution grid and demand for ancillary services by the MDG, the MGCC determines the amount of energy that the MG should import from the MDG, optimizing local production, energy storage systems and/or consumption.

Decentralized control represents another type of MG control, in which the management of individual production unit and the production of an individual distributed energy source is carried out by means of individual (decentralized) control units. Decentralized MG control enables and ensures intelligent and independent operation and control of each production unit in the MG, so that the energy system continues to operate normally in the event of a failure, malfunction, outage, planned and/or unplanned interruptions/interventions of the distributed generation of one of the DESs in the energy system. In a decentralized control, the decentralized control unit and the main device used to connect individual distributed energy source and MG management in a grid-connected and island mode is the micro source controller (MSC).

MSC is an energy electronic device and a main interface between the MG and the MDG used to operate and control different types of production units of DESs in the system and/or energy storage system at the individual level. In MGs, the main principle and goal of MSCs operation and management are focused on controlling the voltage and frequency of the MG and maintaining their stability in conditions of a transient state (failure, planned/unplanned interruption of the individual distributed generator and/or complete system, load change, etc.), whereby all MSCs have the autonomy to perform local optimization of active and reactive energy from DESs (based on MGCC set and sent requests), while in the island mode of operation they have autonomy of rapid load monitoring after switching from a grid-connected mode [1], [13]. An example of the hierarchical control layout of the architecture and structure of the microgrid with MGCC and MSC is shown in Fig. 11.

Within the MG, there are three ways of hierarchical management and regulation of a MG:

1. primary regulation,
2. secondary regulation, and
3. tertiary regulation.

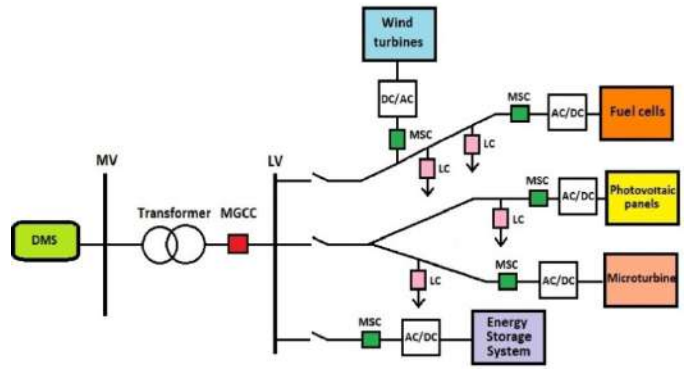

Fig. 11. An example of the hierarchical control layout of the architecture and structure of the MG with MGCC and MSC [13].

Primary regulation in the framework of hierarchical management of the MG is based on the control of the load distribution between the production units (DESs) in the MG and is primarily aimed at controlling voltage and frequency control at the local level. In the context of further hierarchical control of the MG, the secondary regulation performs actions for the purpose of correction (concretely, reduction) and/or complete elimination of the failures in the established state that occurred after primary control, and is primarily directed to frequency control and voltage control. In the final process of hierarchical control, tertiary regulation performs optimum aggregate engagement and control of flows (exchange) of energy between the MG and the MDG for optimal consumption, and aims to optimize the operation of the MG in the grid-connected and island mode. Detailed in [14].

IV. Distributed Energy Sources In The Microgrid Concept "FTN NS"

Following the modern trends of intensive research and development, promotion and use of RESs, the application of EE, and clean energy technologies, the Faculty of Technical Sciences Novi Sad has developed the idea concept of plan and design of the microgrid (MG) "FTN NS".

The idea concept of the plan and design of the MG "FTN NS" is based on the application of the following different types of DESs and distributed electricity generation technologies and consists of the following:

1. photovoltaic power plant "FTN NS 1",
2. photovoltaic power plant "FTN NS 2",
3. wind power plant "FTN NS",
4. combined heat and power plant "FTN NS",
5. electric vehicle "FTN NS 1", and
6. electric vehicle "FTN NS 2".

A. Photovoltaic power plant "FTN NS 1"

Within the framework of the plan and design of the MG "FTN NS", which is based on the application of different types of DESs, there is a photovoltaic (PV) power plant "FTN NS 1".

In terms of microlocation, the PV power plant "FTN NS 1" is installed on a flat roof of the building of the FTN, the geographic coordinates of the microlocation of the building are 45.246259 ° for latitude and 19.851335 ° for the geographical length [7]. For the purpose of better illustration, the satellite view of the position and appearance of the micro-location of the PV power plant “FTN NS 1” is shown in Fig. 12.

In terms of orientation and angle of inclination, the PV panels in the PV power plant “FTN NS 1” are oriented to the south at a tilting angle of 33 ° in relation to the horizon, in order to enable and ensure the maximum production of electricity of the PV power plant.

Fig. 12. Microlocation of the PV power plant “FTN NS 1” [7].

In terms of construction, the PV power plant “FTN NS 1” has a nominal output of 9.6 kWp and consists of the following main parts:

1. 40 PV panels,
2. 1 PV string inverter (DC/AC power converter),
3. 1 AC distribution box,
4. bidirectional meter, and
5. communication control devices and measuring equipment.

The block diagram of the PV power plant “FTN NS 1” within the framework of the plan and design of the MG “FTN NS 1” is shown in Fig. 13.

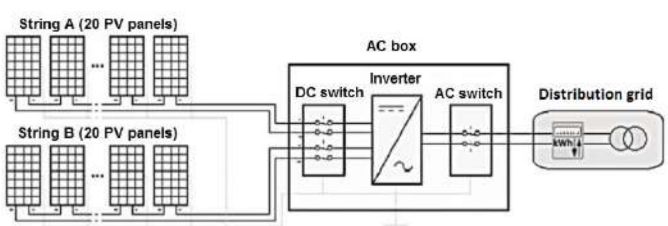

Fig. 13. Block diagram of the PV power plant “FTN NS 1”.

In the process of designing and planning PV power plant “FTN NS 1”, PV panels were formed and realized in two strings, each string consisting of 20 series connected PV panels (polycrystalline, nominal output power 240 W, module efficiency 14.66%) which are further connected to the DC inputs of the PV string inverter with the maximum power point tracking (MPPT). Detailed technical specifications and characteristics of used PV panels and PV string inverter in the PV power plant “FTN NS 1” are given in [15]-[16].

The AC distribution box is an integral part of the PV power plant “FTN NS 1”, which houses a PV inverter string, one-way and alternating switching and protection devices and equipment (overvoltage protection, overcurrent protection, fuses, etc.) in order to enable and provide maximum reliability, security and protection of PV power plant and electricity consumers.

Since the PV power plant “FTN NS 1” is realized in the concept of “ON-grid” (“grid-tie”), the bidirectional meter is one of the components of the solar energy system. Bidirectional meter represents the PCC of the PV power plant and the MDG, where the measurement of the delivered energy into the MDG (more precisely, the electricity produced in the PV power plant) and the electricity from the MDG is carried out.

Communication control devices and measuring equipment within the PV power plant “FTN NS 1” enable and provide remote (internet) access to the portal of the PV power plant in real time, monitoring and control, as well as preservation of technical and ambient data on the micro-location of the PV power plant (daily, annual, total and current generation of electricity, current and total emissions of GHG (CO_2), solar radiation intensity, PV panels temperature, air temperature, wind speed, etc.). Detailed technical specifications and characteristics of used communication control devices and measuring equipment in the PV power plant “FTN NS 1” are given in [17]-[18].

As one of the best evidence that the FTN successfully follows modern trends of research, development, promotion and use of clean energy technologies, is the fact that the PV power plant “FTN NS 1” represents the first grid-connected PV power plant in the Republic of Serbia and the first privileged producer of electrical energy converted from solar energy in Serbia.

B. Photovoltaic power plant “FTN NS 2”

Within the framework of the plan and design of the MG “FTN NS”, which is based on the application of different types of DESs, the PV power plant “FTN NS 2” is located.

In terms of microlocation, the PV power plant “FTN NS 2” is installed on a flat roof of the building of the Mechanical Institute within the Faculty of Technical Sciences, the geographic coordinates of the microlocation of the building are 45.246259 ° for latitude and 19.851335 ° for geographical length [7]. For the purpose of better illustration, the satellite view of the position and appearance of the micro-location of the PV power plant “FTN NS 2” is shown in Fig. 14.

In terms of orientation and angle of inclination, the PV panels in the PV power plant “FTN NS 2” are oriented to the south at a tilting angle of 20 ° in relation to the horizon (the main reasons for the slope of the roof and the position of surrounding buildings on the micro-location of the PV power plant) in order to enable and secure of the maximum electricity production of the PV power plant.

In terms of construction, the PV power plant “FTN NS 2” has a nominal output power of 16.3 kWp and consists of the following main parts:

1. 69 PV panels,
2. 2 PV string inverters i 8 microinverters,
3. 2 AC distribution boxes,
4. bidirectional meter, and
5. communication control devices and measuring equipment.

Fig. 14. Microlocation of the PV power plant “FTN NS 2” [7].

The block diagram of the PV power plant “FTN NS 2” within the framework of the plan and design of the MG “FTN NS“ is shown in Fig. 15.

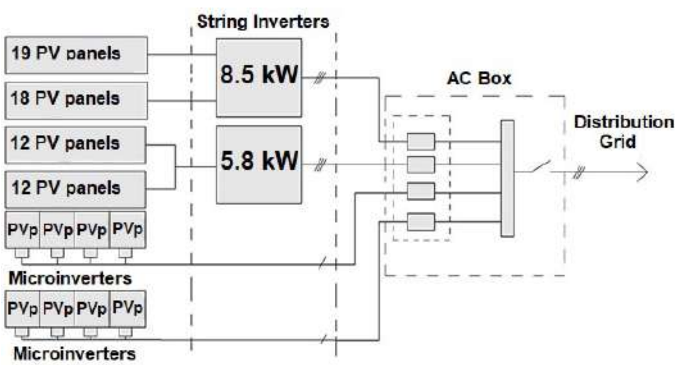

Fig. 15. Block diagram of the PV power plant “FTN NS 2”.

In the process of designing and planning PV power plant “FTN NS 2”, PV panels were formed and implemented in four strings, the first string consisting of 19 series connected PV panels, the second string consisting of 18 PV panels, while the third and fourth string consist each of 12 series connected PV panels. With regard to the concept of connection and realization, the first and second string connected to the one-way inputs of the PV string inverter of nominal output power of 8.5 kW with the MPPT inputs, the third and fourth string are connected to the single-phase inputs of the PV string inverter of nominal output power 5.8 kW with the MPPT, while each of the remaining 8 PV panels is connected to 8 microinverters.

Compared to the PV power plant “FTN NS 1” in which one type of PV panels (polycrystalline silicon) and one PV string inverter are installed, three PV panels (monocrystalline silicon, polycrystalline silicon, and thin film silicon) and two types of PV inverters (string inverters and microinverters). Detailed technical specifications and characteristics of used PV panels and PV inverters in the PV power plant “FTN NS 2” are given in [15], [19]-[23]. The technical characteristics and specifications of AC distribution boxes, bidirectional meters, communication control devices and measuring equipment in the PV power plant “FTN NS 2” are practically identical to those of the PV power plant “FTN NS 1”, which justifies the omission of further detailed descriptions.

C. Wind power plant “FTN NS”

Within the framework of the plan and design of the MG “FTN NS”, which is based on the application of different types of DESs, there is a wind power plant (WPP) “FTN NS”.

In terms of microlocation, the WPP “FTN NS“ installation is planned on a flat roof of the building of the Faculty of Technical Sciences, the geographic coordinates of the microlocation of the building are 45.246073 ° for latitude and 19.851939 ° for the geographical longitude [7]. For the purpose of better illustration, the satellite view of the position and appearance of the micro-location of the WPP “FTN NS“ is shown in Fig. 16.

Fig. 16. Microlocation of the WPP “FTN NS” [7].

In terms of construction and design, the wind power plant “FTN NS” has a nominal output of 2 kW and consists of the following main parts:

1. wind turbine (wind generator),
2. inverter (DC/AC power converter),

3. AC box,
4. bidirectional meter, and
5. communication control devices and measuring equipment.

The block diagram of the WPP "FTN NS" in the framework of the plan and design of the MG "FTN NS“ is shown in Fig. 17.

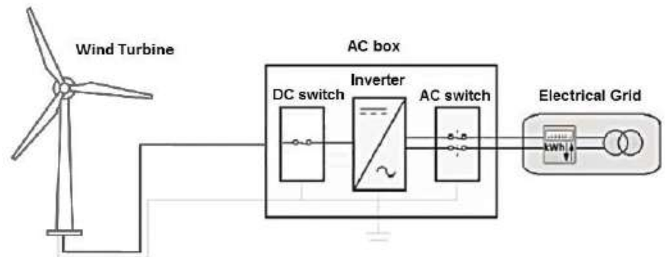

Fig. 17. Block diagram of the WPP "FTN NS".

With regard to the technical specifications of the main parts, equipment and components, within the WPP "FTN NS" is planned to install and use a wind turbine with a nominal output of 2 kW, a maximum output power of 2.95 kW, initial wind speed (cut-in speed) 2.5 m/s, working wind speed from 3 m/s to 25 m/s, nominal wind speed 8 m/s, maximum rotational speed 400 rpm and average average wind speed of 5 m/s is 4,672 kWh. The detailed technical characteristics of the WPP "FTN NS" are given in [24].

D. Combined heat and power plant "FTN NS"

Within the framework of the plan and design of the MG "FTN NS“, which is based on the application of different types of DESs, the combined heat and power (CHP) power plant "FTN NS“ is located.

In terms of microlocation, the CHP plant "FTN NS“ is planned in the building of the Mechanical Institute of the Faculty of Technical Sciences Novi Sad.

In terms of design, the CHP power plant "FTN NS" has a nominal output of 10 kW and consists of the following main parts:

1. combined heat and power generator,
2. distribution panel,
3. system controller,
4. heat and power devices and equipment.
5. communication control devices and measuring equipment.

A block diagram of the CHP power plant "FTN NS" within the framework of the MG "FTN NS“ is shown in Fig. 18.

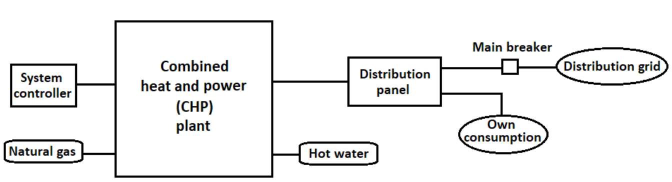

Fig. 18. Block diagram of the CHP power plant "FTN NS".

In terms of the plan and design of the CHP power plant "FTN NS", the following technical characteristics are provided: the nominal output power 10 kWe, the phase current 14 A, the recovered heat 17.5 kWt, the water inlet/outlet temperature 80°C/60°C, the total efficiency 86.5%, efficiency of electricity production 31.5%, efficiency of heat recovery 55%. The detailed technical characteristics of the CHP power plant "FTN NS" are given in [25].

E. Electric vehicle "FTN NS 1"

Within the framework of the plan and design of the concept of the MG "FTN NS", which is based on the application of different types of DESs, there is an electric vehicle EV "FTN NS 1".

The EV "FTN NS 1" has power output of 4 kW (nominal voltage 48V, nominal current 104 A) and other technical characteristics of the engine system that enable and provide short distance driving of up to about 60 km. The power supply of the EV "FTN NS 1" is carried out by DC voltage 48 V by series connection of 5 batteries with a capacity of 145 Ah and a voltage of 12 V and 100 Ah and a voltage of 8 V, while the drive is a DC motor with a series-wound of a nominal speed of 2800 rpm. The detailed technical characteristics of the EV "FTN NS 1" are given in [26]. A block diagram of the drive of a DC motor of the EV "FTN NS 1" is shown in Fig. 19.

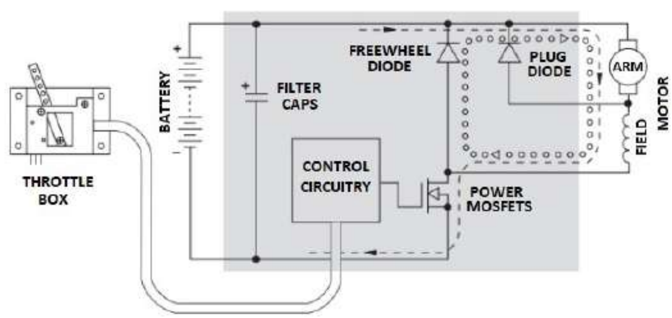

Fig. 19. Block diagram of the EV "FTN NS 1" [26].

F. Electric vehicle "FTN NS 2"

Within the framework of the plan and design of the concept of the MG "FTN NS", which is based on the application of different types of DESs, there is an electric vehicle EV "FTN NS 2".

The EV "FTN NS 2" has a power output of 2.5 kW and technical characteristics of the engine system that provide and enable short-distance driving up to about 60 km. The power supply of the EV "FTN NS 2" is carried out by a DC voltage of 48 V by means batteries with a capacity of 55 Ah and a voltage of 8 V, while the drive consists of 4 permanent magnet synchronous motors, one mounted in each wheel, so that the EV "FTN NS 2" represents actually an four-wheel drive (4x4) electric vehicle. The detailed technical characteristics of the EV "FTN NS 1" are given in [26]. A block diagram of the 4 AC motor drive of the EV "FTN NS 2" is shown in Fig. 20.

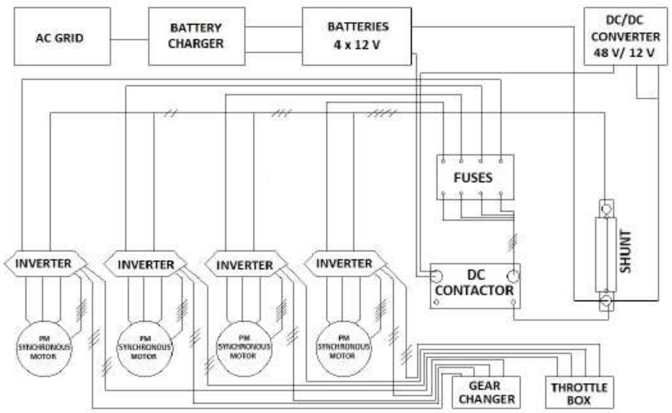

Fig. 20. Block diagram of the EV "FTN NS 2" [26].

G. Battery energy storage system

In order to provide a backup power supply to electric consumers, within the framework of the concept of the MG "FTN NS" based on different types of DERs, the installation of the battery energy storage system is also planned. The main task and goal of the battery storage system is to enable and provide critical consumer power supply for at least 3 hours during an planned/unplanned interruption/outage. In order to meet this requirement, the application of 15 Absorbent Glass Matt Valve Regulated Lead Acid (AGM VRLA) batteries with a capacity of 200 Ah and a voltage of 12 V is planned and designed within the concept of the MG "FTN NS", whose connection provides and enables total capacity of 36 kWh of electricity.

V. Techno-Economic and Ecological Analysis of the MG "FTN NS" concept

In order to verify the feasibility of the realization of the plan and the design of the MG "FTN NS", and the detailed consideration of the technical, economic and ecological aspects of the application of various DESs, the techno-economic and ecological analysis is carried out.

A. Cost and Revenues of a MG

In the process of planning and designing the construction of power plants for the production of electricity and heat from RES, the analysis of technical, economic and ecological factors are of particular importance. For this reason, techno-economic and ecological analysis is carried out. It defines, analyzes and processes different types of costs and revenues of power plants for the production of electricity and heat from renewable sources.

Within the framework of techno-economic and ecological analysis, the total costs are most often defined and processed according to the following formula:

$$C_T = C_I + C_{O\&M} \tag{1}$$

where C_T represents total costs [€], C_I investment costs [€], and $C_{O\&M}$ operation and maintenance costs [€]. In most cases, decommissioning costs are part of the investment costs and are treated in this way in this paper.

Investment costs include the capital costs of the site (land), the costs of making and issuing construction, energy and environmental permits, the design of the idea and the main project, as well as the costs of procuring the equipment and devices of the RES power plant. Operational and maintenance costs include the cost of operation and the costs of planned and unplanned interventions, and are most often counted on an annual level as a certain percentage of the investment costs.

Within the framework of techno-economic and ecological analysis, total revenues are most often defined and processed according to the following equation:

$$R_T = R_{IM} + R_{GHG} \tag{2}$$

where R_T represents total revenues [€], R_{IM} revenues from electricity and heat generation through economic incentive measures (FIT) [€], and R_{GHG} revenues from the avoidance of GHG emissions through ecological-economic incentive measures (e.g. carbon taxes) [€].

The revenues from electricity (R_{IM}) can be calculated on the basis of the following mathematical relation:

$$R_{IM} = E_P \cdot P_{IM} \tag{3}$$

where E_P represents the amount of electricity and/or heat produced from particular type of RES power plant [kWh], P_{IM} price of the incentive measure for particular type of RES power plant [c€/kWh].

The revenues from the avoidance of GHG emissions (I_{GHG}) can be calculated on the basis of the following mathematical relation:

$$R_{GHG} = A_{GHG} \cdot P_{GHG} \tag{4}$$

where A_{GHG} represents the amount of GHG emission avoided by using of certain type of RES power plant [$kgCO_2$], P_{GHG} price of the incentive measure for GHG emissions avoidance [€/$kgCO_2$]. In the world and in European countries, two main ecological and economic mechanisms used to encourage the avoidance of GHG emissions are emission trading systems and carbon tax [27]. Revenues from the avoidance of GHG emissions are calculated according to the (4) and the assumption that the carbon tax is 20 €/tonne CO2.

After detailed verification and determination of the techno-economic and ecological aspects of the proposed solution of the MG at a certain micro-location, it is necessary to determine the factor of the return of the investment (ROI) factor in the MG.

The return of investment factor in the MG is calculated on the basis of the following mathematical formula:

$$ROI = \frac{R_T - C_T}{C_T} \cdot 100\% \tag{5}$$

where ROI represents the return factor of the investment in the MG, R_T represents total revenues of the realization of the

MG, and C_T represents total costs of the realization of the MG.

A detailed techno-economic and ecological analysis of the aspects of the application of various DESs for the case study of the MG "FTN NS" is given below.

B. Cost and Revenues of the microgrid "FTN NS"

After detailed analysis and processing of technical characteristics of different types of DESs and realization of their integration within the framework of the MG "FTN NS" design and plan, in order to obtain a wider picture and detailed results, technical-economic and ecological analysis of the aspects of the proposed concept was carried out.

Techno-economic and ecological analysis of the aspects of the application of different DESs within the framework of plan and design of the MG "FTN NS" consists of and is defined on the basis of the following two parameters:

1. total costs, and
2. total revenues.

The total costs actually represent techno-economic costs of each individual DES in the MG "FTN NS". Techno-economic costs consist of the investment costs and operation and maintenance costs of each individual DES in MG "FTN NS". The results of the techno-economic analysis of techno-economic costs in terms of the application of different DESs in the MG "FTN NS" at annual and life span period (25-year) are given in Table I.

TABLE I
Techno-Economic Costs of the MG "FTN NS"

Type of DES	Investment costs [€]	Operation and management costs [€]
PV power plant "FTN NS 1"	17,000.00	1,000.00
PV power plant "FTN NS 2"	27,000.00	1,000.00
Wind power plant "FTN NS"	3,750.00	750.00
CHP plant"FTN NS"	38,500.00	1,500.00
EV "FTN NS 1"	4,250.00	750.00
EV "FTN NS 2"	5,250.00	750.00
BESS "FTN NS"	6,300.00	0
MGCC	13,000.00	0
Total	115,050.00	5,750.00

Total revenues represent the techno-economic revenues and ecological-economic revenues of each individual DES in the MG "FTN NS". Techno-economic revenues consist of revenues generated through economic mechanisms for stimulating the production of electricity and heat from RESs, as well as ecological-economic revenues generated through economic mechanisms to encourage the avoidance of GHG emissions through the application of RESs.

The main parameters in the framework of the techno-economic analysis of techno-economic revenues are the amount

TABLE II
Techno-Economic Revenues of the MG "FTN NS"

Type of DES	Annual electricity production [kWh]	Annual income through incentive measures [€]	Life span electricity production [kWh]	Life span income through incentive measures [€]
PV power plant "FTN NS 1"	11,346.53	2,609.72	283,663.25	65,243.00
PV power plant "FTN NS 2"	19,265.46	2,561.54	481,636.50	64,038.50
Wind power plant "FTN NS"	2,662.00	244.90	66,550.00	6,122.60
CHP plant"FTN NS"	32,850.00	4,538.955	985,500.00	136,168.65
EV "FTN NS 1"	0	0	0	0
EV "FTN NS 2"	0	0	0	0
BESS "FTN NS"	180.00	0	1,440.00	0
Total	66,309.99	9,955.115	1,818,789.75	271,572.75

TABLE III
Ecological-Economic Revenues of the MG "FTN NS"

Type of DES	Annual GHG emissions avoided [$kgCO_2$]	Annual income through ecological-economic incentive measures [€]	Life cycle GHG emissions avoided [$kgCO_2$]	Life span income through ecological-economic incentive measures [€]
PV power plant "FTN NS 1"	7,970.43	158.81	199,260.75	3,795.25
PV power plant "FTN NS 2"	13,533.12	270.66	338,328.00	6,766.50
Wind power plant "FTN NS"	1,597.20	31.94	39,930.00	798.50
CHP plant"FTN NS"	29,170.80	583.41	875,124.00	17,502.30
EV "FTN NS 1"	970.71	19.41	7,765.68	485.25
EV "FTN NS 2"	970.71	19.41	7,765.68	485.25
BESS "FTN NS"	198.00	0*	1,440.00	0*
Total	54,410.97	1,083.64	1,469,614.11	29,833.05

of electricity produced for DESs [kWh] and the amount of incentive purchase price for the production of electricity from different RESs [c€/kWh], which determines the techno-economic revenue of the microgrid at annual and life span period. In the Republic of Serbia, the Regulation on incentive measures for the production of electric energy from renewable resources and from high-efficiency electricity and thermal energy cogeneration is currently in force [28]. The results of the techno-economic analysis in terms of techno-economic revenues in terms of the application of different DESs in the MG "FTN NS" at annual and life span period are given in Table II.

The main parameters in the framework of the techno-economic analysis of ecological-economic revenues are the amount of GHG emissions (specifically CO2) avoided by the use of different DESs [kgCO2] and the incentive price for avoiding GHG emissions using RESs [€/tCO2], which determines the ecological-economic revenues of the MG "FTN NS" at the annual and the lifespan period. The results of the techno-economic analysis of ecological-economic revenues in terms of the application of different DESs in the MG "FTN NS" at annual and life span period are given in Table III.

VI. Discussion

Based on the ROI factor calculation, the results of the carried out techno-economic and ecological analysis of the feasibility of the plan and design of the various types of DES in the MG "FTN NS" and its integration into the MDG show that the total costs of the realization of the MG "FTN NS" are 120,800 €, while the total techno-economic revenue from incentive measures for the production of electricity from various DESs and ecological-economic revenues from incentive measures to avoid GHG emissions amounts to 271,572.75 € (the worst case, without a carbon tax) and 301,405.80 € (the best case, with a carbon tax).

The results of the calculated return of investment (ROI) factor show that at the end of the power purchase agreement (12-year incentive period) from the different DESs in the MG "FTN NS" a profit of 12.41 % (the worst case, with no carbon tax) and 24.75 % (the best case, with a carbon tax) can be realized. Based on the obtained results of the techno-economic and ecological analysis of the feasibility of the plan and design of MG FTN NS and its integration into the MDG, it can be noticed that in the case of contract extension to the end of the life of distributed energy sources in MG FTN NS the value of total revenues is significantly higher the amount of the total cost of realization, which the MG "FTN NS" proposal makes even more techno-economic and ecological justified solution.

VII. Conclusion

This paper presents the proposal of different types of the distributed energy sources, whose integration is and will be realized in the university campus within the plan and design of the microgrid at Faculty of Technical Sciences Novi Sad. In order to verify the feasibility of implementation of the proposed microgrid concept, a techno-economic and ecological analysis of the aspects of the application was carried out. The results of the work have reached the conclusion that at the end of power purchase agreement (12-year incentive period) and at the end of the life span of the all distributed energy sources in the microgrid in the university campus, the total revenues are higher than the total costs, and that the realization of the proposed microgrid concept is technical, economical, and ecological justified. Further research will be focused on the aspects of the integration of the distributed energy sources into microgrid, the stability and reliability of their work, the problem of optimizing the operation and control of distributed energy sources in microgrid, as well as aspects of the market and the internal aspects of the microgrid concept (variable energy price, vehicle to grid concept, peak shaving, backup power, etc.).

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