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ANALYSIS OF MICROGRID OPERATION IN STAND-ALONE MODE - SUSTAINABLE SMART TOURIST VILLAGE CASE STUDY

ANALIZA RADA MIKROMOREŽE U SAMOSTALNOM REŽIMU RADA - STUDIJA ZA SAMOODRŽIVO PAMETNO TURISTIČKO NASELJE

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Abstract: The aim of this paper is to analyse the stand-alone operation of the microgrid located in Umoljani, Bosnia and Herzegovina. The analysis was performed for two scenarios; one representing a summer day and the other a winter day. The analysed network was modelled using the DIgSilent PowerFactory. The Photovoltaic (PV) system, Wind Generator (WG) and battery sizing were performed using the HOMER software tool. The load data for the location was obtained from JP Elektroprivreda Bosne i Hercegovine. The analysis showed that the network was able to operate in stand-alone mode. Voltage levels were under the voltage limit defined by EN 50160. Line loading was decreased compared to loading in grid-connected mode. As given by the obtained results for the two scenarios, the consumer demand could be satisfied without the inclusion of WG. However, different input data (wind speed data measured on the location) could change the sizing of the production facilities as the results of the optimization calculations in HOMER, which needs to be considered in microgrid configuration.

Keywords: DIgSilent PowerFactory, hybrid power system, microgrid, renewable energy sources, stand-alone operation, quasi- dynamic simulation

Sažetak: Cilj ovog rada jeste analiza nezavisne načina rada mikromreže bazitanoj na lokaciji Umoljani. Analiza je izvršena za dva scenarija koja predstavljaju po jedan ljetni i zimski dan. Analizirana mreža modelovana je koristeći DIgSilen PowerFactory. Dimenzionisanje fotonaponskih (PV) sistema, vjetrogeneratora (WG) i baterije je izvršeno koristeci softverski alat HOMER. Podatci potrošnje za lokaciju preuzeti su iz Elektroprivede Bosne i Hercegovine. Analiza je potvrdila mogučnost nezavisnog rada mreže. Naponski nivoi nisu bili narušeni pod granicom napona definisanom od strane EN 50160. Opterećenje vodova je bilo smanjeno u odnosu na opterećene tokom načina rada s mrežom. Dobiveni rezultati ukazuju da bi se potrebe potrošača mogla zadovoljiti bez uključivanja WG-a. Međutim, drugi unosni podatci (brzina vjetra mjereno na lokaciji) moglo bi promjeniti veličinu proizvodnih objekata kao rezultat optimizacijsko proračuna u HOMER-u, o čemu treba obratiti pažnju tokom konfiguracije mikromreže.

Ključne riječi: DIgSilent PowerFactory, hibridni sistem, mikromreža, nezavistan režim rada, obnovljivi izvori, quasi- dynamic analiza

INTRODUCTION

Microgrid presents a crucial building block of a smart-grid. There are many definitions of microgrid, and according to the U.S. Department of Energy [1] it is defined as: „a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid". One of the advantages of a microgrid is the capability to connect and disconnect from the rest of the grid to enable operation in both grid-connected or stand-alone mode of operation. Furthermore, it allows improvement in the energy distribution to the end-load customer and may allow consumers grid-independence. On remote locations, during a blackout or other unforeseen events or disturbances, the microgrid is able to distribute power to the consumers. In the future, microgrids will become more economically viable if the price of fossil fuels and the penalties for emissions increase [2]. The influence of a more balanced production in the grid and consumption of electrical energy may become one of the most important advantages of a microgrid. For better quality in distribution and production, control and management is important and would bring many advantages to all voltage levels [3]. With the growth of the wind and PV power generation systems exceeding estimation and since different renewable energy sources (RES) complement each other, hybrid power systems have great potential. Their potential lies in providing higher quality and more reliable power to the consumer than a system based on a single RES

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[4]. When designing a microgrid to operate in stand-alone mode, there are four perspectives to be considered [5]:

- To describe the load and its change through time (day/hours, month, year),
- The amount of RES required taking into consideration the location, the weather and other environmental variables,
- The restrictions of the system, such as the stability conditions of interruptions, potential space limitations of RES installation, the system losses, power quality, reactive power compensations, etc.,
- The optimization concerning different objectives like the CO2 emissions reduction, minimum investment, minimum fuel cost, continuity of supply, etc.

The purpose of this project was to establish a hybrid power system for the energy supply of costumers located in a tourist village and to analyse the operation of the microgrid in stand-alone mode. In the first section, the simulation toolboxes used are briefly explained. The input data used, as well as the output characteristics of RES used (WG, PV) and storage elements (battery), are also presented in the first section. The sizing of the storage and production elements were performed using HOMER, which was applied to the model of the village using DIgSilent PowerFactory. In the second section, the presented results show the voltage characteristics and the microgrid line loading.

1. LITERATURE REVIEW

Dali, Belhadj, and Roboam [6] investigated the operation of a hybrid- solar-wind system with battery storage operating in grid-connected and standalone mode. The hybrid system consisted of a 600 W WG and a 400 W PV panel, which partially charge the battery bank to supply the grid. The results showed the capability of the system to operate in grid-connected and in autonomous mode.

Jian, Yannbo, and Lihua [7] classified and summarized the structures of off-grid hybrid systems, where the advantages and disadvantages of different system structures were described and analysed the design of the off-grid wind-solar hybrid power system. The core problem of off-grid wind-solar hybrid power generation systems is the control strategy to ensure the power supply reliability. Off-grid systems have important value for standalone and remote areas.

Bajpai and Dash [8] reviewed the research of unit sizing, management, and modelling of the hybrid renewable energy system components as well as the development in research on modelling of hybrid energy sources, backup energy systems. Hybird power system has great potential to satisfy the load demand of remote, isolated sites and can help greatly in rural and urban development, by increasing system reliability and decreasing central generation capacity. The global use of HPS will not only solve the energy issues but will also ensure green and sustainable planet.

Merzić, Musić, and Redžić [9] analysed the output power of the PV power plant, wind power plant and their combination in a hybrid system. Two cases were considered: where both generation facilities have equal installed capacities (2 MW each) and where the installed capacity of the wind power plant is five times larger. For the first case, the hybrid system reduces the output power variation range compared to the second case. However, independent electricity generation for both cases could not meet the consumer needs. Appropriate storage would be necessary to send the energy when required. However, due to the 3.5 times difference between electricity generation and demand for 8.4% of the time, large dimensions would be required for storage, which is not profitable.

2. METHODOLOGY

2.1. Software Tools Applied

For the purpose of the performed analysis, two software tools have been used.

HOMER software tool was applied to establish an adequate hybrid power system for consumer supply. It is a simulation model that tries to simulate a viable model of combinations of equipment depending on what the user considered. It simulates the operations of a hybrid power system of an entire year in different time-steps from one minute to one hour [10].

Digital SimuLation of Electrical NeTworks (DIgSilent) PowerFactory is a computer-aided engineering tool for transmission, distribution, and industrial electrical power systems analysis. It was the world's first system analysis software with an integrated graphical single-line interface that included drawing functions, editing capabilities, and all relevant dynamic calculation features [11].

For this project, the quasi-dynamic simulation toolbox was used for the load flow calculation for the given scenarios. For the load flow calculation, the network is considered under a single set of operating conditions. However, to better understand the system performance under different scenarios, several different load-flow simulations with a range of operating conditions must be run. DIgSilent PowerFactory contains a dedicated time-varying load flow calculation tool called quasi-dynamic Simulation. This tool calculates the load-flow of the system with the user-defined step-size. To achieve this, the quasi-dynamic Simulation makes use of the time-based parameter characteristic, variations. [11]

2.2. Hybrid System Set up and Analysis

For this case study, a location called Umoljani was considered. It is a small village located on the Bjelašnica Mountain (43° 40′ 10.92″ N, 18° 13′ 39″ E). The presence of the necropolis of medieval tombstones in Bosnia and Herzegovina (stećak) makes Umoljani a location with a potential for tourism. A geo-reference location of Umoljani is shown in Figure 1.

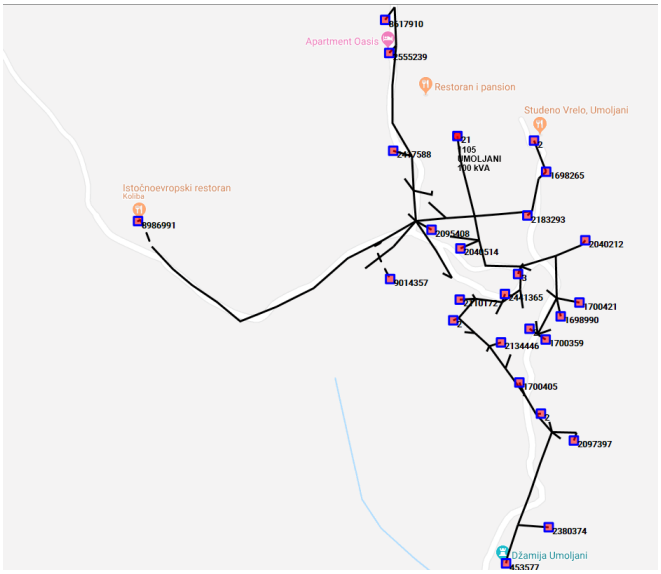

Figure 1: Georeference location of Umoljani

To establish a hybrid power system configuration, one-year consumption data was used to determine the optimal sizing of production and storage elements. For further analysis, the period of the analysis taken was one day, with a 5-minute step size. The network modelled in DigSilent Power factory consists of an external gird, one 10 kV bus, one 10/0.4 kV transformer with 100 kVA apparent power, 23 buses, a diesel generator, PV system, WG, battery and 19 loads. The sizing of production and storage elements was performed using HOMER. The results obtained from HOMER showed that for the microgrid, 59.7 kW for the PV system, 1 kW for WG and a battery with a capacity of 158 KWh would be required.

To achieve the stand-alone-mode operation, the external grid was removed from the network by disconnecting the transformer from the rest of the grid and setting the battery as the reference machine, which maintains constant voltage at the terminal to which it is connected. For the analysis, two scenarios were considered: summer day and winter day in stand-alone mode of operation.

2.2.1 Load Profile

The load specification of Umoljani was obtained from the J.P Elektroprivreda for the one-year period from 1 January to 31 December 2015. The average daily load profiles were taken from the smart meter, installed on the specific site, which measured the energy consumption in a 15-minute time interval for the whole year.

The greatest consumption was recorded during the summer period. The maximum load was 13.26 kW, and the daily average energy consumption was 131.92 kWh. Table 3.1 shows the load characteristics for Umoljani.

Figure 2 and Figure 3 represent the average daily and seasonal profile of the given load, obtained from the HOMER software tool.

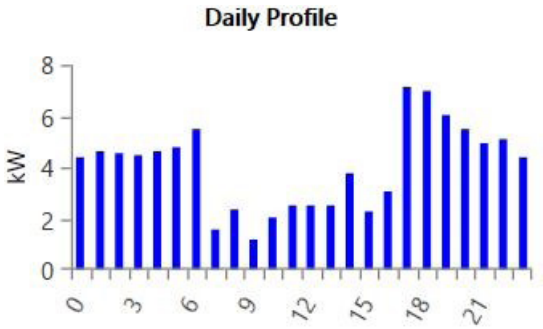

Figure 2: Average daily profile of the location Umoljani

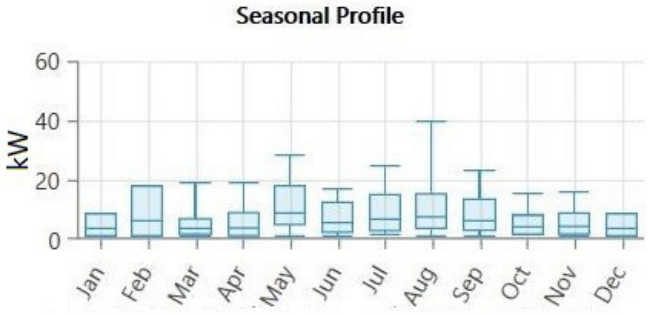

Figure 3: Seasonal profile of the location of Umoljani

2.2.2 Day Profiles Used for Analysis

For the summer period, 9 August 2015 was chosen because of the recorded peak power consumption during the morning hours. For the winter day, 17 November 2015 was taken as this represents an average winter day, where the greatest consumption was recorded during the evening hours. Figure 4 and Figure 5 represent the power consumption for the summer and winter day scenarios.

Figure 4: Power consumption on the summer day

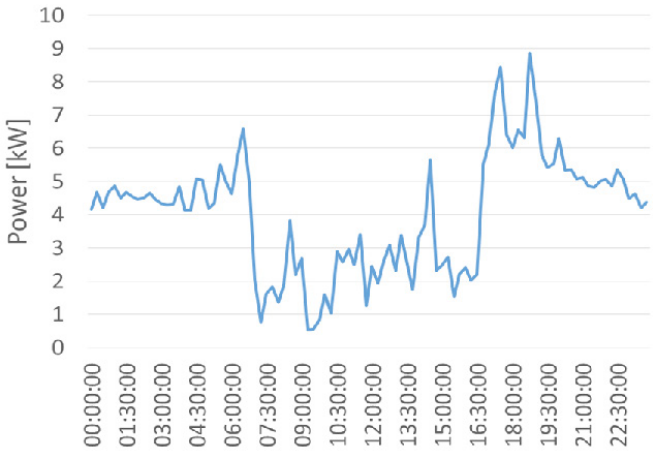

Figure 5: Power consumption for the winter day

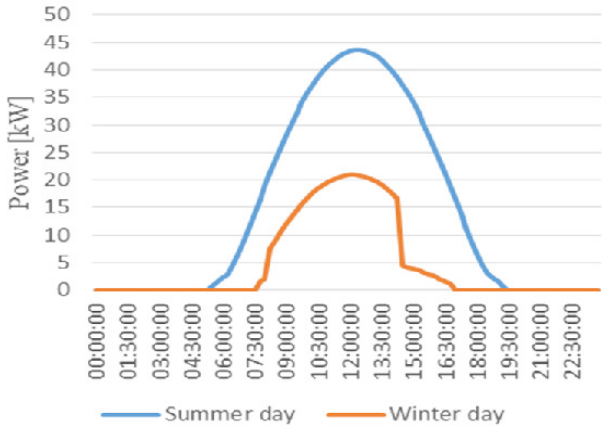

Figure 6: PV output for both cases

2.2.3 PV, WG and battery output characteristics

For PV generation a solar system with 59.7 installed power was considered. Data for solar irradiation was obtained from PVGIS for the specified location. The panels covered an area of 352.37 m^2 with 17% efficiency. The output power of the PV system was calculated using the formula

$$P = 0.17\,G\,A \tag{1}$$

where G is the global irradiation, 0.17 is the PV efficiency and A is the area that the PV systems covers. The obtained values are shown in Figure 6 for the summer and winter day.

The 158 kWh battery was connected to the terminal where the PV system is located. The battery was used to supply the system when the RES are not able to satisfy the load demand or to store the surplus energy produced by the RES. The battery storage operation profile was determined using the following calculation:

$$P_{bat} = P_{load} - P_{gen} \tag{2}$$

where P_{bat} is the battery charging and discharging power, P_{load} is the power consumed by the load and P_{gen} is the power produced by RES. In cases when P_{bat} is positive, the battery is discharging and for negative P_{bat}, it is charging.

The obtained results are inserted into DIgSilent PowerFactory to define battery storage operations for the summer and winter days after which power flow calculations were performed. Figure 7 presents the battery profile of the battery for the summer and winter day scenarios.

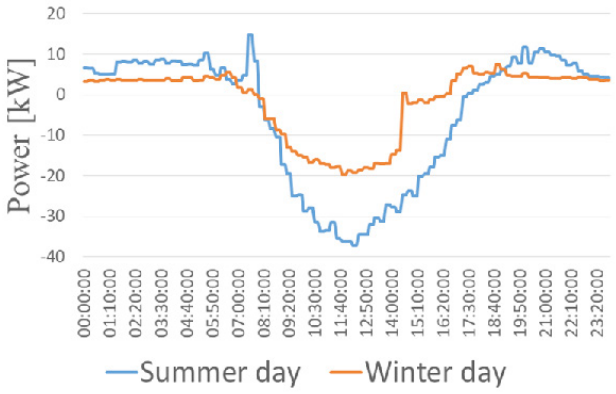

Figure 7: Profile of the battery storage operation

In the case of the WG, 1 kW WG was connected within the microgrid. Wind speed data provided by HOMER can be inaccurate and it is always preferable to use measurements for the given location if possible. For the given location, wind speed data was not available. Therefore, the available data of the broad region of the Bjelašnica Mountain, where Umoljani is located, were taken. This data is more favourable because the wind speed is greater than the wind speed data provided by HOMER. The output power was calculated using the following formula

$$P = k\,\rho\,A V^3 \tag{3}$$

where k is the constant for the output power to be in kW, ρ is the air density, A is the area of the rotor blades and ρ is the wind speed. Figure 8 shows the power output for the summer and winter day scenarios

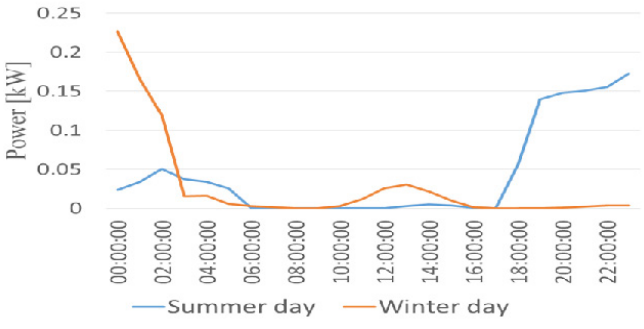

Figure 8: Power output for summer and winter day scenarios

3. RESULTS AND DISCUSSION

For stand-alone mode operation, the network was disconnected from the external grid by disconnecting the transformer. The battery was set as the reference machine that keeps constant voltage on the bus at which it is connected.

In this section, the results for the two scenarios in stand-alone-mode operation will be presented. Summer and winter day scenario will be presented separately with the obtained results for: load profiles, voltage profiles, and network element loading profiles from the terminal where the transformer was disconnected from the two biggest consumers called Restoran Pansion and apartment Oasis.

3.1. Summer Day Scenario

3.1.1 Voltage Profile

In this section, the results of the voltage profiles were taken from the terminal busbar to the 0.4 kV bus of the largest consumer as well as the voltages profiles from different loads. The voltage profile from the main terminal to the largest consumer can be seen in the following figure. The greatest energy consumption for the summer day occurred at 07:30 hrs, for which the voltage decreased in all terminals. In Figure 9, the voltage drop can be observed to be in the same period as in Figure 10.

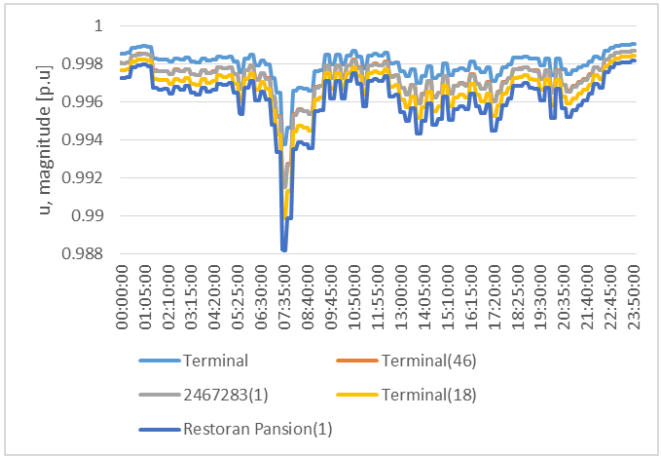

Figure 9: Voltage profile from Terminal to Restoran Pansion

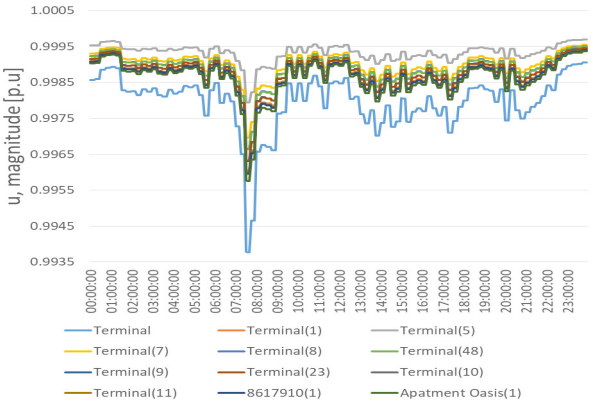

Figure 10: Voltage profile from terminal to Apartment Oasis

3.1.2 Line Loading

In this section, line loading for different lines connecting the terminal busbar to the largest consumer were presented. For comparison purposes, line loading in the grid-connected mode of operation was presented.

Figures 11 and 12 present the line loading for stand-alone mode and grid-connected mode for the summer day. The greatest difference can be observed during the evening hours at 21:25 hrs, where the loading in the grid-connected mode drastically decreases, while in stand-alone mode it gradually decreases.

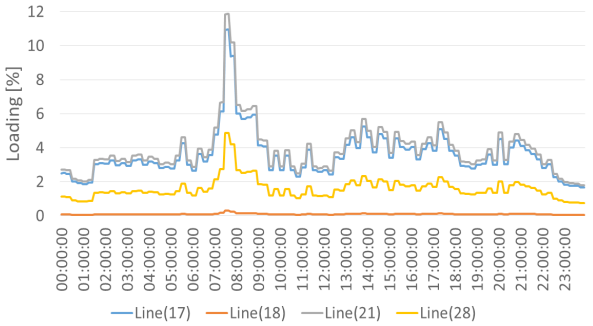

Figure 11: Line loading from Terminal to Restoran pansion-stand-alone mode

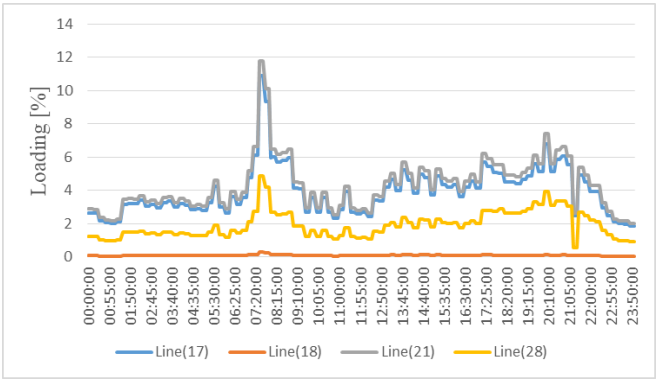

Figure 12: Line loading from terminal to Restoran pansion-grid-connected mode

From Figure 13 and Figure 14, it can be observed that the loading of the lines has decreased in stand-alone mode operations. In stand-alone mode operation, energy is sent to the network to satisfy the demand, while the excess energy produced is stored for use when it is required. In grid-connected mode operations, the produced energy is sent to the grid increasing the loading of the lines.

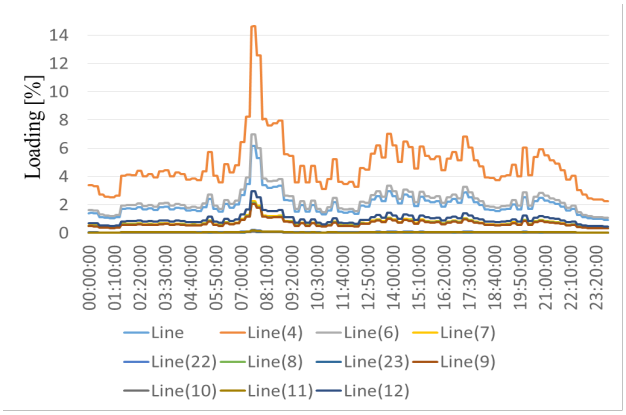

Figure 13: Line loading from Terminal to Oasis- stand-alone mode

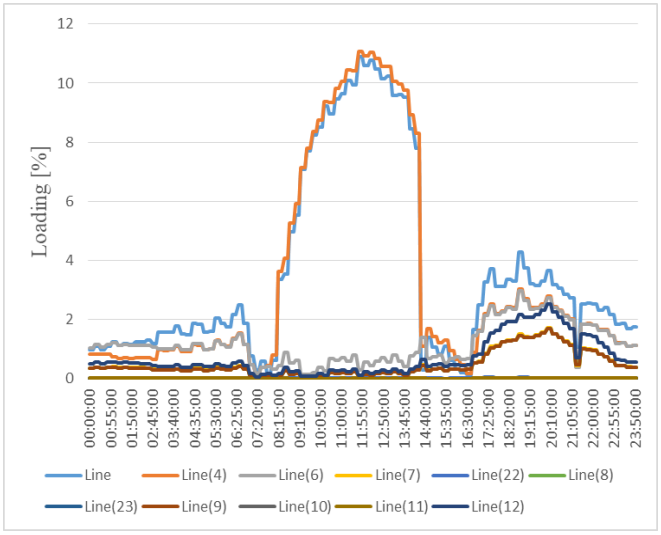

Figure 14: Line loading from terminal to Oasis- grid-connected mode

3.2. Winter Day Scenario

3.2.1 Voltage Profile

Figure 15 and Figure 16 illustrate the voltage profile for the winter day scenario. The largest consumption occurred during the evening hours at 19:00 hrs which resulted in a voltage drop as shown in both figures.

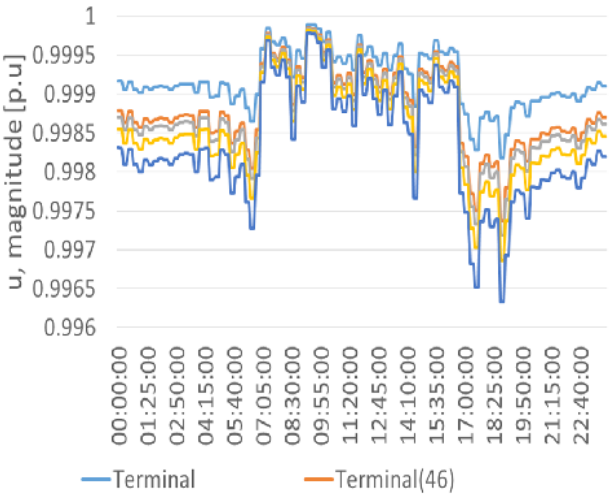

Figure 15: Voltage profile from terminal to restoran pansion

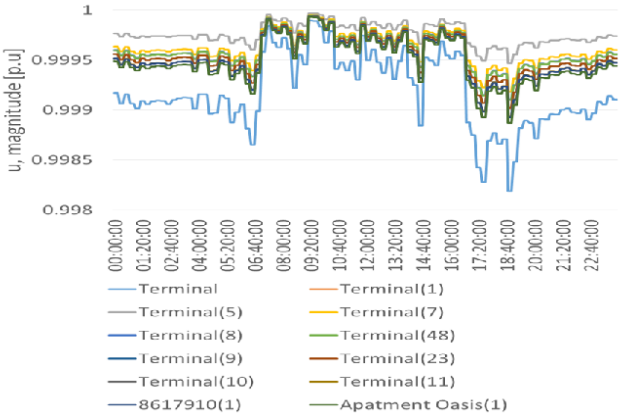

Figure 16: Voltage profile from terminal to apartment oasis

3.2.2 Line Loading

For this scenario, the loading of the lines is presented in stand-alone mode and gird-connected mode. Comparing Figure 17 with Figure 18, and Figure 19 with Figure 20, it can be seen that the loading of the lines has decreased for the stand-alone mode.

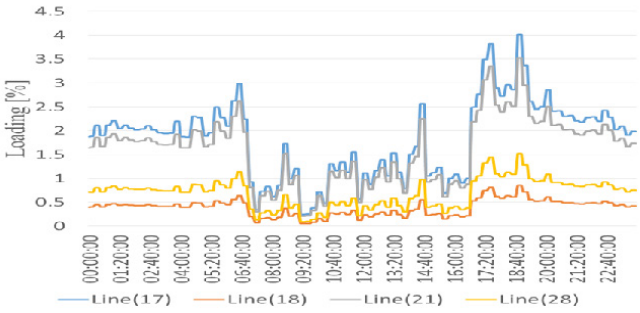

Figure 17: Line loading from terminal to restoran Pansion- stand-alone mode

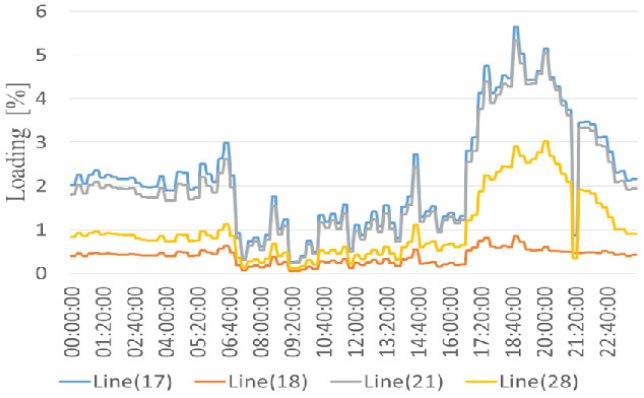

Figure 18: Line loading from terminal to restoran Pansion- grid-connected

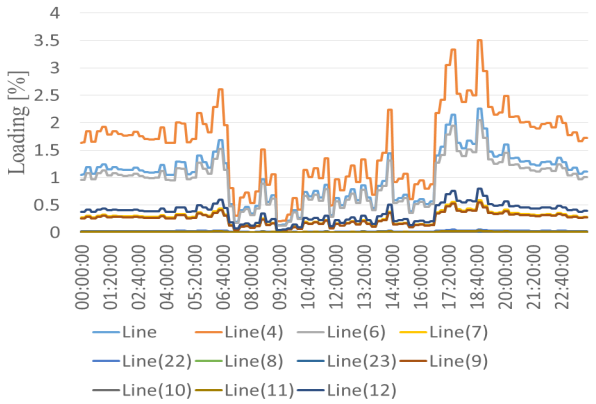

Figure 19: Line loading from terminal to Oasis- stand-alone mode

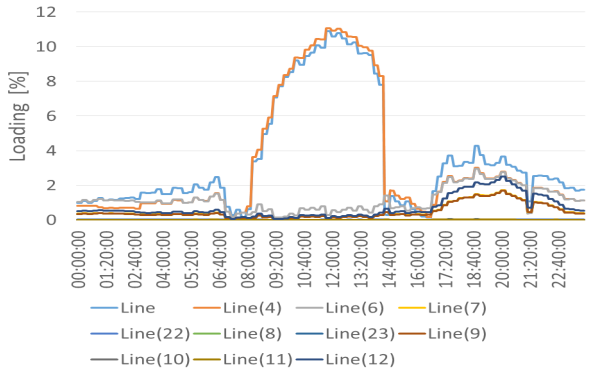

Figure 20: Line loading from terminal to Oasis- grid-connected

4. CONCLUSION

For this project, a microgrid was established and analysed for two cases in stand-alone mode, using professional software tools. During the summer day, RES production was greater than in the winter, because the PV system contributed most of the RES production. For both scenarios, the voltage levels on the busbars did not exceed ±10% Un, defined by EN 50160. Line loading was decreased during stand-alone mode because energy was sent into the system to satisfy consumer demand. Based on the acquired results, it can be concluded that the microgrid is able to operate in stand-alone mode for the given scenarios. Additionally, from the obtained results for both scenarios, the consumer demand could be satisfied with the combination of PV and battery only. However, different input data (wind speed data measured on the location) could change the sizing of the production facilities as the results of the optimization calculations in HOMER, that needs to be considered in microgrid configuration.

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BIOGRAPHY

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