TURNING TOWARD A SMART REGION BY IMPLEMENTING A HYBRID POWER SYSTEM

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ARTICLE INFO

***Article history*:**
Received: 18.12.2023.
Received in revised form: 21.02.2024.
Accepted: 10.09.2024.

Keywords:
Microgrid
Hybrid power system
Renewable energy sources
Smart region

DOI: https://doi.org/10.30765/er.2420

Abstract:

Distributed generation (DG) especially energy acquired from renewable energy sources (RES) plays a significant role in modern power sector due to high carbon emissions around the globe. Its emerging potential is feasible by implementing microgrids as they are beneficial for networks in terms of increasing flexibility and stability, providing frequency and voltage support, power factor compensation etc. This makes the investment into microgrid incorporating RESs attractive, while at the same time reducing overall investment in the grid. Higher cost and stochastic nature of intermittent RES are complications for the implementation and operation of such solutions. This paper will analyse economic feasibility of hybrid power system (HPS) implementation consisting of a wind generator (WG), a photovoltaic system (PVS), gas combined heat and power plant (CHP) and storage batteries. Each of the elements is optimized according to power demand and RES's potential. Technical analysis of the grid integration, parallel operation of the system and the grid is analysed with an example of a real medium-voltage distribution network operating in Bosnia and Herzegovina by using quasi-dynamic load flow simulation of one-week time-period. Finally, different operating mechanisms and strategies will be proposed, following the minimal power form the grid premise to satisfy maximum usability of RES's potential. It is shown that implementing such HPS would be beneficial in terms of both economy and, ecology, as well as in reducing energy losses. Besides, it will reduce power supplying costs and energy losses, as well as and secure better exploitation and utilization of natural renewable energy sources. These technologies positively affect power network by decreasing the risk of network-components overloading, better exploiting the power-generation facilities based on renewable resources and positively impacting voltage profiles. Similar places, situated on remote locations, may use this analysis as an example to follow, to reduce their costs of electricity, acquire more reliable and sustainable power supply, and embrace green future.

1 Introduction

Microgrid represents a key component of the Smart Grid for increasing system energy efficiency, providing possibility of grid-independence to individual end-user sites and improving power reliability and quality. For sustainable development of rural areas electrification has become an effective instrument in both developing and developed countries. Increasing interest has been observed in [1] in the deployment of medium to large scale wind-diesel, photovoltaic (PV), diesel, and wind-PV-diesel hybrid power system (HPS) for rural

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electrification in various countries around the globe. Area of Olympic mountains Bjelašnica and Igman, with its own characteristics, RES potential and winter-tourism potential is a good choice for detailed analysis, presented in this paper. The authors of [2] stated that in future power supply renewable and clean power generation alternative technologies will play an important role due to increased global public awareness of the need for environmental protection and the desire for less dependence on fossil fuels for energy production. In [3], it is argued that system performance can be improved by a hybrid combination of power generation from renewable energy (RE) resources (where most of them have intermittent nature), along with storage and/or alternative power generation. In [4] the issue of supply of the remote consumer areas is addressed, at sites with exploitable RES potential. Similar location was chosen for the analysis in this paper. A network model of a region was developed to understand and analyze the potential for integration of multiple generators of different type. The proposed sustainable HPS, supplies micro location of Bjelašnica tourist center.

The location Bjelašnica and microgrid of named location, supplied by the two 35 kV feeders Bjelašnica and Igman is modelled in DIgSILENT Power Factory software. An HPS composed of wind and solar power plants, gas combined heat and power unit and battery storage is modelled, based on real energy resource data and load profiles by using Homer Energy Pro software. The paper focuses on finding the optimal HPS configuration which reduces power consumption from the grid to minimum yet provides satisfactory power quality to the consumers. All surplus energy will be stored in batteries or sold to the network. Different scenarios with different HPS configuration and network parameters caused by winter or summer seasons are proposed and analyzed for grid-connected operation. Implementation of such HPS will lead to power losses reduction; power will be consumed locally, and the overall CO2 emissions will be reduced, and in the end, such solutions will enable transition from conventional to smart. Finally, a Python-developed Optimization algorithm that defines power consumption strategies, charging strategies, and order of operation for different cases, caused by real and possible situations in terms of energy consumption, was proposed. In the next section, literature review will be presented, followed by the presentation of the case study data and the methodology used in the analysis. Finally, the results and the discussion will be presented in the last section.

2 Literature review

Thesis that a microgrid is able to provide surplus generated power to external customers by involving in the distribution reconfiguration process when faults occurring in upstream network is confirmed in [5]. AC microgrid is probably the most common form of existing microgrid since its feature of easy-to-integrate with existing power systems and loads [6]. However, one significant drawback of AC microgrid is synchronization with host grid is more difficult than DC microgrid as frequency, phase angle, voltage magnitude all need to be matched with host grid. Thus, the power quality requirements for AC microgrid are more than a DC microgrid that only voltage on the DC bus is required to be controlled [7]. A decentralized power management method for the hybrid microgrid is explained [8] in order to make the interacted subgrids operate in coordination and support each other and to ensure the power quality of the subgrids with high proportion of critical loads. Since microgrids can operate in grid connected mode or islanded mode in, the authors analyzed impact of nonlinear loads in a microgrid in terms of power quality. It is recognized from the study that increase in the number of distributed renewable sources facilitate reduction in total harmonic distortion (THD) in voltage profile of microgrid [9]. Small solar systems as DG are making significant impact on the power network. When their penetration level is small, the network supports their integration without consequences. When their penetration level is high, the voltage limits can be violated as observed from the authors' model simulation results [10]. The authors of [11] proposed hybrid power system for power supply to province which is off-grid connected from electrical power systems that comes from main Island so that the electricity is quite limited and it depends on diesel generators.

The authors of [12] presented analysis of different microgrid problems based on the PowerFactory software. The operation of the off-grid system consisted of PV system and diesel generators was analyzed in terms of stability with evaluation of problems that may occur. The authors of [14] analyzed a complementary hybrid system for electricity generation based on solar and wind energy and concluded that proposed hybrid systems were not sufficient for autonomous supply, yet an off-grid system would be feasible with proper storage facilities. The author of [15] analyzed microgrid benefits in improving reliability, energy saving and consumption reduction, environmental protection, investment deferral in transmission and distribution grids from a social perspective.

In [16], it is concluded that although the construction costs of microgrid are high, it is economic to invest in microgrid in view of its social benefits in improving reliability, energy saving and emission reduction, environmental protection, and deferral of investment in transmission and distribution grids. A hybrid PV-Diesel-battery storage system integration with rational strategy can be beneficial in terms of economics [17]. An evaluation strategy was explained to quantify the effects of deficient protection scheme on reliability indices in a microgrid. In particular, the evaluation strategy takes into account the trigger probability of protective actions under abnormal operating conditions, such as warranted trips, rejections and malfunctions [18]. The analysis for optimal dispatch and design of microgrid system is presented in [19]. It is emphasized that general approaches of microgrid dispatch and design should be developed to deal with various situations.

The authors of [20] proposed a dynamic economic dispatch of a microgrid with mathematical models and solution algorithm. Certain microgrid system was established where maximum benefit for the economic dispatch was set as an objective function. An improved particle swarm optimization (PSO) algorithm combined with Monte Carlo simulation is used to solve the objective function, after was concluded that an improvement of the reliability of the microgrid carries an economic cost, the battery fulfills the role of peak load shifting and stabilizing power fluctuations, and increasing the capacity of the battery can reduce system power loss. In [21], the authors considered random characteristics of PV power and wind turbine power output, as well as different characteristics of energy storage in order to provide insight into intermittent uncertainty of power output in the microgrid to achieve optimal power dispatch in the grid. The example showed that proper managing the charging and discharging of the batteries considering electricity prices can obtain more profits and reduce operation cost when on-grid. In another case, using the waste heat of the combustion turbine to supply heat load in the off-grid microgrid is an efficient way to use energy and reduce operation cost.

The review for modelling, planning and optimal energy management of combined cooling, heating and power microgrid is presented in [22]. Authors in [16] present a literature review on microgrid infrastructure and control methods. Typical structures of AC microgrid, DC microgrid and hybrid microgrid are introduced respectively. Several control strategies for controlling AC and DC microgrids are proposed. The aim of this paper is to present a methodology for optimizing the HPS capacities provided with the analysis of economic and sustainability, and technical aspect that covers all relevant factors for a project of implementation of a smart region by employing all RESs available at the geographical location of Bjelasnica. Additionally, analysis performed with a case-study based on all real-data and using professional software tools provides a strong base for drawing relevant conclusions. In this smart region, wind, solar and natural gas resources are used for generating electricity, while other smart grid technologies, i.e., battery storage are paired with controlling algorithms to ensure the optimal and intelligent power flows and consumption-generation relations within the microgrid. This can serve as a base for the future analysis of similar phenomena. This can be translated to other models, networks etc. It provides clear guidelines for defining adequate steps in approaching the problem analysis of such phenomena. Since the bulk integration of RESs imposes a great challenge for the network conditions, it is important to include different aspects in investigating their impact. Many business cases for microgrid investments are based on achieving resilience and stability, economic and energy efficiency, and sustainability. Hence, such analyses are highly contributing the understanding the overall feasibility of similar projects.

3 Analysis Of A Real Distribution Network At Location Of Bjelašnica And Igman

Presented in this paper is a case-study of a real micro-location. It is situated on Bjelašnica, central part of Bosnia and Herzegovina, having a high potential for winter tourism, coordinates: 43°42′14″N 18°15′25″E. Historical background of the location signifies its importance; it was the place for Sarajevo Winter Olympic Games 1984. This place is very popular among the inhabitants of Sarajevo and foreign tourists. The aim of this paper is to show that this location can exploit solar and wind resources in order to make a feasible HPS and enable high-level renewable powering of Bjelašnica and Igman, as well as similar places. A comparative analysis is performed in order to present importance of HPSs comparing to conventional power supplying by power distribution network.

The current network supplies a total of 24 modelled loads. Out of a total number 23 of them are 0,4 kV loads which include apartments, hotels, ski-lifts, artificial snowmaking machines etc., and 1 load was modelled as 20 kV load including several neighboring villages, that are supplied from the same 35 kV feeder. These consumers are connected to the power grid and are supplied from two 110/35 kV transformer substation of

31,5 and 20 MVA transformer installed power respectively, and by 10 kV and 20 kV power lines and cables. Proposed HPS supplies consumers listed above. For the purposes of this research, the network was modelled as a microgrid, where consumers were supplied by only one 35 kV feeder which is connected to the external 110 kV power network through 110/x transformer station FAMOS. A single-line diagram of the analyzed part of the power network is presented in Figure 1.

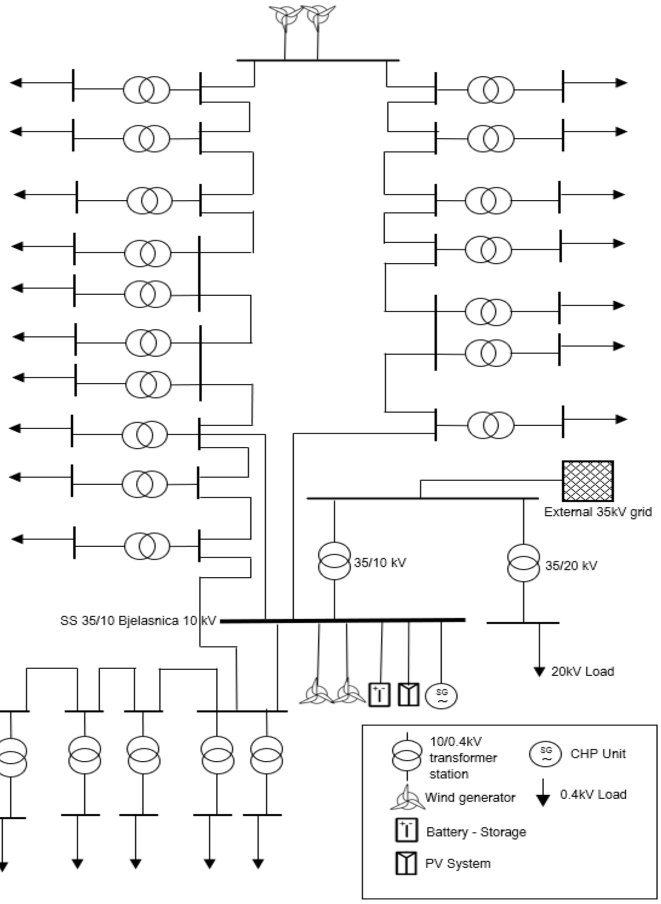


Figure 1. Single-line diagram of the analyzed network.

3.1 Load Profiles

Since this location has the winter-tourism potential, power consumption is at highest during winter season. The average seasonal and daily load profiles are taken from real measurements from smart metering devices, installed on the consumer side, with time step of 15 minutes for period from 1 January to 31 December 2017. The data is still relevant since following years yields the similar consumer habits.

The maximum load (peak) was on 1st January. It was expected to be in January when most of tourists spend their winter holidays. During the summer, lower energy consumption was recorded. Representation of load characteristics is presented in Table 1.

Table 1. Load summary characteristics table representation.

Metric	Baseline
Average (kWh/d)	31,685
Average (kW)	1,320.2
Peak (kW)	3,210.03
Load Factor	.41
Load Type	AC

3.2 Weekly load profiles used in analysis

The specific weekly load profiles are taken from same data set, mentioned in previous subheading, but for two weeks that are to be analyzed individually: 20-26th February and 14-20th August. These two weeks are chosen for the analysis since their load profiles are the most typical i.e., February week for winter and August week for summer. They are presented in Figures. 2 and 3, respectively.

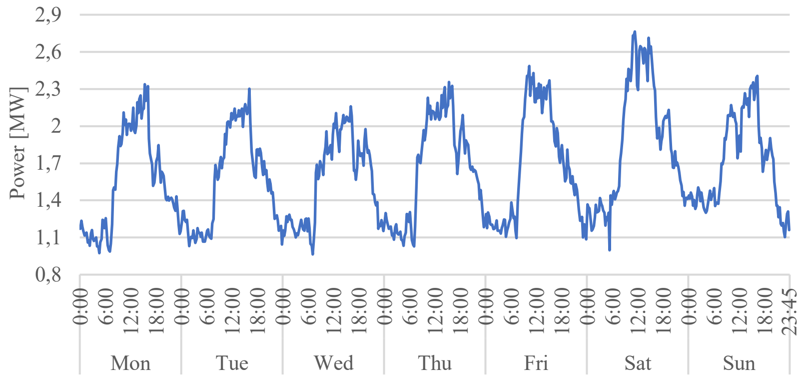


Figure 2. Active-power load profiles of the analyzed network for analyzed week of winter season.

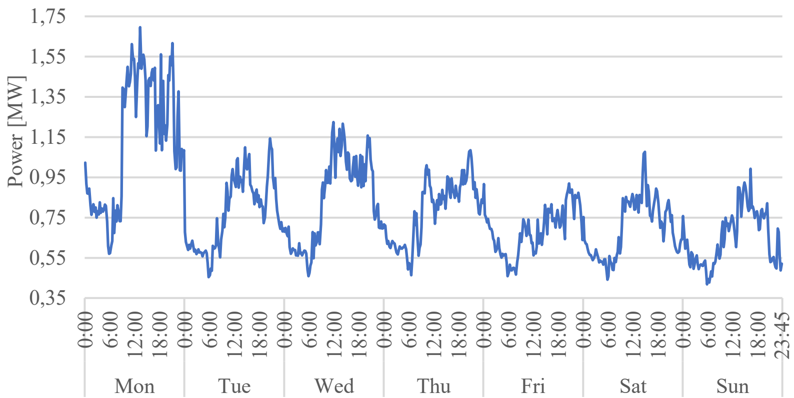


Figure 3. Active-power load profiles of the analyzed network for analyzed week of summer season.

Considering wind potential, wind data are taken from wind Atlas in form of monthly average values at Bjelašnica region. According to that data, annual average wind speed is 6.37 m/s. PVGIS data for solar irradiance and wind data measured at Bjelašnica region with an anemometer 33-meter-high, for one-year period, are used as an input data for obtaining the optimal sizes of HPS components. Same data with lower time-step was used for analysis of technical aspects of the HPS implementation, for the period of two weeks, one week per analyzed seasons, winter and summer. In this case-study the network is modelled in the DIgSILENT Power Factory software. Each of the 22 loads is modelled on 0.4 kV buses, while just one on 20 kV bus, that represents equivalent load for some villages that are located near this location and are powered by the same feeder. Proposed wind generators (WG), PVS, CHP unit and storage batteries are modelled on 10 kV bus of the Bjelašnica 35/10 kV transformer because it is the most suitable area for setting PVS and WG, geographically. And two more WGs are modelled on Igman 10 kV bus. The highest wind speeds were measured in the winter months and in early spring in March and April, while wind speeds are lower in summer, which contrasts with solar radiation, which is highest in summer.

3.3 Thermal Load

Another aspect that is to be analyzed and presented in this paper is regarding thermal load and CHP operation. A HPS proposed in this project, consisting of CHP which use natural gas as fuel. Being that analyzed location has installed pipeline for natural gas supply, installed boilers in the apartments, hotels, and other accommodation capacities, this HPS integrates a CHP unit, that is going to be used for generating electricity during winter season, with effective cogeneration where waste heat will be used for heating of the accommodation premises at the site. After approximation, that was sufficient for the analysis, 80000 m2 is a result that was obtained as a space that needs to be heated. Being that this location is at 1275 meters above sea level with a colder climate simple rule was used for obtaining power required for heating, i.e., to heat 1 m2 – 130-150 W of heat power is required, which gives a value of around 10.4 – 12 MW. Heating period of the year is defined in Bosnia and Herzegovina and starts from late October until early April. Same strategy is used in this project in terms of defining periods when heating is needed at the analyzed site. During summer months, CHP unit was out of operation. Additional info regarding the thermal load is available in Table 2.

Table 2. Thermal load characteristics for the analyzed location.

Metric	Baseline
Average (kWh/d)	98,739.72
Average (kW)	4,114.16
Peak (kW)	20,608.96
Load Factor	.2

4 Methodology

This paper analyzes a real medium-voltage network, case study of a winter-tourist center. All analyzes regarding the economic and technical aspects are performed by using three different software tools, i.e., Homer Energy Pro, DIgSILENT Power Factory and Python.

4.1 Methodology for Defining HPS Configuration and Economic Analysis of the HPS Implementation

The HPS configuration was obtained by the HOMER Energy Pro Software, which calculates the optimal sizing of the HPS elements by using optimization algorithms. The methodology for analysis of an HPS, defined in such a way, was presented in Table 3. Two scenarios are compared in order to present the benefits that can be achieved by using a HPS which enables sustainable and renewable power supply of the consumers differentiating from the conventional supply by power distribution network from centralized power generation units. The S1 scenario represents the HPS configuration obtained by simulations in the HOMER software tool consisting of PVS, WG, CHP unit and vanadium-flow battery which is used as the electricity storage. The S2 scenario represents the conventional approach – consumers connected to the grid and centralized generation units.

Table 3. Load summary characteristics table representation.

Scenario	PVS	WG	CHP Unit	Battery
S1	1 MW	8 MW	1 MW	3.75 MWh
S2	n/a	n/a	n/a	n/a

Software compares different configuration with different element's sizes to provide optimal configuration in terms of the lowest net-present cost (NPC). All simulations are performed based on the input data that is to be presented below.

4.1.1 Solar Irradiance and Temperature

Figure 4 shows annual monthly-average solar irradiation and Clearance Index for analyzed location. Data was automatically downloaded from the internet using Homer software and this data include NASA's surface meteorology and solar energy data for solar irradiance and temperature for desired location.

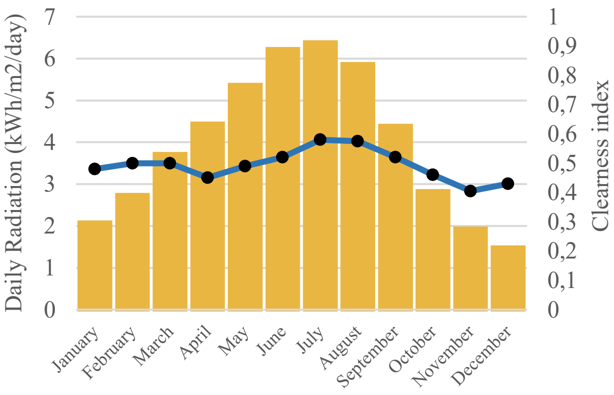


Figure 4. Annual monthly-average solar irradiation and Clearance index for analyzed location.

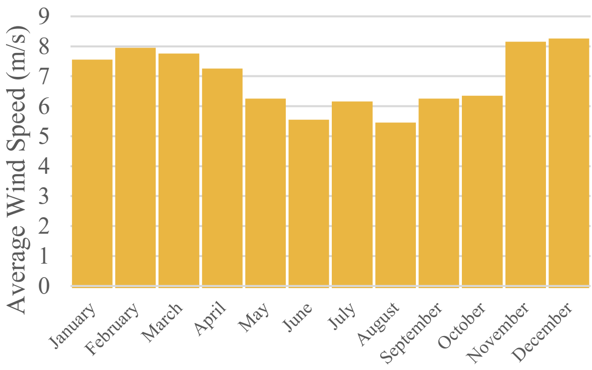


Figure 5. Annual monthly-average wind speeds at analyzed location.

4.1.2 Wind speeds

Figure 5 presents annual monthly-average wind speeds used as a wind resource in Homer software. Wind speeds are taken from electronic wind atlas for Bjelašnica region and are imported into the software as monthly averages.

4.1.3 Additional Constraints

Further optimization is performed taking into account additional constraints i.e. discount rate of 8%, inflation rate of 2%, maximum annual capacity shortage allowed to 2% and project life time is set to 25 years. The lifetime of the WG is 20 years, CHP unit lifetime is 40,000 operating hours, and PVS has a lifetime of 25 years. Required replacements of parts or some units in HPS are taken into calculations as well as operating and maintenance (O&M) costs. The prices for the elements are approximated according to the world market. Fuel prices are also predefined. Natural gas price was set to be 0.4$/m3 which is the average price for natural gas in Bosnia and Herzegovina according to gas company in Sarajevo that supplies this location. Furthermore, electricity prices are also defined. Being that proposed HPS will operate in parallel with existing power grid, prices for electricity buying and selling were defined. According to Agency for Statistics of Bosnia and Herzegovina, average price of electricity per kWh is $0.085, while energy sold to the grid, produced by renewables is $0.175 according to Federal Regulatory Commission for Energy in Federation of Bosnia and Herzegovina.

4.2 Methodology for Analyzing technical aspect of the HPS implementation

DIgSILENT Power Factory software which provides the Quasi-Dynamic Simulation toolbox is used. It simulates the power network operation and calculates load flow for different time intervals using a full AC Newton-Raphson technique. This simulation toolbox is used for the analysis with the time interval of a week. HPS from S1 scenario will be analyzed in different scenarios presented in Table 4

Table 4. Scenarios for analyzing technical aspects of the HPS implementation.

Scenario	Season	Grid Connection
S1-1	Winter	Yes
S1-2	Summer	Yes

4.2.1 S1-1 Scenario

S1-1 scenario is used for the case of winter week. The 20-26th February week was chosen for a typical winter week representation. This scenario analyzes the microgrid connected to the existing power distribution network and an on-grid, parallel operation.

4.2.1.1 PV System Power Output

PV system power output for S1-1 scenario is presented in Figure 6. This is the representation of one-day power output because other days in the week gives the same solar irradiance, hence power output is the same.

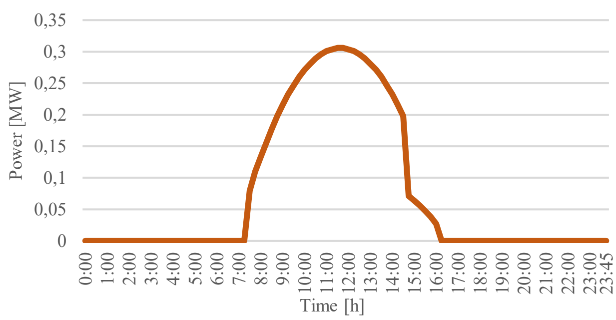


Figure 6. Active-power output from PVS in the HPS for a day in winter, S1-1 scenario.

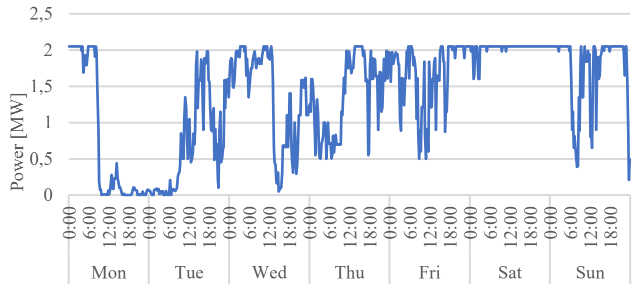


Figure 7. Active-power output from WG for the S1-1 scenario.

4.2.1.2 Wind generator Power Output

Wind speeds are taken from the actual measuring station located at Bjelašnica region for two analyzed weeks. Measuring station is equipped with first class anemometer 33-meter high. Wind speeds are measured in 10-minute time step. WG used in this analysis is Enercon E-82 E2 with 2 MW installed power. Cut-in wind speed for this wind turbine is provided in datasheet and is 2 m/s. When the wind speed reaches the value of 25 m/s, wind turbine will automatically turn off to prevent possible damages. When wind speed reaches 13 m/s, wind turbine generates nominal power of 2.05 MW. The output power from the WG for winter week, analyzed as S1-1 scenario, was calculated then – Figure 7.

4.2.2 S1-2 Scenario

Same procedure, as explained in previous section is repeated for the S1-2 scenario. A week of 14-20th August was chosen for the analysis, and it serves as an example of a typical summer week. This scenario analyzes the microgrid connected to the existing power distribution network and an on-grid, parallel operation.

4.2.2.1 PV system Power Output

Figure 8 shows PVS power output for a S1-2 scenario. One-day power output was presented for typical day of the summer season, which is repeated 7 times to obtain power output for the analyzed week.

4.2.2.2 Wind generator Power Output

Power output for the wind generator is obtained and presented in Figure 9.

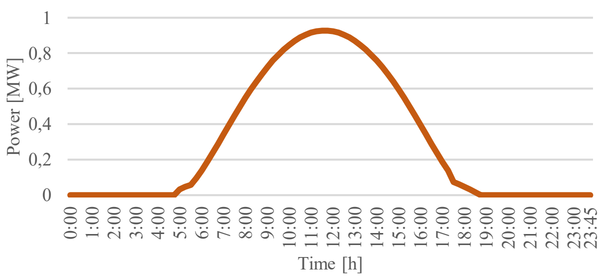


Figure 8. Active-power output from PVS in the HPS for a day in summer, S1-2 scenario.

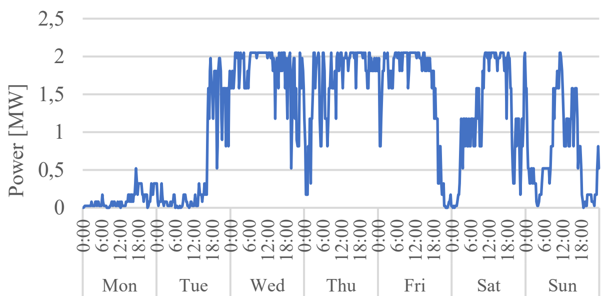


Figure 9. Active-power output from the WG for the S1-2 scenario.

5 Results and discussion

The results of the analysis presented in the methodology are elaborated in two main subheadings i.e., HPS configuration and economic aspects of the implementation that are mainly focused on the results and outputs provided by the Homer Software and Technical aspects of the HPS implementation that are analysis with respect to output results and the power flow calculations performed by the DIgSILENT Power Factory software with the Quasi-Dynamic Toolbox.

5.1 HPS configuration and economic aspects of the implementation

After performing several simulations of the system, software presented configuration described in S1 scenario. It is consisted of flat PVS with 1 MW installed power, 4 Enercon E-82 E2 WGs with 8 MW (4x2) of total installed power, CHP unit fueled by natural gas with 1 MW installed power and 4 strings of Vanadium-flow battery with 3.75 kWh energy connected via system converter of 300 kW. This type of wind turbine is very suitable since it operates well under bad weather conditions which is important because it would be installed in mountain area with low temperatures during winter when the danger of snow and icing is higher. A comparative analysis of HPS over traditional power supply by power distribution network is performed. Resulting characteristics of S1 scenario and HPS configuration are presented in Table 5. The NPC consisted of capital investment, O&M costs, fuel costs, replacement and salvage obtained by the software, regarding mentioned characteristics of calculation equals to $16,193,638.00. The prices for each system in HPS are calculated based on available prices on the market for similar products. Note that prices are constantly changing and may vary depending on the region.

Table 5. Results summary for S1 Scenario – HPS configuration.

Scenario	HPS configuration	Storage	Production MWh/year	Renewable percent	Capacity shortage %/year
S1	PVS: 1 MW WG: 4x2 = 8 MW CHP: 1 MW Converter: 300 kW	Vanadium-flow 3,5 MWh 1 string	32,099[1]	93.5	0

Being that this project analyzes real location, which is connected to the grid, capacity shortage is zero because the grid is used for backup. In Figure 10, the graphical representation of NPC, shown for each component individually, is presented. The most earnings will be achieved through 'Operating'. Selling generated energy to the grid is covered by this, as well as other operating and maintenance cost. Having negative NPC value, the project falls into group of financially profitable. Project profitability can be observed from the cash-flow, projected for a 25-year lifetime, shown in Figure 11.

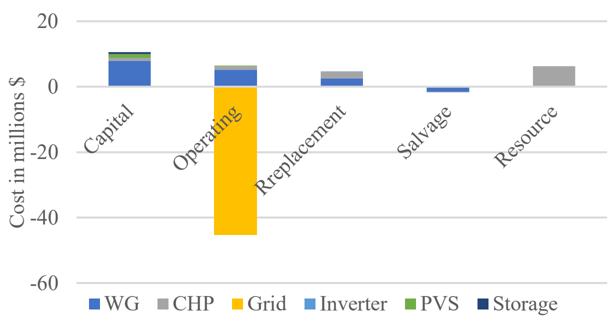


Figure 10. NPC:Graphical representation for the HPS.

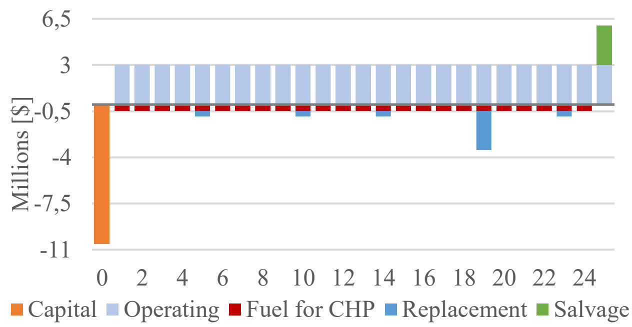


Figure 11. Cash-flow projection for 25-years lifetime of the HPS.

[1] The value includes the energy purchased from the grid.

Salvage and operating are two positive items in the cash-flow. Fuel cost, presented in this figure is related to fuel required for CHP, i.e., natural gas. The cash-flow diagram confirms the profitability of the project emphasizing the importance of harvesting locally available resources for power generation.

5.1.1 Electrical Summary

Figure 12 shows monthly average power production by HPS components. The highest production is from WG as expected. Power generated from PVS is highest during summer. In the real application of this HPS, the CHP unit shall operate only during the winter months, i.e., following the thermal energy demand schedule. In the analysis provided in this paper, the CHP unit is generating power during the whole year, since it was modelled to serve electric demand as its primary function. Defining adequate operating strategies, CHP unit should be out of operation during summer, i.e., through seasons without thermal energy demand. A summary of the production of the HPS is presented in Table 6.

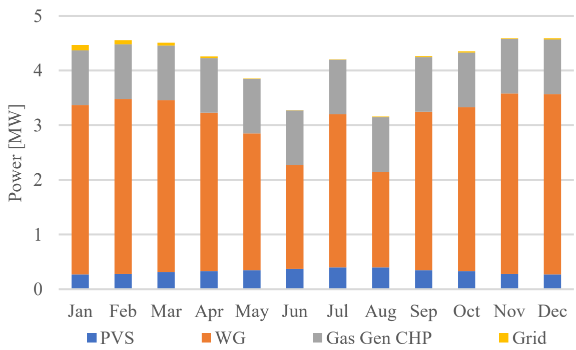


Figure 12. Monthly average power production by HPS components.

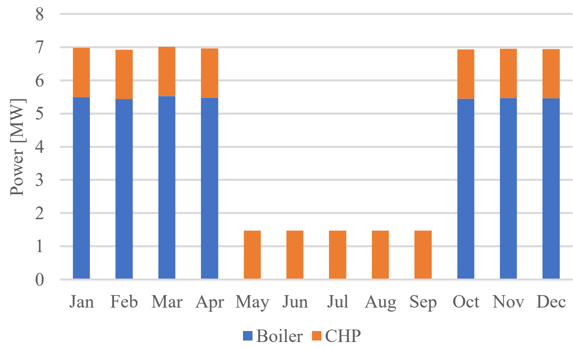


Figure 13. Monthly average thermal power production by HPS components.

Table 6. Electrical Summary, power production by HPS components.

Production			Consumption		
Components	MWh/year	%	Type	MWh/year	%
PVS	1,300	4.05	Load	11,565	36.4
CHP	8,760	27.3	Grid Sales	20,237	63.6
WG	21,601	67.3			
Grid	473	1.36	Total	31,802	100
Total	32,099	100			

Being that this HPS is always connected to the power grid – parallel operation with the grid, there is no excess electricity, because all surplus electricity is sold to the network.

5.1.2 Thermal Summary

Figure 13 shows monthly average thermal power (heat) production by HPS components. Additional thermal summary is available in Table 7.

Table 7. Thermal Summary – additional information.

Thermal Summary	Thermal Load	Excess Thermal
kWh/year	36,039,998	5,452,260
%	100	13.2

5.1.3 Emissions and Social Aspects

Comparing the HPS from S1 with S2 scenario several conclusions can be drawn. Micro location of Bjelašnica and Igman is connected to the power grid, which relies on centralized generation units which dominantly use domestic coal for electricity production, while the rest of production portfolio is based on large hydro power plants, with the average ratio of thermal-hydro energy being 80-20 %. The CO2 emissions are approximately 1000 kg/MWh in total Bosnia and Herzegovina production portfolio. When the cost of electrical energy – 0.12 $/kWh (average price of electricity, June 2017, Agency for Statistics of B&H), for 25 years, which is the lifetime of the project, is multiplied with the total electricity generated by the HPS, value of $96,297,000.00 is obtained. This amount of money is higher than the total investment costs and NPC for the proposed HPS. Even excluding the investments in the network infrastructure, total investment costs and NPC of the proposed HPS are lower. Reliability of the network was taken into consideration by limiting the annual capacity shortage. However, this area is always connected to the grid, and parallel operation was proposed, so the capacity shortage will be minimal, or possibly zero. Another important aspect is the provided emissions report.

The conclusions drawn from this report show benefits of the HPS in terms of emissions. This HPS produces approximately 32,099 MWh per year. That will be 32,099 tons of CO2 emissions per year, if it is supplied by the power network. But if HPS was implemented, CO2 emissions would be reduced to 11,370 tons per year. Profit-driven implementation of such project would play a significant role in fulfilling social aspects, as well. Social aspects in terms of reducing emissions, exploiting locally available resources, and reinforcing the sense of local identity will be improved by implementation of the project, and this shall be an additional way of promoting tourism. This will have a positive impact on the increase in employment, attract new investments and lead to salary increases. Improving the tourism offer, labelling this already popular place as environmentally friendly, will further strengthen the place's position on the map of popular destinations while ensuring that social and cultural aspects are also met.

5.2 Technical aspects of HPS implementation

Figures 14 and 15 show active power output, generated in the microgrid by HPS components for S1-1 and S1-2 scenarios, respectively. From those two figures it can be easily spotted how power generation is defined by PV system production. For every day, peak production occurs around noon, when the solar irradiation is the highest. During winter, the CHP unit will also operate and generate 1 MW of power, since its waste heat will be used for heating. For all scenarios, the results obtained from the software show that all of the generated power comes from the two buses i.e., 10 kV side of Bjelašnica 35/10 kV transformer where HPS components are connected, and 10 kV bus Igman, where two remaining wind turbines are connected. This leads to a conclusion that this HPS generates enough power to supply the microgrid of Bjelašnica and Igman in terms of covering peak value, yet due to intermittent nature of renewable resources, and either too expensive or hardly feasible method of energy storing, this HPS will operate in parallel with the grid. All surplus power can be either stored to storage battery implemented in the HPS or can be delivered to the grid by the 10 kV medium-voltage power distribution network.

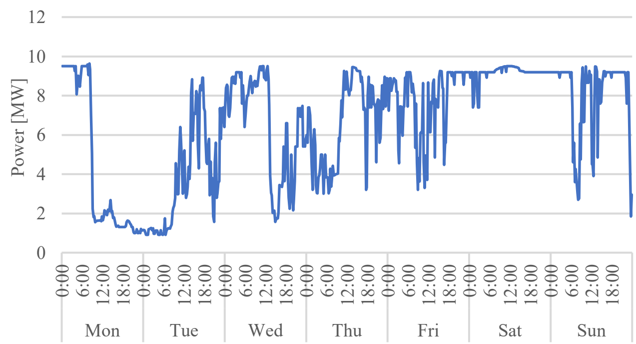


Figure 14. Active-power generated in the microgrid for S1-1 scenario.

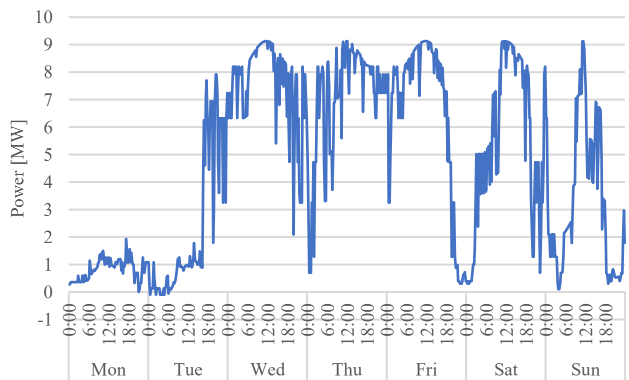


Figure 15. Active-power generated in the microgrid for S1-2 scenario.

Figure 16 shows power flow measured at the connecting point of the HPS and external grid, where positive values represent the power that is consumed from the grid, while negative values represent the surplus HPS power that flows into the external grid for S1-1 scenario, while Figure 17 gives same representation of power flow for S1-2 scenario.

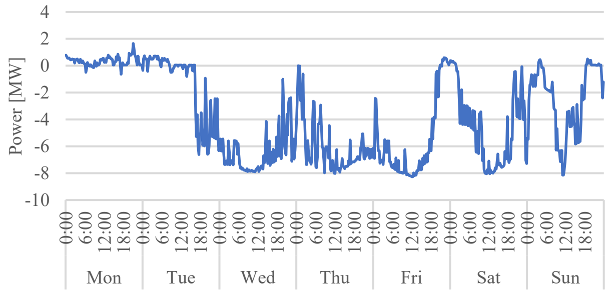


Figure 16. Active-power flow from and to an external grid for S1-1 scenario.

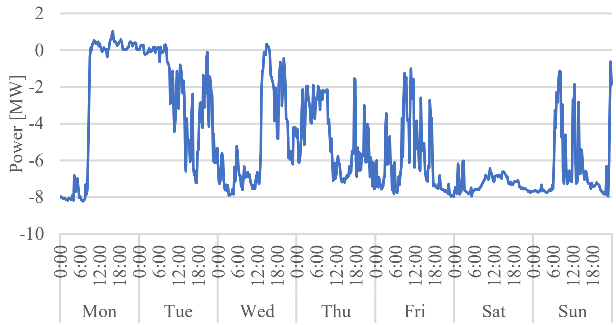


Figure 17. Active-power flow from and to an external grid for S1-2 scenario.

In this configuration, none of the voltages in the network have lower value than 1 p.u. There is significant power-generating units that increase voltage level in the analyzed microgrid. On the other hand, same reason caused a bit higher voltage on certain elements. In the Figure 18 the voltage at Igman 10 kV bus and two lines that are connected to this bus, where the voltage values are the greatest comparing to other voltages in the network is shown for all analyzed scenarios. As seen, even the voltage drop is high it is within ±10% Un which is satisfactory in terms of voltage limit defined by EN 50160 European norm for voltage quality.

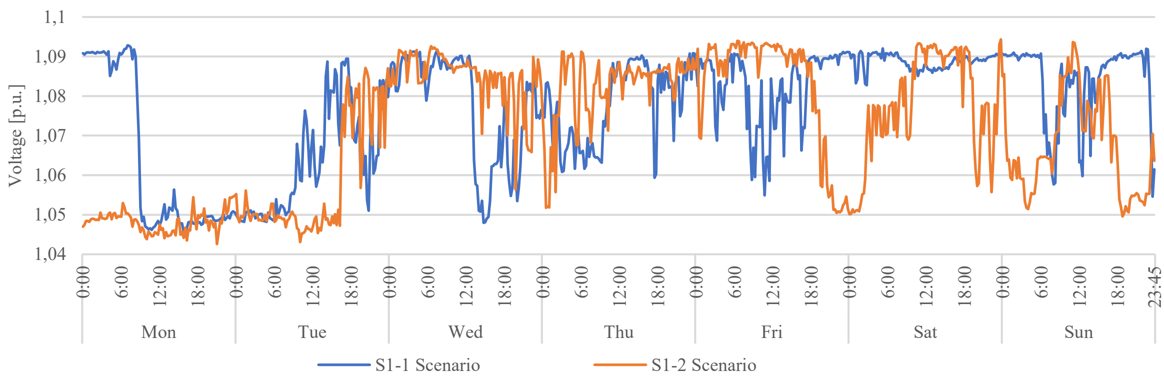


Figure 18. Voltage levels at Igman 10 kV bus, for analyzed scenarios.

None of the voltage values in the network exceed nominal voltage level. As seen, implementation of the HPS positively affects the network power system by enhancing better exploiting the power-generation facilities and renewable resources, decreasing the need for network expansions, and positively impacting voltage profiles. HPS implementation does not affect load profiles except reducing them in terms of electricity generation from renewable energy sources and increasing them in terms of storing electrical energy in the battery during off-peak periods. Figure 19 shows voltage at two 0.4 kV buses; one that is the closest to the external network, TS Bjelašnica Apartmani 7, and one that is the most distances point in the network, TS Bjelašnica vrh for both scenarios.

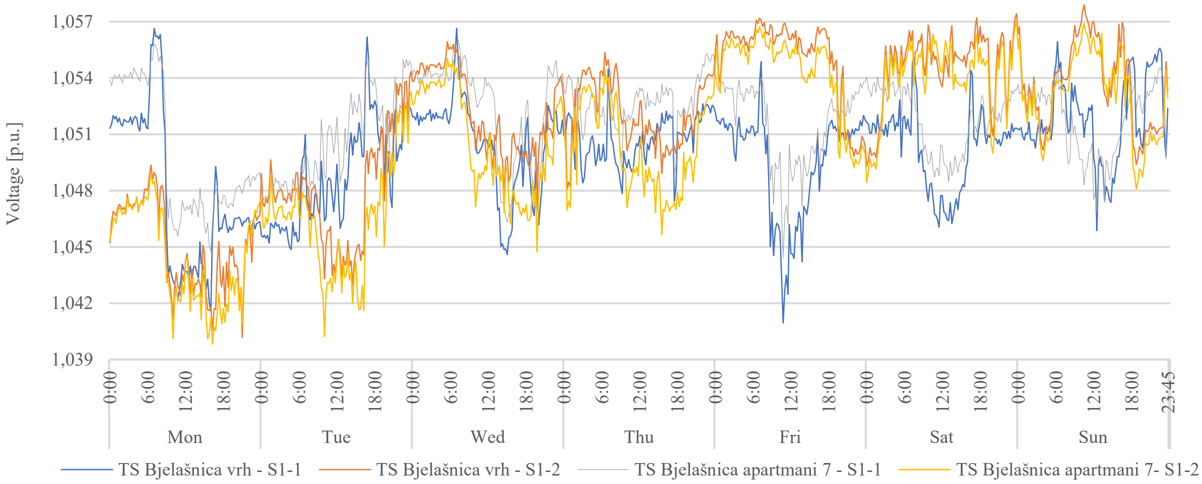


Figure 19. Voltage levels at TS Bjelašnica vrh and TS Bjelašnica apartmani 7, for both analyzed scenarios.

5.2.1 Power Losses

Figure 20 shows active-power losses for all scenarios for one winter and one summer week. Losses are presented in MW, where 15-minute averages are used. As per observation, losses are directly related to the power generation. This is the case because this network has long lines so energy travels far distances to be consumed or delivered to grid, so most of these losses occurs in the distribution lines. Furthermore, transformer losses (summary of all transformer losses of the analyzed network for both scenarios) are presented in Figure 21.

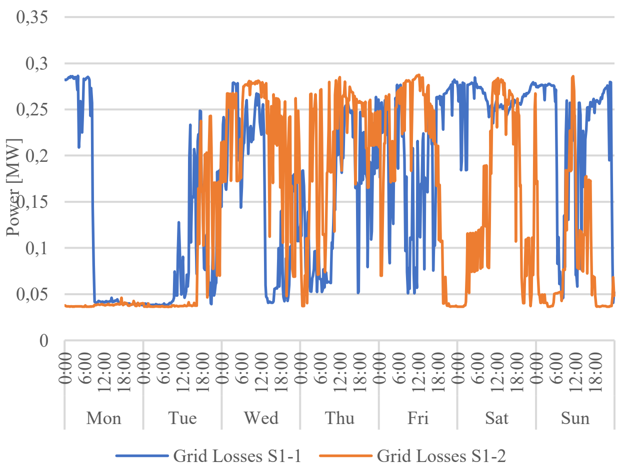


Figure 20. Total grid active-power losses per scenarios.

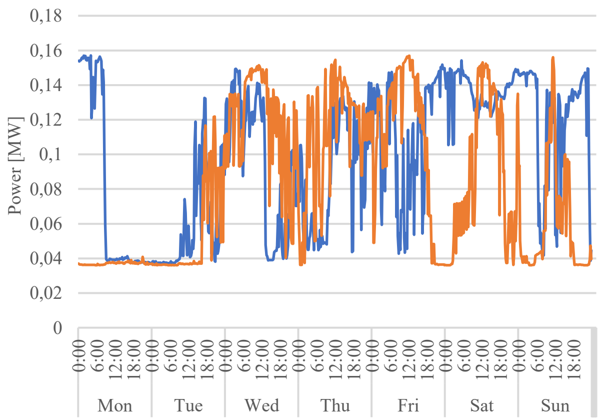
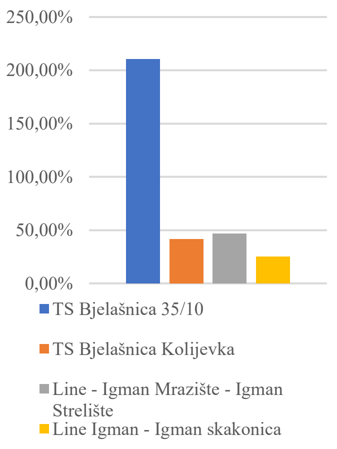


Figure 21. Transformer losses summary for analyzed scenarios.

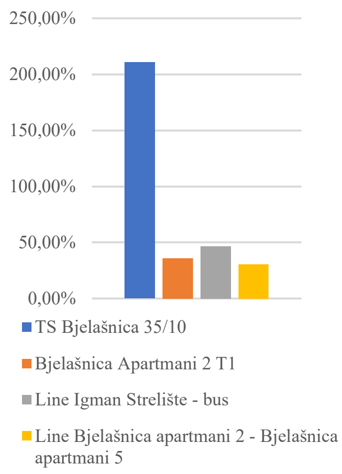
5.2.2 Loadings

The transformers and lines loadings for each scenario are presented such that highest loading percentage will be shown for two most loaded elements. All other elements that are not presented have lower loading percentage. Fig. 22 shows the most loaded transformers and lines for the S1-1 (a) and S1-2 (b). Since this network was built dozens of years ago, it is not dimensioned to accept this level and power of integration, which can be seen in terms of loading the main Bjelašnica 35/10 kV transformer. First step that needs to be performed in order to enable this HPS integration is to change aforementioned transformer with greater nominal power, which would enable RES's integration, or install another transformer with same power.

The most loaded line; Igman Mrazište – Igman Strelište is always the same and bellow limit. All other lines and cables are less loaded than this one. All the lines and cables are loaded well below their nominal capacity.



a)



b)

Figure 22. Elements loadings for scenarios.

5.2.3 Optimization algorithm and operation strategies

Operation strategy in terms of optimal dispatch is introduced in this project. All figures presented in section *5.2.* presents different characteristics that are obtained by implementing the following algorithm and operation strategy. This algorithm and its control strategy is presented in the following flow chart in Figure 23. In the proposed strategy, the CHP unit is used only to meet part of the thermal load, during winter season. CHP will produce constant power output of 1 MW of electric energy if heating is required. During summer season, CHP will not operate at all, unless unpredicted event occurs. Because of the CHP's easy start, it is possible to rely on CHP's response in critical conditions. According to the strategy, the battery will be charged always and only by the RESs, i.e., only if difference between RES's production and total load is greater than zero. If difference is less than zero, battery will provide energy from its capacity (if available) until the moment when the difference is again greater or equal to zero, or until battery's state of charge (SOC) reaches 20% of nominal capacity. Otherwise, battery will wait empty for the difference to become greater than zero again. Grid will not affect battery operation. If battery is fully charged, and the difference is still greater than zero, all surplus power will go to the grid. This strategy is applicable to the system with low renewable DG penetration. The batteries are used mainly to fill up the supply shortage that cannot be met by the RESs or to store the excess renewable energy. Mathematical model of the proposed strategy is presented below:

$$P_{bat} = -\left(P_{gen} - P_{load}\right) \tag{5.1}$$

$$-P_{conv} \leq P_{bat} \leq P_{conv} \tag{5.2}$$

where Pbat is the battery power of charging or discharging.; Pgen is the total generated power from RESs; Pload is the total load for the analyzed microgrid; Pconv is the converter power, connecting battery storage system to the grid.

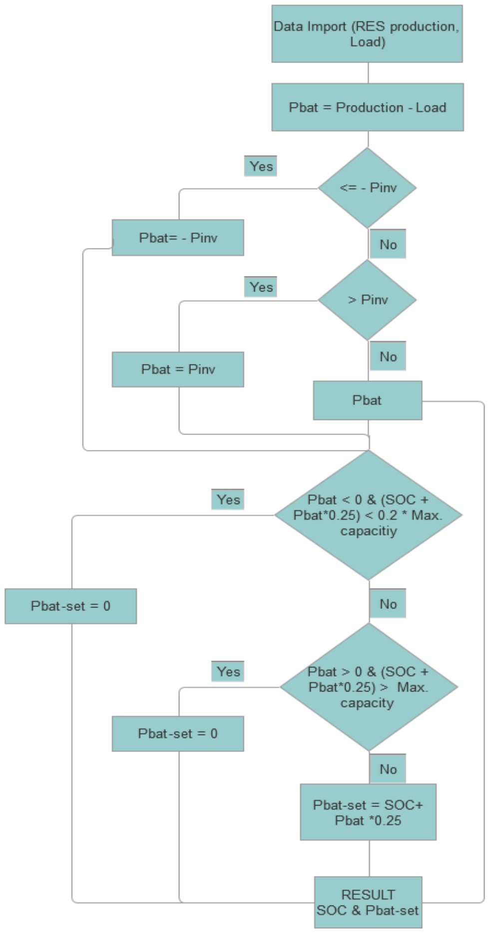


Figure 23. Flow chart of the proposed operation strategy.

The state of charge (SOC) of the battery refers to the ratio of the residual energy to the rated energy. It is very important to predict the SOC of the battery accurately for controlling the charging/discharging process and the system dispatching. The PYTHON code of optimization algorithm is developed. After the optimization, two datasets are obtained, i.e., one that will present SOC of the battery for the tested scenario, and the other one that is used as an import file to the DIgSILENT Power Factory software, to define battery operation. Figure 24 shows SOC of battery for both analyzed scenarios. It is assumed that batteries were fully charged before the simulations.

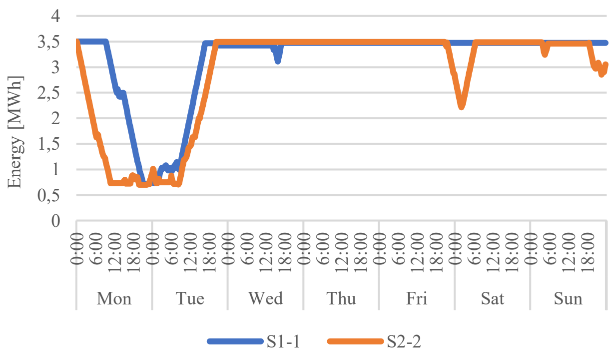


Figure 24. State of charge of the battery system of the HPS per each scenario.

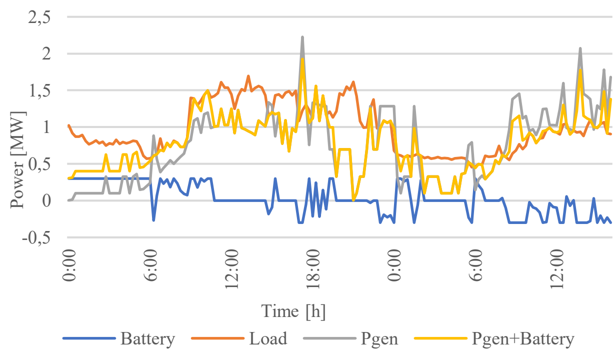


Figure 25. Battery operation presentation – Power flow.

Figure 25 shows powers for a part of the day in the middle of summer season week, where the battery operation and impact can easily be observed. Battery energy is used in order to cover the load when there is not enough power production by the renewables in the HPS, but the total power introduced from the battery is limited by the converter.

6 Conclusion

This paper proposes an HPS consisting of PVS, WG, gas microturbine with CHP and storage battery as an alternative to supply from conventional power system. Besides economic factors, the analysis showed that other aspects of sustainability are fulfilled including environmental aspects. The conclusion drawn from this study is that proper HPS configuration and implementation of it can positively affect environment, reduce power supplying costs, and secure better exploitation and utilization of natural renewable energy sources. Moreover, the HPS configuration in this paper is based on actual and real parameters of power consumption and solar and wind potential at the site. In this way, possible solution for distant places is proposed enabling autonomous power supply for consumers, which will completely rely on local sources in forms of wind and solar power, combined with electricity storage in battery. There is also gas microturbine with CHP which will serve primarily to heat the space at the analysed location since it is a winter-tourist centre, a lot of apartments and hotels will require thermal energy.

This HPS will always be connected to the external grid, and parallel operation with the network was analysed, so the grid will be backup of power in cases of outage and other problems affecting reliable power supply. Besides, implementation of this system will increase reliability of power supply because when power outage happens and affect the existing power network, HPS can independently operate, and by that supply the consumers. A proper HPS configuration is proposed to satisfy consumers' needs and enable highly renewable power supply of consumers. HPS mostly relies on wind and solar resources in combination with electricity storage in batteries and gas microturbine with CHP for heating and as power backup and compensate lack of these resources parallel operation with the grid was analysed to achieve power flow balance. Implementation of HPS with configuration presented in this paper positively affects the network power system by decreasing the risk of network-components overloading, better exploiting the power-generation facilities based on renewable resources, decreasing the need for network expansions, and positively impacting voltage profiles. HPS does not affect load profiles except reducing them in terms of electricity generation from renewable energy sources and increasing them in terms of storing electrical energy in the batteries during off-peak periods. To make this microgrid possible to operate in island mode, completely independent of existing power distribution network, ensuring reliable power supply of consumers, as future improvement of this project, stability of this network should be analysed and solved in the sense of frequency stability. With the properly developed control and operating mechanisms to have stable microgrid, this microgrid will be able to operate in island mode, completely independent of existing power distribution network, ensuring reliable power supply of consumers.

Analysis performed in DIgSILENT Power Factory software have confirmed that the HPS and microgrid can operate within allowed boundaries for voltage variations and without overloading of HPS elements in grid-connected mode. In the same software, proposed algorithm and microgrid operation are verified and confirmed on the examples of winter and summer weeks. A detailed analysis of the case-study showed the feasibility of implementation of such HPS. Simulations performed by using two professional software tools, i.e., Homer EnergyPro, and DIgSILENT Power Factory, while defining the operation strategy in Python, emphasizes the comprehensive approach in finding an optimized solution. Combination of the two, will provide a full picture and complete overview off all relevant factors, analysing separate but complementary aspects of the HPS implementation. HPS like this one offers the best penetration of renewables, the lowest CO2 emissions and levelized cost of electrical energy is the lowest which will lead to the consumers' satisfaction.

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