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A proposed power control solution for industrial application in decentralized energy production

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Abstract

Communities and industries across the globe depend on decentralized power generation to ensure the availability and security of supply. As the world moves toward decarbonization, energy generation systems are increasingly turning to small-scale turbines or engines operating on hybrid solutions with renewables as a cleaner, intermediate step toward a truly sustainable future. The infrastructure of the main electricity network in Albania is very problematic and about 90% of the energy is produced by hydropower plants, increasing the dependence on rainfall. Based on this problem, in order to have the independence of the electrical energy of the industry from the main electrical energy network in the country, in this study is proposed a solution of energy control for decentralized energy production. The proposed solution interconnects groups of distributed energy resources and loads at a defined electrical boundary. It can operate in either island/isolated mode or networked mode. In a system consisting of a generator and photovoltaic plant, this automated solution guarantees minimum fuel consumption by maximizing PV penetration without compromising minimum genset load requirements. This decentralized system of energy resources is based on IIoT, helping to develop smart cities. Decentralized control support identifying and control of important challenges for our unstable energy grid. Beyond the technical hurdles, our energy grid also needs a new paradigm for resilience, protecting against natural disasters and cyberattacks.

1. Introduction

For decades, power grids have been structured in a hub-and-spoke model, with a few large, centralized power-generating plants providing electricity to a huge consumer base connected via long transmission and distribution lines [1-7].

The idea was that the larger you build the plant, the more efficient the electricity system. For a long time, that logic held true. But with the urgent need to pursue decarbonization, the large increase in intermittent renewable energy on the grid, the still-expensive nature of energy storage, declining costs of decentralized generation, and the need for greater grid resiliency, decentralized power generation is increasingly recognized as a crucial tool during the energy transition [1].

Albania, with around 2.8 million people, differs from most of the countries in southeast Europe in its energy mix. Its state-owned power utility, Albanian Electro-energetic Corporate (AEC), owns three large hydropower plants on the Drin River and a 98 MW gas and oil power plant in Vlora which never started commercial operations due to technical problems [8].

As of the end of 2019 there were around 200 privately-owned power generation facilities – mainly small hydropower plants – rendering Albania's power sector completely dependent on hydropower, and in dry years, electricity imports.

Around two-thirds of heat is produced by electricity, a fifth by biomass, and smaller amounts by oil and gas [9] as shown in Figure 1.

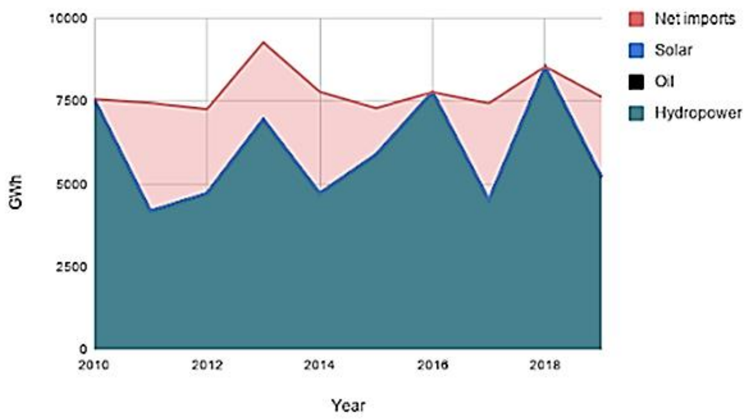

Figure 1. Electricity generation in Albania, 2010-2019

This puts further strain on the electricity sector, but also represents an opportunity to leap straight to heat pumps rather than embarking on gasification, which would entail massive investment in infrastructure that would have to be changed again in order to advance the decarbonization process [6].

Today Albania had an advantageous starting point in its renewable energy target compared to other countries, but diversification of the energy blending is still sorely needed. Two auctions have been held for large solar installations, but the country's installed solar capacity at the end of 2019 amounted to no more than 15 MW [8].

One of the aims of Albania's energy transition has to be to reduce the massive fluctuation in its annual electricity generation – as well as the environmental damage wrought by rampant hydropower development.

The country needs to stabilize its electricity generation by diversifying its renewables combination. Its long relationship with hydropower may make it hard to let go, but the situation has long since passed the point where adding more hydropower has any added value. It is time for other energy sources, mainly solar and wind, to make their contribution [10].

Decentralized energy systems provide promising opportunities for deploying renewable energy sources locally available as well as for expanding access to clean energy services to remote communities [3]. In the article is proposed a power control solution in a decentralized energy production system. This is given through a concrete application of the industry's need for energy production, creating dependence on the network in the country.

In the exciting system that the factory has to produce electricity consisting of a generator and the main energy network, it is proposed to integrate a renewable source such as a photovoltaic plant and also a controller for power management according.

The system proposed in the article offers a reliable, fully integrated and optimizing solution between sustainable power plants and generating power plants. The system is designed for green applications and includes controllers that can interface with PV inverters and other power source controllers.

With the usage of an intelligent and flexible generator controller, power generation becomes more efficient without additional climate impact. With a highly configurable electric switchboard, power goes where it needs to go and ensures uninterrupted uptime.

The experimental results of this study show that in a decentralized, renewable-energy-based electricity system, appropriate spatial planning and nature protection is arguably even more essential than in a centralized one.

In section 2 are presented technologies for energy control systems. In section 3 is given the methodology for the implementation proposed intelligent solution. Results and discussions are presented in section 4 and conclusions in Section 5.

2. Technologies for energy control systems

2.1 Decentralized energy system

Decentralized electricity production is the opposite of centralized electricity production. The power systems in Europe have mainly been built to accommodate central power plants, meaning large fossil fuel condensing plants, nuclear plants and hydro power stations [6]. This is changing, more and more distributed energy resources are being introduced into the power system. The distributed energy resources concern the power system and are seen to include not just distributed generation, but also energy storage and demand response. End-users are becoming not only producers but also active participants in network balancing operations [3].

A decentralized energy system is characterized by locating energy production facilities closer to the site of energy consumption. A decentralized energy system allows for more optimal use of renewable energy, reduces fossil fuel use and increases eco-efficiency [4].

A decentralized energy system is a relatively new approach in the power industry in most countries. Traditionally, the power industry has focused on developing large, central power stations and transmitting generation loads across long transmission and distribution lines to consumers in the region [11].

Decentralized energy systems seek to put power sources closer to the end user. End users are spread across a region, so sourcing energy generation in a similar decentralized manner can reduce the transmission and distribution inefficiencies and related economic and environmental costs.

Decentralized power systems are more resilient in the long run. Depending on the legislation in force, decentralized energy systems rely on small renewable energy producers that are connected through a decentralized grid to end-users who can buy and also produce energy and sell it back to the grid or the local micro-grid. This means one can simultaneously be an energy producer and a consumer [4, 11]. Examples of decentralized energy systems include combined heat and power (aka cogeneration or CHP), waste plants, burning biomass, solar and energy or geothermal. They can serve a whole community (e.g., an ecovillage), a building (e.g., a condominium) or even a village as presented in Figure 2.

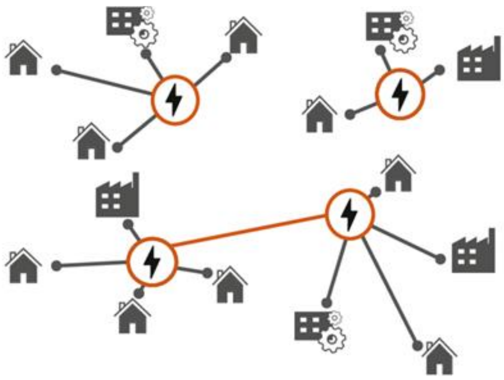

Figure 2. Decentralised energy system

As the energy system decarbonizes, it is becoming more complex and more interconnected. In the traditional energy system, gas, power and heat grids operated in a one-way fashion providing energy to the consumer; the links between different sources of energy were limited to the power generation sector. The energy system that is emerging today is fundamentally different as shown in Figure 3:

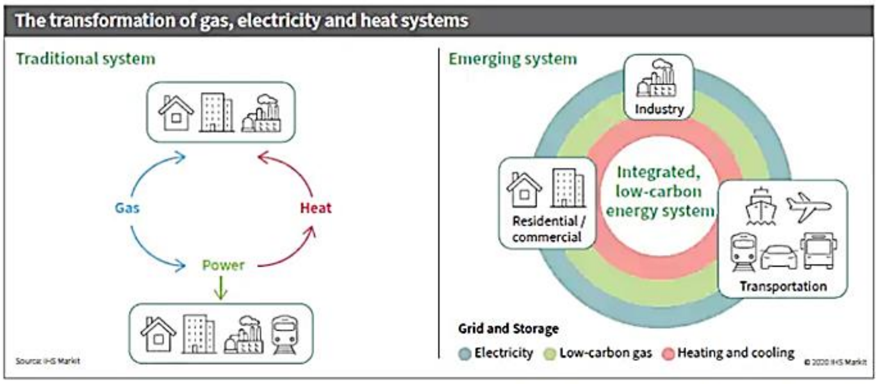

Figure 3. Integrated low carbon energy system

Many uncertainties underlie the future path of the energy system, but electrification will continue and energy storage systems, low-carbon gas (hydrogen technology and renewable gas), solar and wind energy will grow. The growth of these four technologies will be driven by the following [10]:

- Continued electrification
- Solar and wind energy will dominate global power generation capacity additions
- Electricity storage will enable high penetration of renewable energy and system resilience
- Gas will remain an essential component of the energy mix, but it will decarbonize

2.2 Hybrid energy system

Hybrid power systems generally integrate renewable energy sources with fossil fuel powered diesel generator to provide electric power where the electricity is either fed directly into the grid or to batteries for energy storage. The role of integrating renewable energy in a hybrid power system is primarily to save diesel fuel [2-7].

There are generally two accepted hybrid power system configurations:

- Systems based mainly on diesel generators with renewable energy used for reducing fuel consumption; and
- Systems relying on the renewable energy source with a diesel generator used as a back-up supply for extended periods of low renewable energy input or high load demand

A typical hybrid power system may contain a combination as in Figure 4:

- Renewable energy sources (solar / photovoltaic, wind turbines, micro hydro, biomass);
- Internal combustion generators (e.g., diesel engine);
- Battery storage; and
- Power conditioning equipment (inverter, battery charge regulator)

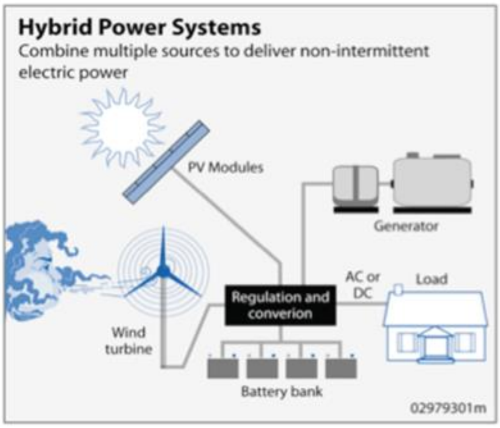

Figure 4. Components of a hybrid power system

Hybrid systems can reduce reliance on fossil fuels and increase the share of renewable energy resources, including intermittent ones, thus increasing the eco-efficiency of energy production and energy security.

Renewable hybrid energy systems can reduce the cost of high-availability renewable energy systems. This results from the system's ability to take advantage of the complementary diurnal (night/day) and seasonal characteristics of available renewable resources at a given site [2].

The hybrid energy systems have various advantages [13]:

1. **Continuous power supply** – The hybrid systems provide power continuously, without any interruption, as the batteries connected to them store the energy. So, when there is an electricity outage, the batteries work as inverter to provide backup. This is also the case during the evening or night time when there is no sun and energy is not being generated; batteries provide the back-up and life goes on without any interruption.
2. **Utilize the renewable sources in best way** – Because the batteries are connected to the system to store the energy, there is no waste of the excess energy generated on bright sunny days. So, these systems make use of the renewable energy in best way, storing energy on a good day and utilize the stored power on a bad day. The balance is maintained.
3. **Low maintenance cost** – The maintenance cost of the hybrid energy systems is low as compared to the traditional generators which use diesel as fuel. No fuel is used and they do not require frequent servicing.
4. **High efficiency** – The hybrid solar energy systems work more efficiently than traditional generators which waste the fuel under certain conditions. Hybrid solar systems work efficiently in all types of conditions without wasting the fuel.
5. **Load management** – Unlike traditional generators, which provide high power as soon as they turned on, most of hybrid power systems manage load accordingly. A hybrid solar system may have

technology that adjusts the energy supply according to the devices they are connected to, whether it's an air conditioner requiring high power or a fan which requires less.

3. Material Proposed Solution Implementation Methodology

The solution proposed in this article is based on the management of energy efficiency through the control of energy sources in a single system as in Figure 5. This automated solution interconnects groups of distributed energy resources and loads at a defined electrical boundary and it can operate in either island/isolated mode or networked mode.

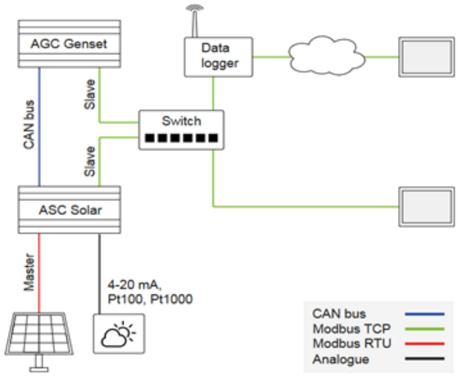

Figure 5. Hybrid Energy System

Island mode operation relates to power plants that operate in isolation from the national or local electricity distribution network.

There are two key types of island mode operation:

- Stand-alone generators not connected to the electricity grid presented in Figure 6
- Generators connected to the electricity grid in parallel mode, meaning they can generate power independently in the event of a grid power outage

In a system consisting of a generator and photovoltaic plant, this automated solution guarantees minimum fuel consumption by maximizing PV penetration without compromising minimum genset load requirements.

This proposed IoT-based solution provides steady voltage and frequency from a range of fossil-fueled and renewable hybrid sources. Through quick controller communication and compatibility with a wide range of sensor, meter, sky imager, and weather station solutions, they maintain power in application at all times, seamlessly switching sources as required [5, 14].

Figure 6. Stand-alone energy system

In hybrid applications with one or more renewables, proposed controllers are factory configured to maximize sustainable power penetration from PV panels, wind turbines, and more, and they facilitate the use of energy storage systems (ESS) to store green power, provide fast backup, and carry out peak shaving and load sharing.

Adding an ESS gives many design options. Like a genset, it can provide spinning reserve functionality to ensure uptime, and it can be configured to ensure optimal genset load.

We can use energy source or power source control, and the ESS can run in grid-forming, grid-following, or droop mode (acting as a virtual synchronous generator). We can base charging/discharging on schedular command timers and set up the ESS to communicate with a BCU, BMS, or PCS over Modbus.

To implement the desired commands in the controller, it is used m-logic as presented in Figure 7. The M-Logic functionality is used to execute different commands at predefined conditions. M-Logic is not a PLC but substitutes one, if only very simple commands are needed.

M-Logic is a tool based on logic events. One or more input conditions are defined, and at the activation of those inputs, the defined output will occur. A great variety of inputs can be selected, such as digital inputs, alarm conditions and running conditions. A variety of the outputs can also be selected, such as relay outputs, change of genset modes and change of running modes.

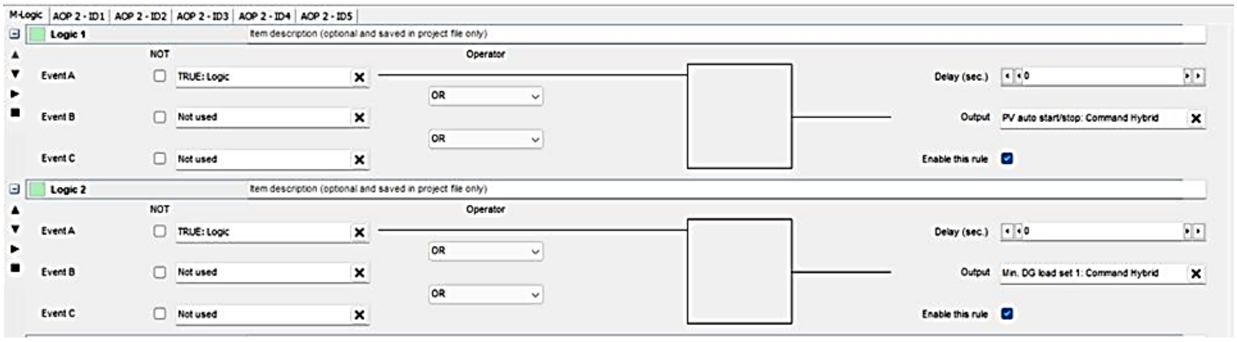

Figure 7. M-logic - tool based on logic events

The AGC 150 Hybrid is designed for protection and control of a hybrid installation with PV energy and genset. In a hybrid setup with a single genset, the controller can fully control the generator in connection with AVR and GOV control.

Proposed hybrid controller is compliant with the SunSpec communication standards as presented in Figure 8. This supports in fast and secure communication with the inverters.

Fronius	Interface	PV protocol*
Data manager	Modbus RTU (RS-485) or Modbus TCP	SunSpec Generic
Eco	Modbus RTU (RS-485) or Modbus TCP	SunSpec Generic

Figure 8. Communication protocols of inverters

The controller communicates with the inverters directly or through a gateway device. The standard communication follows the SunSpec protocol, which is a generic Modbus RTU protocol where the controller is the master device and the inverters are the slave as illustrated in Figure 9.

Broadcast is used in interfaces with multiple inverters where the controller itself needs to control them all. In this case, the controller does not address each inverter directly. Instead, it broadcasts the commands to all inverters. This is done to have a sufficiently fast control speed. The response is not mandatory as the controller continuously transmits the commands. The operating status of the inverter cannot be considered by the controller because the inverters do not feedback status information to the controller.

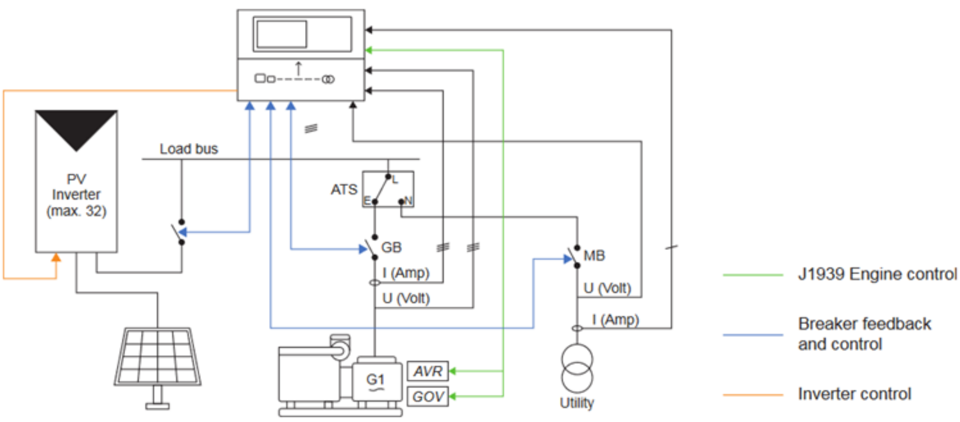

Figure 9. Communication between components of the hybrid system

4. Results and Discussion

In this work, we have proposed a solution for energy management in decentralized energy systems, where this solution helps to overcome the barriers for a sustainable energy transition in Albania.

The proposed system consists of a generator and a photovoltaic plant, which operate separately from the grid or in parallel with the grid.

Through the controller we control the inverters and the generator. The generator is put into operation in its minimum conditions without affecting the minimum operating load.

The PV plant fulfills about 80% of the annual consumption of the factory. The rest is completed by the generator and the main electrical network.

Since power outages are frequent, the inverters do not work, there is no source to provide the voltage and frequency references. This would affect problems in the main electrical network.

Therefore, the generator is put into work through the controller under minimum load operating conditions, which gives the references to the inverter.

Figure 10 presented the case of system operation, when there is no network and the factory's consumption needs are met by PV and the generator according to the algorithm set in the controller.

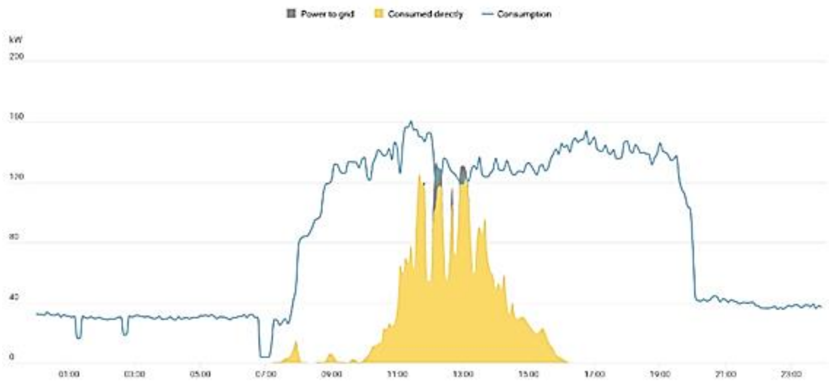

Figure 10. Energy consumed, produced by PV and received from the grid in a factory

Figure 11 presented the flow of energy at a certain point in time, where we have the energy produced by the PV plant which meets the consumption needs of the factory.

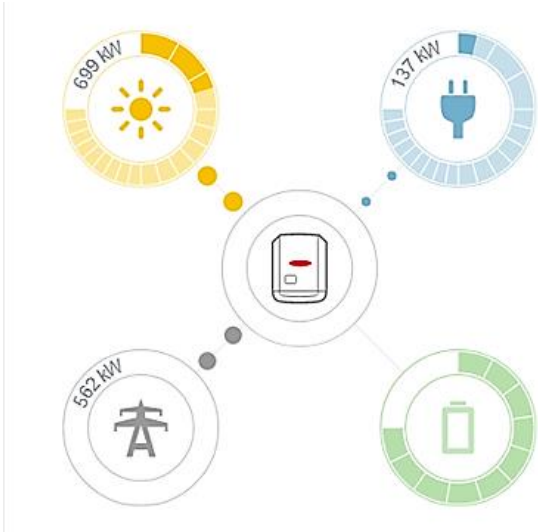

Figure 11. Energy flow in the system

The remaining part of the energy produced by the PV plant is exported to the network, which serves as a battery for a period of 1 month, according to the law in Albania for net energy measurement.

The system is located in Shkoder and it can be seen that the solar radiation is high as showed in Figure 12, indicating that the energy production forecast will be at high values that meet the system's need for electricity.

Figure 13 shows the energy balance of the system in which the controller is also integrated, and it is understood that for moments when we do not have the presence of the main electrical network, the system continues to function, fulfilling the energy requirements of the factory.

In this way, its implemented decentralized energy production through an efficient and sustainable system.

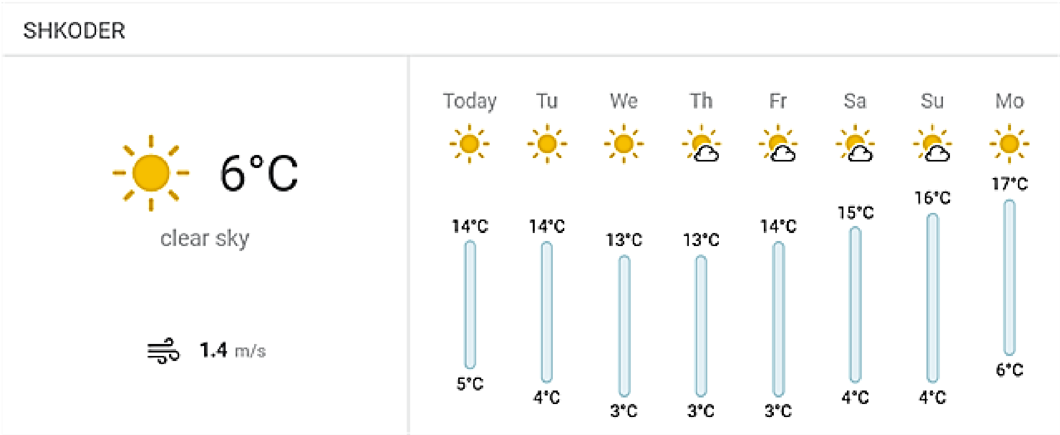

Figure 12. Weather and radiation analysis at the system location

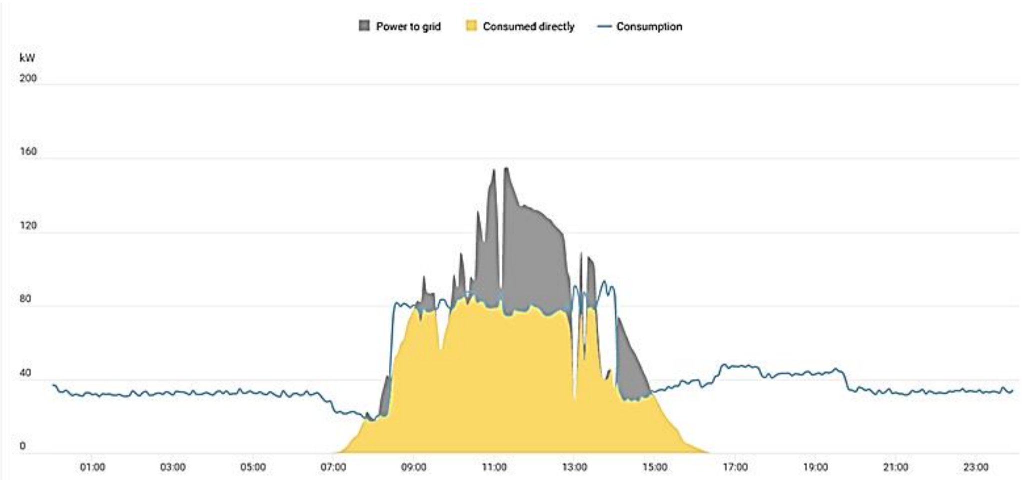

Figure 13. Energy balance of the system in which the controller is integrated

In Figure 14, the energy balance for one week is shown, where the independence of the system from the main electrical grid is shown by decentralizing the energy production. So, an independent system of energy production has been created, not being affected by the problems of the infrastructure of the Albanian electric grid.

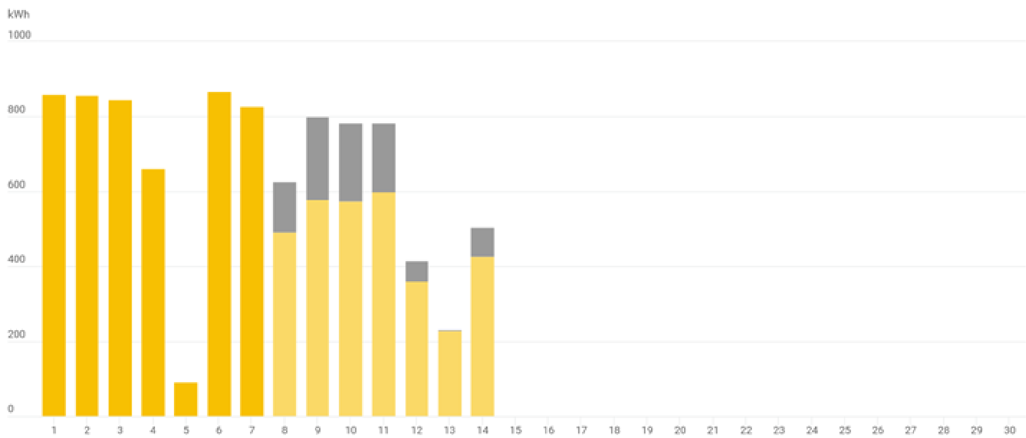

Figure 14. Energy produced by the system for one week

Albania has some advantages which should make its energy transition easier than for other countries in the region notably the lack of fossil fuel power generation and coal mining. But it has similar risk factors connected to corruption and low government capacity.

To put the necessary transition into action, much stronger action to apply the rule of law is needed. Decision makers need to be accountable for their actions, clear follow-up is needed on pledges made, and genuine public consultations must be carried out on policy matters, particularly those with environmental impacts.

In a decentralized, renewable-energy-based electricity system, appropriate spatial planning and nature protection is arguably even more essential than in a centralized one. Albania needs to do much more to provide real protection to valuable natural areas and to properly enforce environmental legislation.

Public participation is needed across the board, not only to prevent destructive projects, but even more so to move forward with increasing energy efficiency with smart and green solutions, offering huge opportunities in long term for the country.

Identified challenges in the proposed solution are:

<u>Institutional</u>

- State-controlled electricity markets hamper the development of a decentralized energy system because distributed generation encourages many actors to become power producers.

<u>Technical</u>

- If not properly planned, large-scale deployment in distributed generation may result in the instability of the voltage profile.
- Emerging technologies, such as smart grid, renewable energy, and energy storage, will require the operation criteria of the whole power system to be redesigned and modified.

5. Conclusion

Contrary to centralized energy supply, decentralized energy supply is the provision of energy through smaller plants which are closer to the consumers. This definition has a geographic as well as a quantitative component. The decentralized energy conversion plants are located where energy is needed, and the energy is provided by relatively more numerous but much smaller plants compared to the central energy supply. This results in new requirements for energy management, grid operation and protection technology.

The proposed hybrid power solution combines renewable energy sources, the generator, and the main power grid in a hybrid power plant or microgrid.

The proposed solution interconnects groups of distributed energy resources and loads at a defined electrical boundary. It can operate in either island/isolated mode or networked mode. In a system consisting of a generator and photovoltaic plant, this automated solution guarantees minimum fuel consumption by maximizing PV penetration without compromising minimum genset load requirements.

The proposed decentralized system of energy resources is based on IIoT, helping to develop smart cities. Decentralized control support identifying and control of important challenges for our unstable energy grid. Beyond the technical hurdles, our energy grid also needs a new paradigm for resilience, protecting against natural disasters and cyberattacks.

Based on obtained results, it's come to the conclusions that such power control systems in decentralized energy production systems have the main benefits:

- Rural electrification: Because grid integration of distributed generation and storage requires major technical upgrades, countries in the region can focus on distributed generation for rural electrification – either through off-grid or mini-grid systems.
- Increases in the share of renewable energy: A decentralized energy system is designed to accommodate many energy sources, including renewable sources with intermittent production, such as wind and solar. Distributed generation, demand management and storage can all facilitate increased inflows of renewable generation.

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Author contributions

Miranda Harizaj: Conceptualization, Methodology, Investigation, Writing-Reviewing and Editing. **Igli Bisha:** Writing- original draft preparation, operation and testing.

Conflicts of interest

The authors declare no conflicts of interest.

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