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MODELING AND SIMULATION OF A PHOTOVOLTAIC PLANT WITH LITHIUM-ION AND THERMAL ENERGY STORAGE SYSTEMS

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Abstract- Albania is a country that does not fulfill its energy demand with domestic production. This study aims to model a PV system combined with storage solutions and assess the best option for achieving self-sufficiency in Albania's energy system. The installation of a PV plant and the storage system was accepted as a solution to compensate for the missed energy due to the availability of solar energy in Albania (more than 300 sun hours per month). Two cases of storage systems were assessed: lithium-ion battery storage and thermal energy storage. The energy system was simplified as an island system with the goal to minimize the energy import, balancing it with the energy generated from the PV plant. An equivalent model with three parameters to be determined was selected to quantify the electric power of the PV unit under any given temperature and irradiance scenario. The equations given below are based on the research and scientific experiments carried out. MATLAB was used to elaborate the calculation. A simulation model to evaluate the synergy between solar energy and hydroelectric energy was built up, and again, for the calculation was used MATLAB. The results of the simulation were analyzed for two cases: battery storage system and thermal storage system. For the first option, PV plant + battery energy storage, we found that the best economic solution with 99% self-sufficiency of the system was the combination of the 22500 modules and 16000 kWh storage, with a total cost of $8.5 million. For the second option, PV plant + thermal energy storage, we found that the best economic solution with 99% self-sufficiency of the system, was the combination of the 22500 modules and 18000 kWh storage, with a total cost of $6.52 million. The results show that the proposed solution, PV plant + battery energy storage, is feasible and can be adapted in the Albanian energy system without any problem. With the energy storage system, the PV plant doesn't affect the stability of the transmission system.

Keywords: 1D + 3P Model, Solar Irradiance, PV Max Power, Battery Storage, Thermal Storage, Energy Balance.

1. INTRODUCTION

Albania is a country that does not fulfill its energy demand with domestic production. The installed capacity in Albania in 2023 was 2675 MW. The energy production is mainly from the HPP and only a small part from PV plants [1]. There is one CCPP, which is out of operation due to the high cost of energy production with fuel oil [2]. A lot of PV plant projects are ongoing, and the energy production is increasing rapidly. Data of the energy generation and import – export for the last 5 years was taken from the official site of the Energy Regulator Authority of Albania. The worst hydrologic year with less production in the last five years was 2019, and the model was based in this year.

This study aims to model a PV system combined with storage solutions and assess the best option for achieving self-sufficiency in Albania's energy system. Between the renewable energy options, the photovoltaic option was accepted as a solution to compensate for the missed energy due to the availability of the sun in Albania (more than 300 sun hours per month).

The combination of the high intensity of solar radiation, its long duration, the air's temperature and humidity, etc., determines a huge energy potential for the use of solar energy. Many places are exposed to radiation that ranges from 1185 kWh/m^2 per year to 1700 kWh/m^2 per year [3]. It is important to note that Albania's western region, particularly its southwest, offers abundant solar energy.

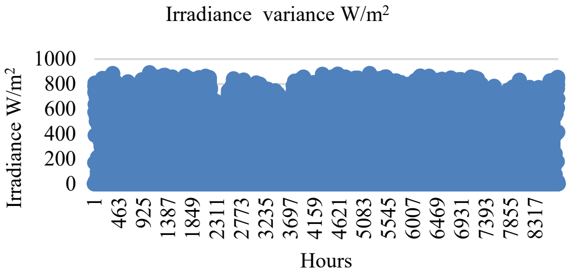

Figure 1. Irradiance (W/m^2) for every hour (2019)

Figure 2 and Table 1 show the solar irradiance, temperature, and energy import/export in Albania are related to 2019 [4] and will be used as input for our model. Temperature and irradiance are used for the first model to calculate the PV cell power, while the data of energy import/export are used in the second model to calculate the energy balance and self-sufficiency of Albania's energy system.

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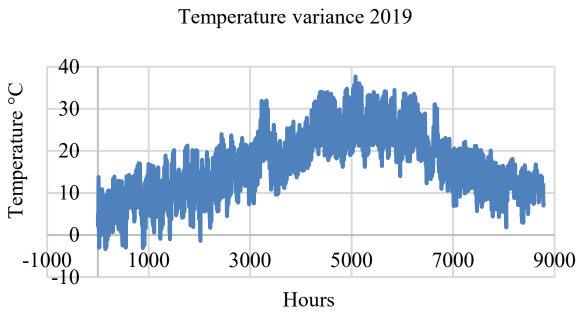

Figure 2. Temperature variance (°C) (2019)

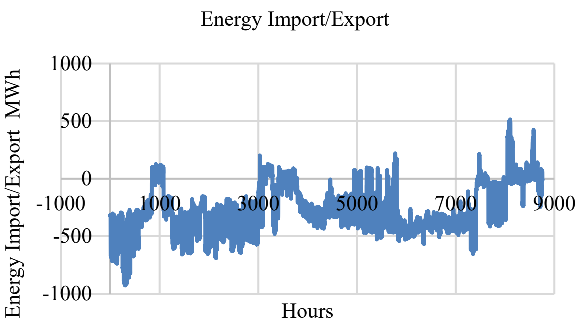

Figure 3. Energy import/export (MWh) (2019)

Table 1. Energy production, consumption, and import/export data for Albania (2019-2023)

Year	2019	2020	2021	2022	2023
Production (GWh)	4772	4898	8438	6507	5954
Consumption (GWh)	7178	7174	7891	7428	8000
Import/Export (GWh)	-2406	-2276	547	-921	-2046
Import/Export (%)	-34%	-32%	7%	-12%	-26%

2. PV MODELING

2.1. The Model of the PV Module

The following equations are used to calculate the electric power of the module, according to the database provided by the manufacturers, under any given irradiance and temperature scenario. The equations given below are based on the research and scientific experiments carried out. An equivalent circuit of a PV module – one diode and three parameters (1D + 3P) model - was used [5]. This is the simplest model, non-very accurate, but usually is used for a faster evaluation of the PV unit behavior. This model requires solving only one nonlinear equation and doesn't need commercial software for the computation.

The Standard Test Conditions (STCs) are the accepted conditions for the PV test in the factory, and in the equations below, the letter r is relevant to STCs. Referring to such conditions, the irradiance G^r = 1000 W/m^2 and module temperature θ^r_m=25 °C (T^r=298 K). Normal Operating Conditions (NOCs) are accepted for irradiance G^{NOC}=800 W/m^2 and the temperature of ambient θ_{amb}=20 °C. The current across the diode I_D is [5]:

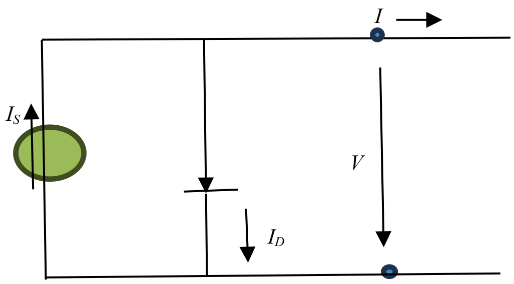

Figure 4. Equivalent circuit of a PV module

$$I_D = I_0\left(e^{\frac{V}{mV_T}-1}\right) \tag{1}$$

where, I_0 is the diode's saturation current, V is the terminal voltage, and m is the diode's ideality factor. For ideal diode m=1xN_S and for real diode m>1xN_S, where N_S is the number of cells of the module connected in series. The thermal voltage $V_T(V)$ is [5]:

$$V_T\left(T\right) = \frac{k}{q}T \tag{2}$$

where, k is the Boltzmann constant (1.38×10^{-23} J/K), T is the absolute temperature (K), and q is the electron's electrical charge (1.6×10^{-19} C). The reference thermal voltage for T^r = 298 K (25 °C) is [5]:

$$V_T^r = \frac{kT^r}{q} = 0.0257V \tag{3}$$

As per Figure 4, the current I is [5]:

$$I = I_S - I_D = I_S - I_0\left(e^{\frac{V}{mV_T}-1}\right) \tag{4}$$

where, I_S is the current created by the photovoltaic effect which is equal to the short circuit current I_{SC} when V = 0. The output DC power P for a given temperature and irradiance is given [6].

$$P = VI = V\left[I_{SC} - I_0\left(e^{\frac{V}{mV_T}-1}\right)\right] \tag{5}$$

For dP/dV=0, we have the maximum power [5]:

$$e^{\frac{V}{mV_T}} = \frac{\frac{I_{SC}}{I_0}+1}{\frac{V}{mV_T}+1} \tag{6}$$

Calculating maximum power is essential because PV modules have an electronic device to control their operation, which assures that the PV panel is operating at its maximum power under current temperature and radiation circumstances. The solution of Equation (6) gave V=V_{MP}, the voltage of the maximum power, and I=I_{MP}, the current of the maximum power [5]:

$$V_{MP}=mV_T\ln\left(\frac{\frac{I_{SC}}{I_0}+1}{\frac{V_{MP}}{mV_T}+1}\right) \tag{7}$$

$$I_{MP}=I_{SC}-I_0(e^{\frac{V}{mV_T}-1}) \tag{8}$$

The maximum power is:

$$P_{MP}=V_{MP}xI_{MP}=P_{DC} \tag{9}$$

To solve the non-linear Equation (7), the iterative methods are required. Using the Gauss-Seidel method, the below equation should be solved [6]:

$$V_{MP}^{(k+1)}=mV_T\ln\left(\frac{\frac{I_{SC}}{I_0}+1}{\frac{V_{MP}^{(k)}}{mV_T}+1}\right) \tag{10}$$

where, *k* is an iteration number. To solve the equation (10) we can start with the value $V^{(0)}{}_{MP}=V^r{}_{MP}$. We used Equation (4) to calculate the three parameters; short circuit current at reference state (V=0), inverse saturation current at reference state (I=0) and ideality factor ($I=I_{MP}$ and $V=V_{MP}$). Short circuit at reference state (V=0) [6]:

$$I_{SC}^r=I_S^r \tag{11}$$

Open circuit at reference state (I=0): [6].

$$I_0^r=\frac{I_{SC}^r}{e^{\frac{V_{OC}^r}{m^rV_T^r}}-1} \tag{12}$$

Ideality factor ($I=I_{MP}$ and $V=V_{MP}$) [5]:

$$m^r=\frac{V_{MP}^r-V_{OC}^r}{V_T^r\ln\left(1-\frac{I_{MP}^r}{I_{SC}^r}\right)} \tag{13}$$

We can calculate the parameters of the model using the technical specification of the module.

- The ideality factor is constant $m^e=m$.
- The short-circuit current, $I_{SC}=I_{SC}(G)$, depends on the irradiance.
- The inverse saturation current, $I_0=I_0(T)$, depends on module temperature.

Experimental results show that these approximations are valid [7]. The Equation (10) became as below for any combination of temperature and irradiance [6].

$$V_{MP}^{(k+1)}(G,T)=mV_T(T)\ln\left(\frac{\frac{I_{SC}(G)}{I_0(T)}+1}{\frac{V_{MP}^{(k)}}{mV_T(T)}+1}\right) \tag{14}$$

The function of the inverse saturation current from temperature is [5]:

$$I_0(T)=DT^3e^{\frac{-N_S\varepsilon}{mV_T(T)}} \tag{15}$$

where, D is constant, ε = 1.12 eV is the silicon bandgap, and N_S is the number of cells of the module connected in series. The D is not important, because if we write the Equation (15) at STCs [5]:

$$I_0(T)=I_0^r\left(\frac{T}{T_r}\right)^3e^{\frac{N_S\varepsilon}{m}\left(\frac{1}{V_T^r}-\frac{1}{V_T(T)}\right)} \tag{16}$$

A linear dependence between the short circuit current and irradiance is accepted [6]:

$$I_{SC}(G)=I_{SC}^r\frac{G}{G_r} \tag{17}$$

Solving Equation (10), the voltage of the maximum power was calculated for any combination of irradiance and temperature values. After we obtain the $V_{MP}(G, T)$, we can calculate the current of the maximum power [6]:

$$I_{MP}(G,T)=I_{SC}(G)-I_0(T)(e^{\frac{V_{MP}(G,T)}{mV_T(T)}}-1) \tag{18}$$

The DC power of the module is [6]:

$$P_{DC}(G,T)=V_{MP}(G,T)xI_{MP}(G,T) \tag{19}$$

In this paper, we have used a simplified version of the model to avoid the solution with iterative methods [5]. The Equation (18) can be written [5]:

$$V_{MP}(G,T)=mV_T(T)\ln\left(\frac{I_{SC}(G)-I_{MP}(G,T)}{I_0(T)}\right) \tag{20}$$

As we see, the I_{MP} depends on V_{MP}, and to simplify calculation, we assume a linear dependence between the maximum power current and the irradiance [6]:

$$I_{MP}(G)=I_{MP}^r\frac{G}{G^r} \tag{21}$$

The V_{MP} can now be calculated without iterations [6]:

$$V_{MP}=mV_T\ln\left(\frac{I_{SC}(G)-I_{MP}(G)}{I_0(T)}\right)=$$
$$=mV_T\ln\left(\frac{\frac{G}{G^T}(I_{SC}-I_{MP})}{I_0^r\left(\frac{T}{T^r}\right)^3e^{\frac{N_S\varepsilon}{m}\left(\frac{1}{V_T^r}-\frac{1}{V_T}\right)}}\right) \tag{22}$$

From the multiplication of the Equations (21) and (22) we have the DC electric power of the module. To measure the efficiency of a PV unit, the Fill Factor at STC is used.

$$FF=\frac{P_{MP}}{I_{SC}xV_{OC}} \tag{23}$$

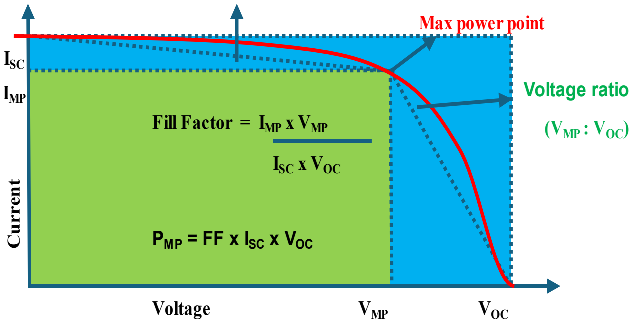

Figure 5. The definition of the FF based on the capability curve of the PV module

2.2. Computation of the Model

The computation of the above system of equations for determining the power output of a solar panel was carried out on the MATLAB platform [8]. There are two input variables needed for the calculation of the output values: T_{NOC} (Normal Operation Condition Temperature) and G_{NOC} (Normal Operation Condition Irradiance). The 8760 values for G_{NOC} and T_{NOC} are taken from the available data for the 2019 year [4], as shown respectively in Figures 1 and 2. These 8760 values are used (for loop) calculations and are repeated uniformly in all the equations.

2.3. Model Validation

The validation of the above introduced model was performed. Experimental data were not available, and for validation, we take in reference the PV data sheet of different manufacturers. Due to space reasons, here are shown the results only for the Bisola (Mult crystallin Silicon Photovoltaic Module) [9]. A 245W PV panel with 60 cells was selected. The panel was tested for the combination of the irradiance G = 800 W/m^2 and the temperature T = 44 °C = 317 K. The percentage error PE was calculated with the following formula.

$$PE = \frac{P_{DC}\left(G,T\right) - P_{DC}}{P_{DC}} \times 100\% \tag{24}$$

The results are shown in Table 2.

Table 2. The PE between the model and data-sheet values

	From the data-sheet	From the model	Error
Max Power (*W*)	181	175.5	3.03 %
MP current (*A*)	6.59	6.12	7.13 %
MP voltage (V)	27.5	28.65	4.1 %
Module Efficiency (*%*)	13.8	13.73	0.52 %

The output power from the model simulation for one year is shown in Figure 6.

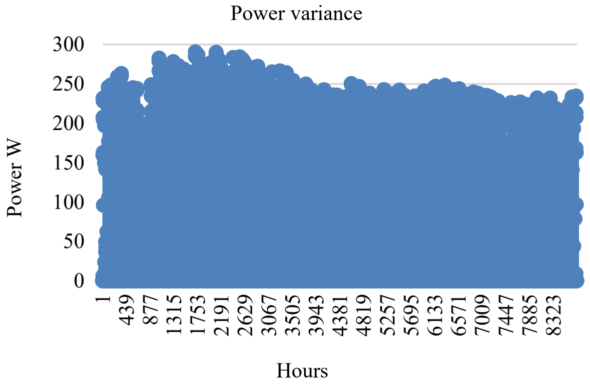

Figure 6. The output power of one module during one year

The output energy of the PV plant is calculated by multiplying the energy produced by one module with the number of modules.

$$Totalenergy = energy1module \times numberofmodules$$

The results from the model simulation are exported for further calculation.

3. ENERGY STORAGE SYSTEM

3.1. Energy Balance

The aim of this study was to find the best combination between the installed power of the PV plant and the energy storage system capacity. The criteria to evaluate this combination will be the self-sufficiency of the system and the economic cost of the storage system [10].

Energy storage is essential to support renewable energy systems because PV systems have the drawback of not producing electricity when there is insufficient radiation. Energy conservation is a key factor for having a reliable, balanced electrical system. There are different energy storage systems; we can single out some of the most efficient ones: electric battery, thermal energy storage, chemical energy storage, hydrogen, compressed air, flywheel and pumped hydro. The main difference between them is the form of energy conserved in the system, like mechanical, chemical, or thermal energy. In this study, the PV plant is connected to the network, and the goal is to balance the energy of the system. To convert back to electric energy the mechanical energy and thermal energy another power plant is needed, whereas the chemical energy is converted into electric energy in the same battery and is ready to be injected in the network. Based on that criterion, the best solution is Battery Lithium-ion system, but in our study, we included the Thermal Storage System as well, more for comparison reasons [11].

The balance of the energy is necessary for determining the storage system. The balance of the energy is the difference between the total energy produced and imports or exports, which means the energy entering or leaving the energy storage system. So, it is calculated:

$$EnergyBalance = TotalEnergyProduced + Import / ExportEnergy$$

In Table 1, the imported energy is given with a negative sign (-), whereas the exported energy is given with a positive sign (+).

3.2. Battery Lithium-Ion System

Energy efficiency is the key component for selecting a battery storage system. The efficiency in Battery Lithium-ion is close to 95%, although it is declining due to several issues. Lithium batteries are the most common technology and are chosen for their relatively low maintenance requirements. However, there are some factors that affect the efficiency, and, in our calculation, we assumed a value of 90%. The state of charge (*SOC*) represents the level of charge of a battery and is expressed as a percentage (0% = empty and 100% = full).

$$SOC_{BATTERY} = \frac{EnergyAvailable_{BATTERY}\left(t\right)}{TotalCapacity_{BATTERY}} \times 100\%$$

Both factors - the SOC of the battery and balance of energy - are important to determine the correct capacity of the battery storage system. Due to lower efficiency, which produces energy losses during the storage process, other kinds of batteries were not considered [12].

3.3. Thermal Storage System

Just to compare the battery storage system, we take into consideration the thermal storage system, which usually is not used in the PV plants. We can conserve energy by heating or cooling a medium and then using the energy when needed. To simplify, the medium in the reservoir is heated at times when the PV plant is producing energy more than the demand, and the energy is then conserved in the medium for use when energy is less available.

By exploiting this feature, it is possible to use different materials with different thermal properties, which can result in different thermal storage applications. The efficiency of the thermal energy storage (TES) systems is between 50 and 90 % [9], depending on thermal insulation technologies and the specific heat of the storage medium. Phase change materials (PCM) can increase efficiency, reaching a range of 75% to 90%. To analyze this system, an efficiency of 85% was assumed. The concept of the SOC for a thermal storage system is expressed as follows:

$$SOC_{THERMAL} = \frac{EnergyAvailable_{THERMAL}\left(t\right)}{TotalCapacity_{THERMAL}} \times 100\%$$

Both factors, the *SOC* of the thermal system and balance of energy, are important to determine the correct capacity of the thermal storage system.

4. SIMULATION MODEL

4.1. Combined Model

We have explained above the equations, where is based the equivalent model with three parameters to be determined, used for PV module output computation. Another model was created to assess the efficiency of the energy storage system, taking into consideration two cases: Battery Lithium-ion and Thermal Energy Storage. This model has as input the energy production from the PV plant taken from the first model.

Evaluation of synergy between solar energy, import/export, and usage patterns, which are computed in MATLAB gives an output multiplier to meet the demand. The following diagram briefly shows the steps of how our model works. From data processing and calculations, we get the outputs, which are: Energy flow analysis, Import analysis, Export analysis, and Economic analysis.

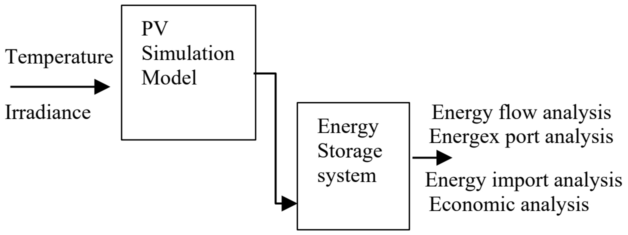

Figure 7. Simplified scheme of the steps followed

4.2. Simulation Study and Results

The total energy produced from the PV plant is calculated by multiplying the energy of one panel with the number of panels.

$$Total\ energy = Energy\ 1\ model \times number\ of\ modules$$

To estimate the number of the panels for the plant, the simulation was carried out for a range from 5000 to 30000 modules, along with energy storage options. Based on market data [13], the price was in a range from 0.370 to 0.390 $/Wp, and an average value of 0.380 $/Wp was selected. The calculations were carried out for two cases of storage systems, described here above.

4.3. Analysis with Battery Storage System

We can't determine the exact storage capacity of the system because this is relevant to the PV plant's size. To fit with the purposes of this study, the storage capacity selected was in the range of 6000 to 36000 kWh [14]. Self-sufficiency of the system is the ability to provide all the required energy. Here below is shown the self-sufficiency of the system as a combination of two variables: the number of modules and storage battery capacity (kWh).

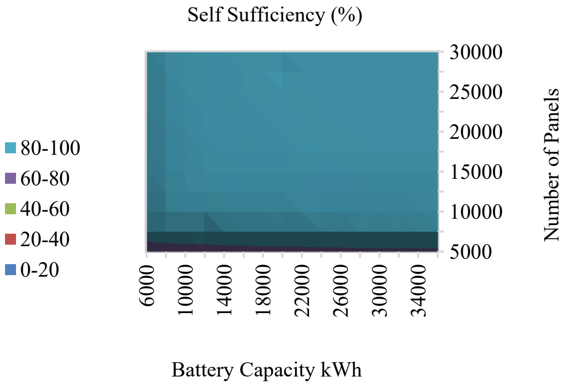

Figure 8. Self-sufficiency dependance from the number of modules and storage capacity

Different PV is batteries combinations have self-sufficiency in the range from 70% to 100%. It's evident that any combination with more than 14000 kWh storage and more than 12500 modules results in a self-sufficiency greater than 97%. With less than 7500 modules resulting in a self-sufficiency less than 90% regardless of the storage capacity.

Figure 9 shows the energy import (MWh) under different operating scenarios. The energy import for 2019 was 2514 GWh. Considering 5000 modules with 6000 kWh storage, the energy import decreased to 831 MWh, almost one-third of the energy imported in 2019. To increase the energy generation, the number of the PV units and the storage capacity should be increased. The extreme combination of 30000 modules and 36000 kWh storage capacity results in –69 MWh, which means that the system does not import, but export 69 MWh of energy.

To perform the economic analysis, we take into consideration some figures: the cost of the installation for one module is $226 [15], the module cost is $70 [16], and the cost of the battery storage is $151 per kWh [17].

To produce all the required energy is feasible. Figure 10 shows that for the combination of the 22500 modules and 16000 kWh storage capacity, the self-sufficiency is 99.01%, which results in the most suitable solution from the economic point of view, with a total cost near $8.5

million. Increasing the self-sufficiency to 100% the total cost of the investment will increase up to $9.54 million and can be reached with different combinations, for instance using 20000 modules and 28000 kWh storage, that reduces the import with 25.1 GWh.

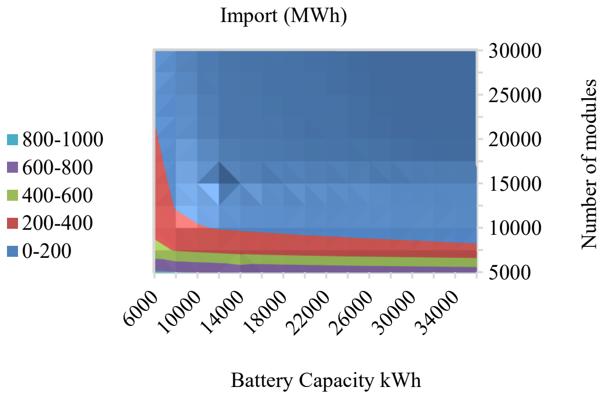

Figure 9. Energy import (MWh) with different PV and battery storage operational scenarios

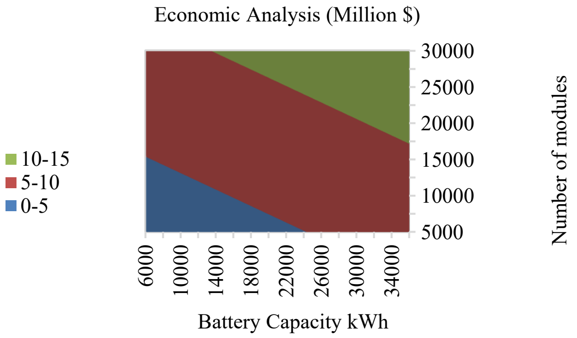

Figure 10. Economic analysis (Million $) in relation to number of modules and storage capacity

For an operation scenario with 22500 modules and 16000 kWh storage capacity, Figure 11 shows the SOC of the battery.

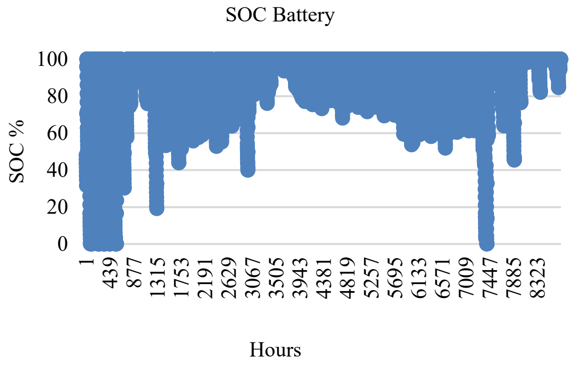

Figure 11. State of charge of the battery storage system

4.4. Analysis with Thermal Energy Storage System

This system was selected due to relatively warm average temperatures, which favor thermal systems with heat, and the terrain is favorable for such energy storage systems. Here below is shown the self-sufficiency of the system as a combination of two variables: the number of modules and the thermal storage capacity (kWh).

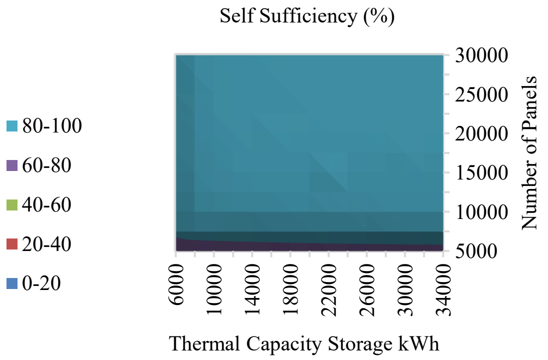

Figure 12. Self-sufficiency dependance from the number of modules and storage capacity

To fit with the purposes of this study, the storage capacity selected was in the range of 6000 to 34000 kWh. Different PV–storage combinations have a self-sufficiency in the range from 71% to 99%. It's evident that any combination with more than 14000 kWh storage and more than 12500 modules results in a self-sufficiency greater than 96%. With less than 7500 modules resulting in a self-sufficiency less than 90% regardless of the storage capacity. Figure 13 shows the energy import (MWh) under different operating scenarios. The energy import for 2019 was 2514 GWh. There are a lot of combinations between the module number and storage capacity that give an energy import range from 2 to 202 MWh. To remain within this interval, we can start with a combination of 11000 modules and 12000 kWh of storage capacity.

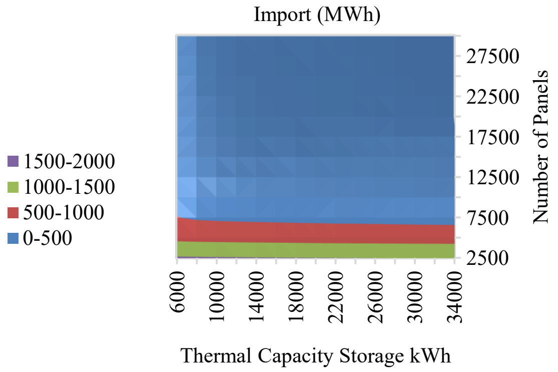

Figure 13. Energy import (MWh) with different PV and thermal storage operational scenarios

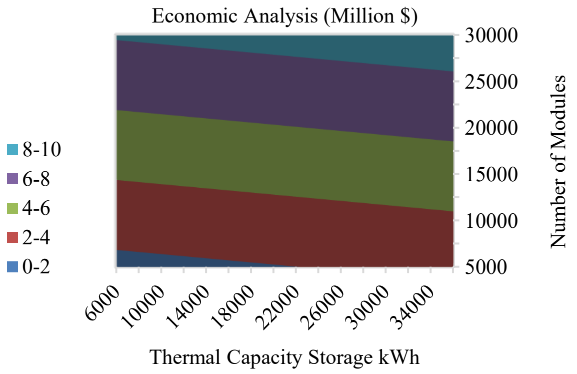

Figure 14. Economic analysis (Million $) in relation to number of modules and storage capacity

To perform the economic analysis, we take into consideration some figures: the cost of the installation for one module is $226 [15], the module cost is $70 [16], and the cost of the thermal energy storage (TES) is $30 per kWh [18]. To compare with the first case (battery storage), we will keep the same level of self-sufficiency, close to 99%. The best solution regarding the cost of the PV plant is the combination of 22500 modules and 18000 kWh storage capacity, which results in a 99.02% self-sufficiency and a cost of $6.52 million. For an operation scenario with 22500 modules and 18000 kWh storage capacity, Figure 15 shows the SOC of the thermal storage.

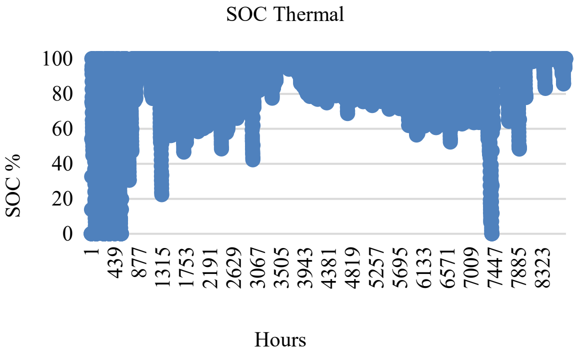

Figure 15. State of charge of the thermal storage during one year

5. RESULT AND DISCUSSION

1. The error's percentage PE of the equivalent model with one diode and three parameters (1D + 3P) was reasonably low and fit the chosen level of uncertainty for this study. In Table 2 are shown the results for one module under the specific conditions of the irradiance G = 800 W/m^2 and the temperature T = 44 °C = 317 K, which are used to test the PV panels in the factory. Additionally, the STC with the irradiance G = 1000 W/m^2 and the temperature T = 25 °C = 298 K are also carried out in the factory, and the data of tests for all the panel sizes and technologies are accessible. We ran and calibrated the model for a lot of cases, and the figures in Table 2 are significant because they statistically represent the error's mean value. The results we got are reliable, taking into consideration the scale of the PV plant.

2. We considered an island energy system, and our solution tried to provide the system's energy needs without accounting for the price of energy on the market or the option of obtaining energy through the interconnection lines. Because there are too many variables involved and the price fluctuates too much, the issue becomes too complex. However, as a hypothesis, producing energy is less expensive than acquiring it.

3. An energy storage plant was chosen as the option to ensure network stability due to the oscillations in the electricity generated by photovoltaic plants. The graph in Figure 9 illustrates the amount of imported energy that is related to the number of PV modules and battery capacity for the first option, which is the PV plant plus battery energy storage. The interval of imported energy for any combination of PV modules and battery capacity is represented by the colored fields. Combining the data for the system's self-sufficiency and imported energy, we discovered that the combination of the 22500 modules and 16000 kWh storage, at a total cost of $8.5 million, provided the most cost-effective option with 99% system self-sufficiency, Figure 10. This solution requires a small amount of energy to be imported based on energy balance.

4. The graph in Figure 13 illustrates the amount of imported energy that is related to the number of PV modules and storage capacity for the second option, which is the PV plant + thermal energy storage. The interval of imported energy for any combination of PV modules and storage capacity is represented by the colored fields. Combining the data for the system's self-sufficiency and imported energy, we discovered that the combination of the 22500 modules and 18000 kWh storage, at a total cost of $6.52 million, provided the most cost-effective option with 99% system self-sufficiency, Figure 14. This solution requires a small amount of energy to be imported based on energy balance.

5. For an operation scenario with 22500 modules and 16000 kWh storage capacity, figure 11 shows the SOC of the battery during all the year, and for an operation scenario with 22500 modules and 18000 kWh storage capacity, figure 15 shows the SOC of the thermal storage during all the year. We can see that the graphs are very similar because both systems are dealing with the same scenario of the energy system, and their capabilities are almost equal. The storage systems are very dynamic and are working properly; for most of the hours during the year, the SOC is between 70 and 100%.

6. To provide the data for potential radiation per square meter (1500 kWh/m^2) PVGIS was used. NASA was used as a source for the earth's surface temperature, to calculate the power output of the PV modules. We believe that such sources produce reliable results.

6. CONCLUSIONS

1. To produce all the required energy is feasible, even in the worst hydrologic year. With both options, we can provide the needed energy in Albania. The solution of thermal storage is cheaper compared to battery storage for the same scenario. Despite this, due to easy and direct conversion between chemical and electrical energy and other technical reasons, the size of the plant, the availability of the materials, the comfort of service, and the needed infrastructure, the most suitable solution is battery storage.

2. For the economic assessment, only the cost of the PV panels and the storage plant were considered; the cost of the terrain and of the other equipment needed for the plant's completion were not considered. So, the total cost of the plant should be higher than the figures given above. Nevertheless, the trend of the PV power plants cost is in decline and the trend of efficiency is on the rise, which makes more feasible the investment in solar energy sector.

3. In Albania, photovoltaic plant installations are expanding quickly, particularly in the southwest coast, near the lagoon of Vlore [19], where solar radiation is strongest, and the soil is unsuitable for farming. Across Albania, the capacity for hydropower energy generation is

nearly fully utilized, making the PV plant the more sensible choice. Because sunny days and rainy days are connected, rainy days offset each other such that we have less energy produced by PV plants during favorable hydrologic years (more rain). Large basins in Albania's hydropower facilities indicate a great potential for energy conservation during the summer months when the PV plants are working at maximum capacity. Albania will soon be able to export electricity due to the potential for future synergy between hydro and PV - generating.

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