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MATLAB® Modeling of a Microgrid: Towards a Vision Based on Entropy Balance

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Abstract. A microgrid is defined as the link of consumer loads and decentralized energy assets with the ability to control the entire system as a whole. The modeling of an electromagnetic microgrid is discussed in this work to analyze energy effectiveness and entropy balance. The method computes the associated losses and simulates the electrical behavior of the components. The model is built and tested by using the MATLAB Simulink application. The system is made up of several blocks consisting of solar panels, batteries, consumer loads, and the inverter needed to connect them all. Their energy efficiency is assessed using the findings from each of these components. The system's entropy generation is also calculated to study how it relates to performance.

Keywords. Microgrid, Entropy, Sliding Mode Controler, Energy Efficiency, Maximum Power Point Tracking (MPPT).

1. Introduction

A significant increase in the usage of renewable energy like solar and wind is anticipated in response to the present environmental crisis and the need to alter the conventional electrical paradigm. These can be applied in a decentralized and small-scale manner, in contrast to the traditional electricity network, which is based on high-power and centralized power plants. This suggests the necessity for a new system, the so-called Microgrids [1], that can adapt to this transition. It operated more reliably and profitably while linked to the electrical grid or in isolation, or in what is known as "island mode." [2] [3].

In this research, topology is defined as how each component of the network is related to every other component. Finding the topology that is most suited to the anticipated application and its features is crucial when designing a microgrid since it will have an impact on the system's proper operation [4]. Typically, the distribution of electricity determines the structure of a microgrid. In this regard, three other significant variations can be emphasized: hybrids (AC-DC), direct current (DC) microgrids, and alternating current (AC) Microgrids [5]. In addition, the 3-NET network structure is useful and provides more versatility [6].

Two primary goals stated in this study. The first is to create a model that represents a microgrid and mimics its behavior in terms of thermal and electrical loss. The second goal is to analyze the energy of the planned system depending on how it generates entropy. This study presents a model that based on a simple model but makes use of a managed voltage supply to apply a signal that derived depending on the battery's operating circumstances and replicates the dynamic behavior of the battery.

The model also takes into account the thermal behaviour of the components since it influences efficiency in addition to the electrical component and inefficiencies. The system's entropy output also computed based on the model's findings to connect this idea to renewable energy. To assess an electrical microgrid's energy efficiency, this research gives a model of one. The model calculates the associated losses and replicates the electrical behavior of the components. The temperature during operation is then calculated. A set of solar cells, a battery, a workload, and the inverter used to connect them all make up the planned system. Their energy consumption assessed using the results for each of these components.

2. Model Description

The Simulink tool and the most recent version of MATLAB R2022b were used to model and simulate the Microgrid to meet the goals.Simulink is used for modeling and simulation, but the output is transferred to MATLAB for evaluation and processing. To make the circuit easier to grasp, it has been separated into four blocks.

A. Block 1: Photovoltaic Panel

First, the input for the thermodynamic PV model is provided; from here, we use addition and product on the input. The PV array receives two inputs: one from *G* and another from a model of thermic PV (Fig. 1). For the panel model, a ready-made block from the Integrated

Power Systems library is utilized. The operational curves for the group of panels are chosen by the program itself based on these parameters. It features three exit signals and two entering signals. Two electrical impulses that correlate to the terminals of the assembly are produced by entering the cell's illumination and temperature parameters. Port m represents an information output containing various measures, including the panel's current and voltage values.

Fig. 1. PV array's thermic model

By extrapolating the temperature and irradiance of the panel with reference values, the current produced by the solar array is calculated. These are derived from curves created using panel parameter values. The manufacturer Era Solar's polycrystalline panel model ESPMC280 [7] has been selected for the microgrid design, and four units will be employed, divided into two sets of parallel configurations made up of two panels each. The model block has been set up using its settings as indicated in Fig. 2. Under established test settings (Standard Test Conditions, STC), which equate to an incoming irradiance of 1000 W/m^2 and a module temperature of 25 ºC, the producer verified these results in a lab setting. It has been found that while the maximum voltage significantly falls with temperature, the current somewhat increases. Due to this fact, the max power value at extremely high temperatures decreases, as does the panel efficiency.

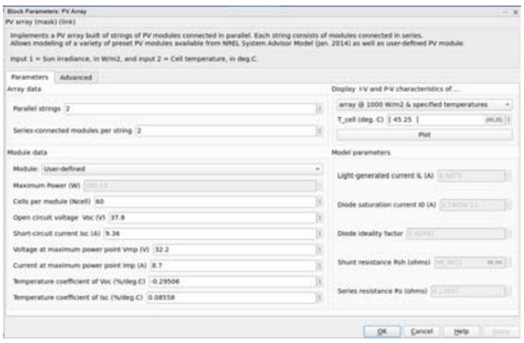

Fig. 2. PV array's parameters

B. Block 2: MPPT

PV panels are connected through MPPT tracking to the Buck converter block. Power converters are used for system control and for connecting the various components. To get the most power out of PV panels, an MPPT converter is required. This is done with a step-down converter because the solar assembly's standard voltage is greater than the DC bus's (Fig. 3).

C. Block 3: Battery

The battery with a rated voltage of 12V is attached to MPPT tracking via the battery charger subsystem of the bidirectional dc-dc converter. Similar to the last phase, the battery is modeled using a pre-built block. It displays two electrical ports that correspond to the battery terminals and one info output port by default. Choose from many model iterations with the option to include thermal behavior or aging effects. With the latter, a second input port that corresponds to the outside temperature is visible. All parameters manually entered in the configuration block as battery respond time is 30 seconds. A predetermined profile for a battery of the LiFeMgPO4 type is utilized with initial state of charge as 70 second (Fig 4).

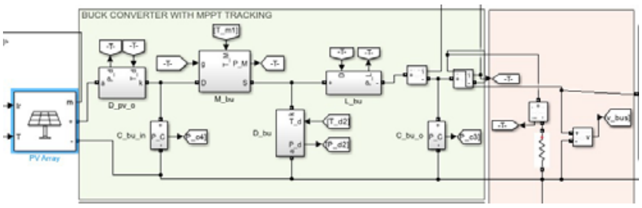

Fig. 3. MPPT Converter

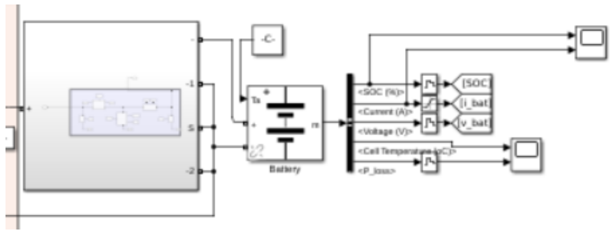

Fig. 4. Battery's modeling

The investigation of the equipment in this case research comprised the thermal and electric sectors. Three components were used to create this multi-domain model one for the electrical component, a second one for the thermal component, and a third one one for the loss model, which serves as a bridge between the two. The power dissipation brought on by electrical components calculated by this loss model and used by the simulation analysis to estimate temperature change. In contrast, these temperatures are required to calculate these losses, which also have an impact on how the electrical system behaves.

D. Block 4: Sliding Mode Control (SMC)

Compared to other nonlinear control techniques that offer a more modest control action, sliding mode management must be used with more caution. The forceful sliding mode-control operation can result in chatter, energy dissipation, plant damage, and the stimulation of nonlinear dynamics because transducers have delays and other flaws. Consistent control design methodologies can be modified to resemble sliding-mode controllers and are less prone to these issues.

$$X^{\bullet}(s) = A\hbar + Bu \qquad (1)$$

The control of systems with changeable structures naturally lends itself to sliding mode control (SMC), as is well established.Traditional linear control, which is small-signal premised, only enables one to operate the converters optimally for a limited set of operating conditions [8]. The fundamental justification is that the construction of a nonlinear controller does not need the existence of a linear curve of the power converter. The variable-frequency characteristic of SMC, which makes the construction of an output filter challenging, is the fundamental issue with its usage. SMC is a robust control design approach for power converters, though, and it has plenty of possibilities for commercial uses if this issue is adequately addressed.

A switching function is a mathematical function that is used to control the operation of a switching device, such as a transistor or a power electronic switch, in a power electronic circuit. The switching function is typically a pulse-width modulation (PWM) signal that determines when the switching device turns on and off. The most commonly used switching function is the rectangular waveform, which can be expressed mathematically as:

$$s(t) = A * \text{sign}\,[\sin(2\pi fsw\ t + \theta)] \quad (2)$$

where s(t) is the switching function, A is the amplitude of the waveform, fsw is the switching frequency, θ is the phase angle, and sign denotes the sign function. The sign function returns a value of +1 or -1 depending on the sign of the argument.

The switching function can be used to control the output voltage or current of a power electronic circuit, by adjusting the duty cycle of the waveform. The duty cycle is the percentage of time that the waveform is in the "on" state, and is typically adjusted using a control signal, such as a voltage or current reference.

A rectifier or voltage source inverter is what the 3 phase, two-level AC DC voltage source inverter (VSI) is [9]. It serves as the main interface for a wind turbine (WT) generator while functioning as a rectifier, transforming the WT source AC voltage to a fluctuating output DC voltage under maximum power point tracking (MPPT) monitoring. The VSI serves as the most crucial component of the adapters, which function as DC/AC converters because microgrids are typically AC microgrids. VSI connects the DC-link output of renewable energy sources (RES), the DC-link output of energy storage systems (ESS), and the microgrid. To put active and reactive power into the microgrid, it transforms DC voltage to AC voltage using the microgrid voltage and frequency.

An AC/DC converter's control goals are to follow the AC with the least amount of frequency deviation and to regulate the DC-link voltage [10]. A direct current source is converted from one voltage level to an adjustable or fixed one via a DC/DC converter. Due to irregular input voltage and sudden load variations, tremendous effort must be taken to adjust the output voltage to the appropriate value when controlling the DC/DC converter. Because its typical model is a no minimum phase system, the control design for the multilevel inverter is more challenging than that for buck adapters. Pulse-width modulation (PWM) approaches are typically employed to overcome the control issues with DC/DC converters, in which a low-frequency intended function is modulated by an external high-frequency signal. SMC is substantially simpler to install than PWM control due to the rise in the resonant speed of available commercially switching devices.

For 3-phase, 2-level grid-connected voltage source inverters as well as DC/DC buck converters, a unique observer-based control is suggested in this chapter. By forcing the input currents to follow the desired values, the suggested control approach can implicitly control the output voltage while reaching a certain power factor. The suggested method includes two control loops. The adoption of a sliding mode-based current control loop and a DC-link voltage regulation loop that comprises an extended state observer (ESO) and SMC The DC-link capacitors' linked load is regarded as interference.

Microgrids are small-scale power grids that can operate independently or in parallel with the main power grid. They typically consist of a variety of energy sources, such as solar panels, wind turbines, and batteries, and are designed to provide reliable and sustainable power to a specific area or community. Analyzing the energy efficiency and entropy balance in microgrids is important for optimizing their performance and improving their sustainability [11]. The energy efficiency, entropy balance, loss and gain is shown in equations (3-7).

The analysis of energy efficiency and entropy balance in microgrids can be done using the following equation:

$$\Delta S = \Delta S\_gen + \Delta S\_load + \Delta S\_loss \quad (3)$$

where ΔS represents the change in entropy, ΔS_gen represents the entropy generated by the energy sources, ΔS_load represents the entropy generated by the load, and ΔS_loss represents the entropy generated by energy losses.

Entropy is a measure of the disorder or randomness in a system, and it tends to increase over time due to energy conversions and dissipation. In the context of microgrids, entropy generation can be caused by a variety of factors, such as electrical resistance, heat transfer, and chemical reactions.

The entropy generated by the energy sources, ΔS_gen, is a measure of the disorder created by converting the potential energy stored in the energy sources into usable electrical energy. This entropy can be calculated using the following equation:

$$\Delta S\_gen = Q\_gen / T\_gen \quad (4)$$

where Q_gen represents the heat generated by the energy sources during the conversion process, and T_gen represents the temperature at which this heat is generated. The entropy generated by the load, ΔS_load, is a measure of the disorder created by using the electrical energy to power various devices and appliances. This entropy can be calculated using the following equation:

$$\Delta S_{load} = Q_{load} / T_{load} \quad (5)$$

where Q_{load} represents the heat generated by the load during the consumption process, and T_{load} represents the temperature at which this heat is generated.

The entropy generated by energy losses, ΔS_{loss}, is a measure of the disorder created by energy conversions that result in the loss of usable energy. This entropy can be calculated using the following equation:

$$\Delta S_{loss} = Q_{loss} / T_{loss} \quad (6)$$

where Q_{loss} represents the heat generated by energy losses during the conversion process, and T_{loss} represents the temperature at which this heat is generated.
The energy efficiency of a microgrid can be calculated using the following equation:

$$\eta = 1 - (\Delta S_{loss} / \Delta S_{gen}) \quad (7)$$

where η represents the energy efficiency of the microgrid. This equation shows that the energy efficiency of a microgrid is inversely proportional to the entropy generated by energy losses, and directly proportional to the entropy generated by the energy sources.
By analyzing the energy efficiency and entropy balance in microgrids, it is possible to identify areas where improvements can be made to increase energy efficiency and reduce entropy generation. For example, energy losses can be reduced by improving the efficiency of energy conversion processes, while entropy generated by the energy sources can be reduced by using more efficient and sustainable energy sources. Overall, this analysis can help to optimize the performance and sustainability of microgrids, and contribute to a more sustainable energy future.

The system is composed of a straightforward microgrid with three components: (1) A storage system, (2) a generating element, and (3) a consumer element. The system is made up of a battery, a load, several solar panels, and the inverter that connects them all. A set of solar cells handle the generation, while a standard DC load is used to measure the usage. Lithium-ion batteries are used for storage, and the system operates in island mode without considering a connection to the mains (Fig. 5). A DC microgrid architecture is convenient because all the components are uninterrupted. For generating, series-parallel panels are utilized in sets.

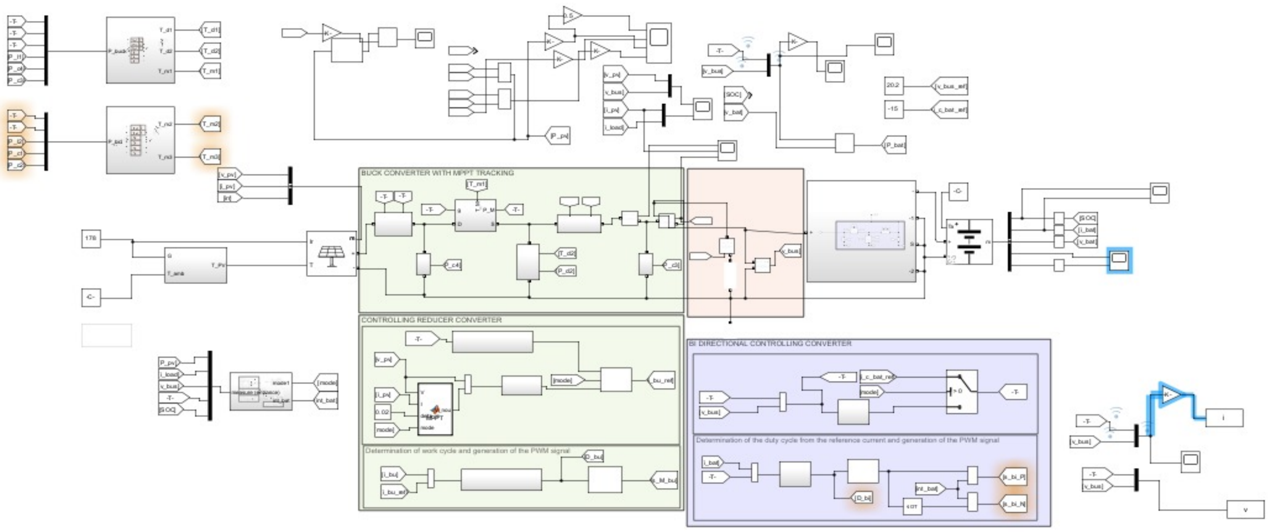

Fig. 5. MATLAB-Simlulink® schematic Components of the microgrid

In addition, a storage second converter is required to control the battery's charging and draining. Because energy must be able to travel both ways, a reversible converter without insulation is utilized. A constant voltage on the DC bus is controlled and maintained using both converters. It has a 100 kHz frequency band.

3. Control Strategy and Results

Four distinct circumstances can be identified based on these states, which are generated by the power flows between various microgrid components:

a) Ppv = Pload + Pbat

The first situation arises when the amount of power the panels produce equals the amount used by the loads and battery.The bi-directional converter controls both the battery charge and the DC bus voltage to maintain a constant value while the step-down converter operates in MPPT mode to harvest the most power feasible.

b) Ppv > Pload + Pbat

The second situation arises when there is more energy generated than is used by loads and batteries. Because the battery is charged or operating at its peak performance, it is unable to fully absorb the surplus energy in this situation. The value of consumption and generation must always be constant to keep the system stable. Because of this, the generated power in this scenario needs to be decreased.

c) Ppv + Pbat = Pload

The third happens when both the batteries and the panels are used to power the load. Here, photovoltaic power is insufficient to completely meet usage, and the battery will make up the difference. Like the first instance, the step-down converter will implement MPPT while the bi-directional one will control the bus voltage. Although, in this instance, the battery is supplied, thus your converter operates in drain mode.

d) Ppv + Pbat < Pload

The fourth scenario is when neither the battery nor the panel can meet the whole demand. The 2 converters are separated by disconnecting themselves from the bus because it is impossible in this situation to preserve the nominal functionality of the system and to prevent potential damage to it.

A. *Photovoltaic Panels*

Since the simulation does not account for its dynamic behavior, the simulation results in a continual entropy generation. Due to this, just this generation's variation concerning the surrounding temperature is displayed. The two factors are displayed combined in Fig 6 to clearly illustrate their connection to performance.

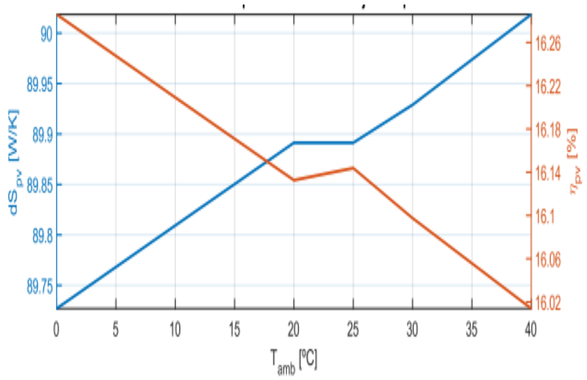

Fig. 6. Generation of entropy and efficiency of the panels depending on the ambient temperature

It has been found that the two ideas have a proportionally inverse connection, with the system's efficiency decreasing as entropy production increases. The behavior is like losses in that, essentially, the higher the temperature, the greater the entropy production and, thus, the lower the value. At 25 ºC, there is a reduction in wastes and, as a result, in the creation of entropy, contradicting this fact in the moderate ambient temperature.

As for the battery, the reverse situation occurs. A decrease in the ambient temperature results in an increase in the generation of entropy. This increase, as happens with losses, is significantly greater at lower temperatures. On the other hand, the variation between 10 and 40 ºC is relatively constant. The generation of entropy does not reach a constant state but keeps increasing throughout the simulation as seen in Fig 7. Most likely this fact is due to the fact that both the temperature and the losses also remain in the transient state. This regulation of the bus voltage is carried out based on the battery charge. This fact can be verified by taking into account the negative direction of its current and the increase of its voltage.

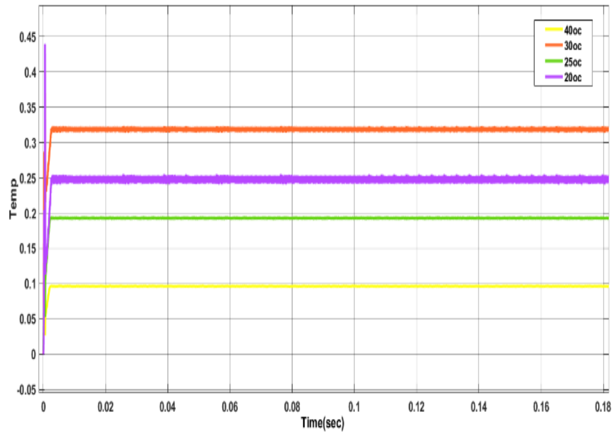

Fig. 7. Generation of entropy in the battery depending on the ambient temperature

In this scenario, the behavior of the system is simulated when it has no consumption for part of the load, the generation being transferred to the battery.

4. Discussion

The simulation findings are analyzed and pertinent conclusions are drawn in this section. Since the bus voltage is related to the change in operating mode, the control system does not respond until its value exceeds predetermined thresholds. As a result, there will always be a voltage variance before the mode change. Reducing this voltage limit interval and reducing the fluctuation before the transition is smaller are two options to lessen this behavior. An excessive amount of this drop, however, could lead the control system to incorrectly determine that a mode change is required. This is because the bus voltage is likely to oscillate or vary at particular times.

Moreover, the type of setting has a direct impact on the solar panels' effectiveness. This fact results from the necessity of reducing energy production when the system is unable to fully absorb it. In this view, the lowest energy utilization occurs when there is no load and all solar generation is absorbed by the battery.

Therefore, it is recommended to always sustain a level of consumption that is equal to the highest generation feasible, especially during periods of higher irradiance. The so-called load shifting method is one employed in this kind of circumstance [12]. This uses the adaptability of specific load types to feed them during these times of surplus. The drawback is the requirement for an additional control system. Concerning the subsection on losses, we may identify two utterly opposed patterns of behavior in the microgrid's components. At higher working temperatures, both the display and the transducers lose more energy.

To evaluate this system's effectiveness to other systems, one may look at the overall entropy it generated. We can see that according to the temperature, not every element's effectiveness is impacted by the same amount. The least variable is photovoltaic panels, which saw a 0.24 % reduction in production from 0 to 40 ºC. The discrepancy in adapters, which is 0.8 and 1.8 % for step-down and bilateral adapters, correspondingly, is significant. The difference between the two figures may be due to the difference in the use of diodes between them. This experience decreased transmission losses as the temperature rises. This information could therefore be used to offset the step-down converter's increased total losses at elevated temperatures. The battery is the element that suffers the most variation, with a loss of 3.08 %. Fuzzy data preprocessing is a useful tool for handling uncertainties and imprecisions in data, which are common in many engineering applications. The approach proposed by Wang et al. (2008) utilizes fuzzy set theory and principal component analysis to transform the original data into a fuzzy representation, which can then be used for further analysis. This approach has been shown to be effective in reducing the impact of uncertainties on the results of data analysis and can be applied to a wide range of applications in engineering and other fields. The paper provides a detailed explanation of the methodology and presents several case studies to demonstrate its effectiveness [12].

5. Conclusion

The establishment of a microgrid model is presented in this study, with the examination of its energy efficiency serving as the primary goal. The inefficiencies that occur in the various system components must be identified to complete this study. These are also affected by their thermal behavior at the same time. This finding led to the division of the model into three categories: thermal, loss, and electric. In the first, the system's electrical activity and control are simulated. The conclusions are utilized to establish the losses that the thermally model relies on to compute temperatures. A battery, a direct current load, and a set of solar panels make up the microgrid that will be analyzed.

Two converters —one buck and another one bidirectional— jointly connect the various components. There are two ways used to perform the efficiency analysis. The computed difference between each element's consumed and useable power is done according to conventional methods. The findings demonstrate that both notions have an inverse connection, with the least efficient systems having higher entropy generation. As a result, the idea of entropy creation can be used to contrast the energy effectiveness of various systems. The collection of solar panels in this case study produces the most entropy. The bidirectional converter has the largest generation out of the three, nearly double the reducer. In all of the simulations, the battery is the component that produces the least entropy.

Several simulations have been run by varying this parameter, resulting in various behaviors of the microgrid's components, to investigate the impact of variations in the ambient temperature on the system. Greater temperatures result in increased losses for both panels and converters. In both situations, the variation in entropy generation is relatively minimal. However, by raising its temperature, the battery lowers its losses, and the fluctuation in entropy generation has a significant impact. In terms of achieving the objectives outlined in this work, it is believed that the model developed can accurately simulate the electrical behavior of the network.

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