ЗЕМАК

ЗДРУЖЕНИЕ НА ЕНЕРГЕТИЧАРИТЕ НА МАКЕДОНИЈА

MACEDONIAN ENERGY ASSOCIATION - ZEMAK

Зборник на трудови

Conference proceedings

МЕЃУНАРОДНА КОНФЕРЕНЦИЈА „ЕНЕРГЕТИКА 2024"

INTERNATIONAL CONFERENCE "ENERGETICS 2024"

СТРУГА
02 - 04 Октомври, 2024г.

STRUGA
02 - 04 October, 2024

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Издавач/Publisher:

ЗДРУЖЕНИЕ НА ЕНЕРГЕТИЧАРИТЕ НА МАКЕДОНИЈА
ул. Даме Груев бр.14а, 1000 Скопје
MACEDONIAN ENERGY ASSOCIATION
st. Dame Gruev no.14a, 1000 Skopje

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Тех. уредник/Technical Editor:
Крешимир Манојловски/*Kreshimir Manojlovski*

Печати/Print:
„2-ри Август" - Штип"/*"2nd August" - Shtip*
Место и година на издавање/Place and year of issue: **Скопје/Skopje, 2025**
Тираж: 50 примероци

CIP - Каталогизација во публикација
Национална и универзитетска библиотека "Св. Климент Охридски", Скопје
620.9(062)

МЕЃУНАРОДНА конференција "Енергетика 2024" (2024 ; Струга)
Зборник на реферати / Меѓународна конференција "Енергетика 2024", Струга, 02-04 октомври 2024 ; [уредници: Невенка Китева-Роглева, Вангел Фуштиќ, Софија Николова-Поцева] = Conference proceedings / International Conference "Energetics 2024", Struga, 02-04 October, 2024 ; [editors: Nevenka Kiteva-Rogleva, Vangel Fustik, Sofija Nikolova-Poceva]. - Скопје : Здружение на енергетичарите на Македонија - ЗЕМАК =Skopje : Macedonian Energy Association - ZEMAK, 2025 (Штип : 2-ри Август). - 372 стр. : илустр. ; 25 см

Дел од трудовите се на англиски јазик. - Библиографија кон трудовите
ISBN 978-608-4764-15-1
а) Енергетика – Собири
COBISS.MK-ID 65501957

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2. ПРЕНОСНИ И ДИСТРИБУТИВНИ ЕНЕРГЕТСКИ СИСТЕМИ

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ЦЕЛИ НА КОНФЕРЕНЦИЈАТА

Главна цел на конференцијата беше да обезбеди можност за демократска и стручна презентација на: искуства, важни информации, професионални постигнувања и истражување на експертите и професионалците од областа на енергетиката. Поканети беа релевантни енергетски компании, претставници од индус¬тријата, истражувачките центри, универзи¬тетите и останати субјекти, како и експерти од земјата и странство. Конференцијата претставуваше форум за споделување и размена на искуства и планови на локално, регионално и глобално ниво.

Според тематските области, на конференцијата беа презентирани и дискутирани предизвиците со кои се соочува енергетскиот сектор, особено компаниите, инвеститорите и корисниците. Со планираните дискусии и реферати се овозможи реална можност за идентификација на соодветните механизми и активности со цел надминување на проблемите во земјата и регионот, како и зајакнување на меѓусебната соработката.

СЕРТИФИКАТИ ЗА УСПЕШНО УЧЕСТВО

На конференцијата се одвиваа паралелно презентациски и постер сесии. Трудовите беа рецензирани од страна на Меѓународниот програмски одбор и категоризирани во три категории: Информација, Стручен труд и Научен труд. За секој рецензиран и презентиран труд (без оглед на категоријата) Програмскиот одбор издаде Сертификат за успешно учество на конференцијата. Посебно беа охрабрени да земат активно учество младите истражувачи и студентите на сите три циклуси студии (додипломски, постдипломски и докторски студии), млади професионалци и истражувачи.

4. ОДРЖЛИВ ЕНЕРГЕТСКИ РАЗВОЈ И ЗАШТИТА НА ЖИВОТНАТА СРЕДИНА

Зборник на трудови ЕНЕРГЕТИКА 2024

Proceedings of the International Conference ENERGETICS 2024
October 02 - 04, Struga

Научен труд/Scientific Paper

Application of Matlab/SIMULINK to Analysis of Photovoltaic System with Batteries

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Abstract

Electricity production from renewable sources is increasing day by day. Photovoltaic plants, wind plants, small hydro plants, biomass energy, fuel cells, etc. are mostly used for this production. Since electricity production from renewable sources is variable depending on weather conditions, and in order to ensure greater consistency in electricity production, there is a possibility of combining two or more sources. The analysis of such systems is specific and more complex in relation to the analysis of individual renewable energy systems, which is why appropriate computer methods and systems are often used for their simulation and analysis.

In this paper, a simulation of a photovoltaic system using batteries to store part of the produced electricity is given using the computer program Matlab/SIMULINK. Apart from the simulation of this system, the paper also provides an analysis of the basic parameters and operating characteristics of the system, primarily the electricity produced, stored and delivered to consumers, the changes in the current, voltage and power of the system depending on the operating mode and conditions on the system.

Keywords: Matlab, Simulink, photovoltaic panels, batteries, solar radiation intensity, ambient temperature.

1. INTRODUCTION TO MATLAB/SIMULINK

MATLAB is a highly structured programming language for engineering and technical applications. It incorporates computation, visualization, and programming within an easy-to-use environment where problems and solutions are represented in familiar and accessible mathematical notation. Typical uses of the MATLAB software package include:

- Elementary mathematics and computation;
- Linear algebra;
- Algorithm development;
- Modeling, simulation, and prototyping;
- Data analysis, research, and visual presentation;
- Scientific and engineering graphs and charts;
- Application development, including Graphical User Interface development.

2. SIMULINK/SIMSCAPE MODEL OF A PHOTOVOLTAIC PANEL AND BATTERY

Usually photovoltaic systems are modeled using a specific type of equivalent circuit. Each photovoltaic model is based on the behavior of a semiconductor diode, which gives the solar cell an exponential characteristic.

In Simulink, solar cells can be modeled with three modeling systems. The first possibility for modeling includes instruments with which any differential equations or algebraic relation of a highly complex mathematical model can be implemented. The second possibility is provided by Simscape™, which allows direct modeling using physical components of the electrical circuit (resistors, capacitors, diodes) to implement the same mathematical equation.

Modeling much more complex systems than the previous methods is done using the Simscape Electrical library, which contains a block called "PV Array" and a block called "Battery".

Simscape Electrical provides component libraries for modeling and simulating electronic, mechatronic and electrical power systems. It includes models of semiconductors, motors and components for applications such as electromechanical actuation, smart grids and renewable energy systems. One can use these components to evaluate analog circuit architectures, develop mechatronic systems with electrical drives, and analyze the generation, conversion, transmission, and consumption of electrical energy at the grid level.

Simscape Electrical helps develop control systems and test system-level performance. One can parameterize models using MATLAB variables and expressions and design control systems for electrical systems in Simulink. Mechanical, hydraulic, thermal and other physical systems can be integrated into the model using components from the Simscape product family. For deploying models to other simulation environments, Simscape Electrical supports C-code generation.

2.1. Block „PV Array"

The PV Array block implements an array of photovoltaic (PV) modules. The array is built of strings of modules connected in parallel, each string consisting of modules connected in series. This block allows you to model preset PV modules from the National Renewable Energy Laboratory (NREL) System Advisor Model (2018) as well as PV modules that you define.

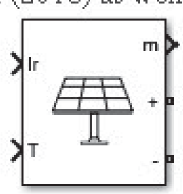

Figure 1 - Block „PV Array"

The PV Array block is a five-parameter model using a light-generated current source (I_L), diode, series resistance (Rs), and shunt resistance (Rsh) to represent the irradiance- and temperature-dependent I-V characteristics of the modules.

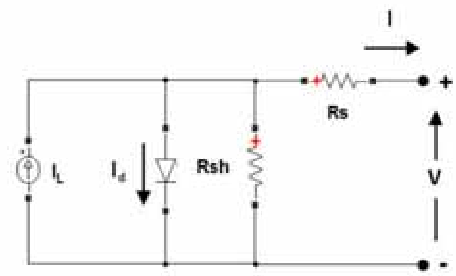

Figure 2 – Equivalent circuit of a photovoltaic panel

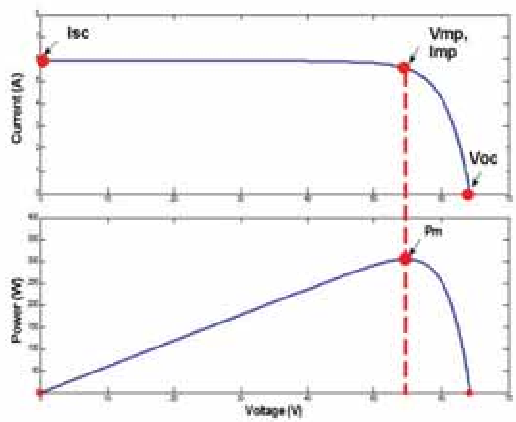

Figure 3 – I-V characteristic of a photovoltaic panel

The I-V characteristic for a unit module is defined by the equations:

$$I_d = I_0 \cdot \left(e^{\frac{V_d}{V_T}} - 1\right) \qquad (1)$$

$$V_T = kTq \cdot nI \cdot N_{cell} \qquad (2)$$

where:

I_d - Diode current (A);

V_d - Diode voltage (V);

I_0 - Diode saturation current (A);

nI - Diode ideality factor, a number close to 1;

k - Boltzman constant = 1.3806e^{-23} (J/K);

q - Electron charge = 1.6022e^{-19} (C);

T - Cell temperature (K);

N_{cell} - Number of cells connected in series in a module.

The block „PV Array"consists of the following ports:

Ir — Control signal defining that irradiance applied to solar panels, specified as a scalar in the range [0, 1000], in W/m^2.

T — Control signal defining temperature of cells, specified as a scalar, in degrees Celsius. The input can be a finite negative, zero, or positive value.

m — Measurements, returned as a five-element vector. You can select these signals using the Bus Selector block in the Simulink® library.

+ — Specialized electrical conserving port associated with the positive terminal of the PV array.

- — Specialized electrical conserving port associated with the negative terminal of the PV array.

2.2. Block „Battery"

The Battery block implements a generic dynamic model that represents most popular types of rechargeable batteries.

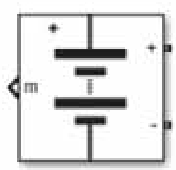

Figure 4 – Block „Battery"

This figure shows the equivalent circuit that the block models.

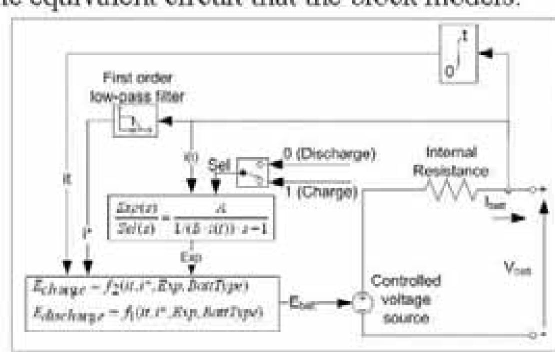

Figure 5 – Equivalent circuit

The circuit parameters can be modified to represent a specific battery type and its discharge characteristics. A typical discharge curve consists of three sections. The first section represents the exponential voltage drop when the battery is charged. The width of the drop depends on the battery type. The second section represents the charge that can be extracted from the battery until the voltage drops below the battery nominal voltage. Finally, the third section represents the total discharge of the battery, when the voltage drops rapidly.

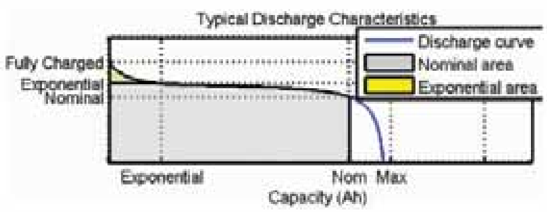

Figure 6 – Typical battery discharge curve

When the battery current is negative, the battery recharges, following a charge characteristic.

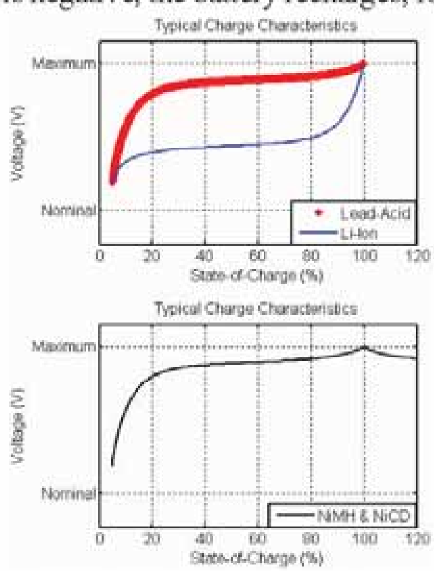

Figure 7 – Typical battery charge curve

The model parameters are derived from the discharge characteristics. The discharging and charging characteristics are assumed to be the same.

The Exp(s) transfer function represents the hysteresis phenomenon for the lead-acid, nickel-cadmium (NiCD), and nickel-metal hydride (NiMH) batteries during the charge and discharge cycles. The exponential voltage increases when a battery is charging, regardless of the battery's state of charge. When the battery is discharging, the exponential voltage decreases immediately.

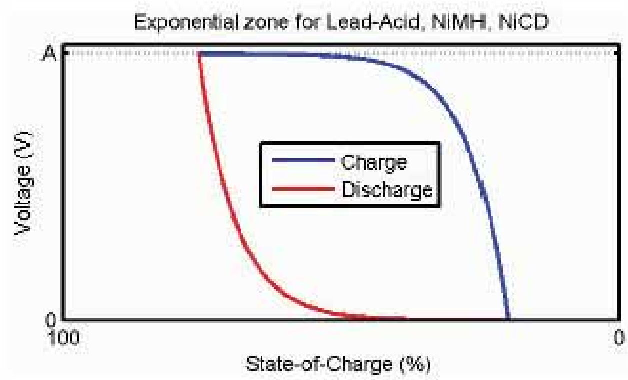

Figure 8 – Exponential battery charging and discharging characteristic

The state of charge (SOC) for a battery is a measure of battery's charge, expressed as a percent of the full charge. The depth of discharge (DOD) is the numerical complement of the SOC, such that $DOD = 100\% - SOC$.

For example, if the SOC is:

- 100% — The battery is fully charged and the DOD is 0%.
- 75% — The battery is 3/4 charged and the DOD is 25%.
- 50% — The battery is 1/2 charged and the DOD is 50%.
- 0% — The battery is has 0 charge and the DOD is 100%.

Limitations

- The minimum no-load battery voltage is 0 V and the maximum battery voltage is equal to $2 \times E_0$.
- The minimum capacity of the battery is 0 Ah and the maximum capacity is Q_{max}.

Assumptions

- The internal resistance is assumed to be constant during the charge and discharge cycles and does not vary with the amplitude of the current.
- The parameters of the model are derived from the discharge characteristics. The discharging and charging characteristics are assumed to be the same.
- The capacity of the battery does not change with the amplitude of the current (there is no Peukert effect).
- The self-discharge of the battery is not represented. It can be represented by adding a large resistance in parallel with the battery terminals.
- The battery has no memory effect.

The "Battery" block consists of the following ports:
Ta — Ambient Temperature, Ambient temperature input port. To activate it, select the type „Lithium-Ion" and select „Simulate temperature effects".
m — Output vector of signals for the battery temperature, state-of-charge, current and voltage. To demultiplex the signals, you can use a Bus Selector block.
+ — Specialized electrical conserving port associated with the battery's positive terminal.
- — Specialized electrical conserving port associated with the battery's negative terminal.

3. MATLAB/SIMULINK SIMULATION OF A PHOTOVOLTAIC SYSTEM WITH A BATTERY

In order to show the practical application of Matlab/SIMULINK systems in the field of renewable energy sources, this paper will present a simulation of a photovoltaic power plant with a battery system. The simulations were made in Matlab/SIMULINK software. Figure 9 shows the Matlab/Simulink model of a photovoltaic system with a battery.

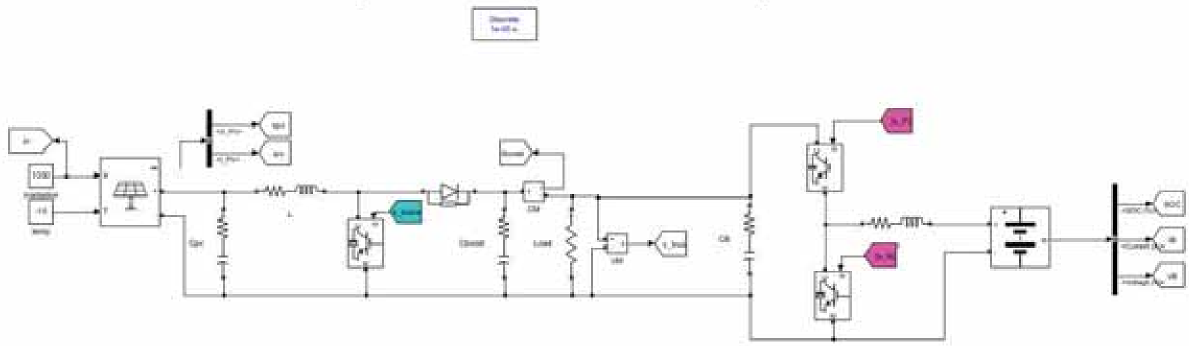

Figure 9 – Matlab/Simulink model of a photovoltaic system

This Matlab/Simulink model controls and manages the parameters for electricity production from a photovoltaic system. From the "PV Array" block, we select that our photovoltaic system is built from photovoltaic panels of the JA Solar, type JAM72S01-360/PR, which consists of 3 parallel strings connected in series with 4 photovoltaic panels each.

From the "Battery" block, we select the battery type to be Lithium-ion with a nominal voltage of 24V and a capacity of 220Ah.

In addition to the "PV Array" and "Battery" blocks, the following blocks are also used:

- **Powergui** - Allows you to select one of the following methods for solving the circuit: Continuous (uses a variable-step solver from Simulink), Discretization of the electrical system for a solution in fixed time steps, Continuous or discrete phasor solution.
- **Constant** - Generates a real or complex signal with a constant value. This block is used to provide a constant signal input. The block generates a scalar, vector, or matrix output.
- **Bus Selector** - Extracts the selected elements by name from the input bus hierarchy. The block can output the selected elements individually or to a new virtual bus. When the block displays the selected elements separately, each selected element corresponds to an output port. When a block provides a new virtual bus, the block has one output port for the virtual bus that contains each selected element.
- **Goto and From** – A Goto block passes its input to the corresponding From blocks. The input can be a signal or a real or complex-valued vector of any data type. The From and Goto blocks allow you to pass a signal from one block to another without actually connecting them. A Goto block can pass its input signal to more than one From block, although a From block can only receive a signal from one Goto block. The input to that Goto block is passed to the From blocks connected to it as if the blocks were physically connected.

➢ **Diode** – A diode is a semiconductor device that is controlled by its own voltage Vak and current Iak. When a diode is forward biased (Vak > 0), it begins to conduct with a small forward voltage Vf across it. It turns off when the current flow in the device becomes 0. When the diode is reverse biased (Vak < 0), it remains in the off state.

➢ **Current Measurement** - The Current Measurement block measures the instantaneous current flowing in any electrical block or connection line. The signal output provides a signal that can be used by other Simulink blocks.

➢ **Voltage Measurement** - measures the instantaneous voltage between two electrical nodes. The signal output provides a signal that can be used by other Simulink blocks.

➢ **Scope** - Visually displays signals

➢ **PWM Generator (DC-DC)** - The pulse width modulation technique controls the transfer of energy from one electrical component to another by quickly switching between full energy transfer and no energy transfer.

➢ **MATLAB Function** - Allows you to define your own function in Simulink models using MATLAB.

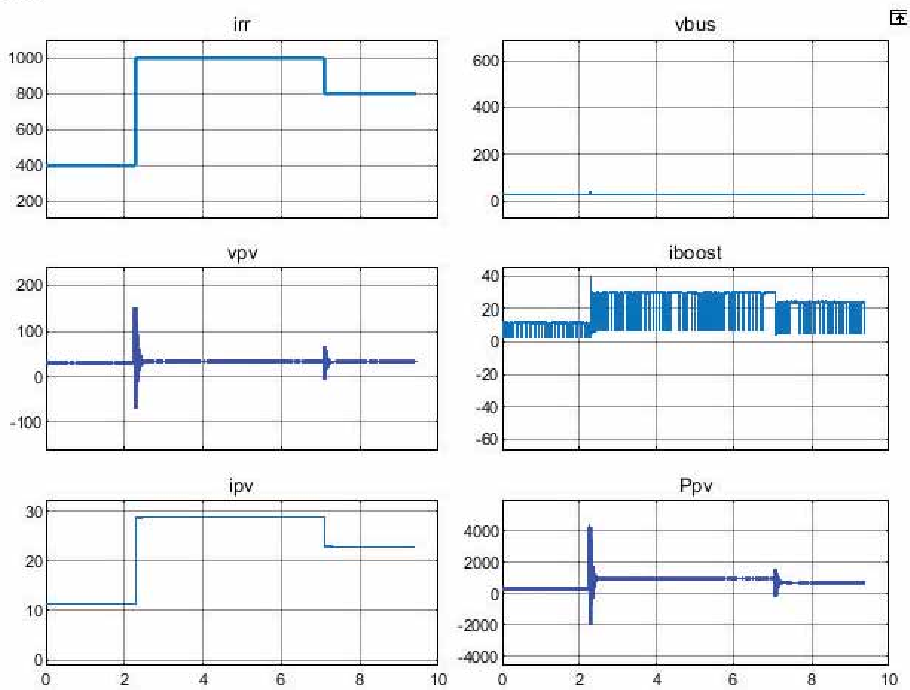

Figure 10

The simulation results in Figure 10 were made by changing the solar radiation intensity from 400 W/m^2, then 1000 W/m^2 and finally 800 W/m^2 at a consumer resistance of 100Ω. The ambient temperature is -15°C. When changing the ambient temperature from -15°C to 70°C, we obtain the results given in Figure 11.

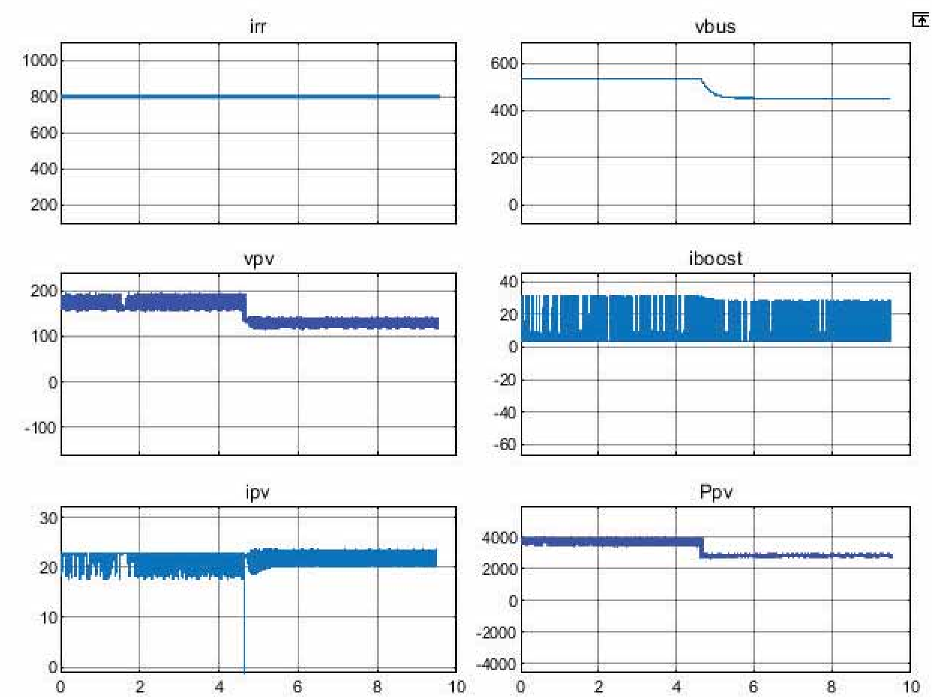

Figure 11

The simulation results in Figure 12 were made by changing the solar radiation intensity from 1000 W/m^2, then 200 W/m^2 and finally 0 W/m^2 at a consumer resistance of 6Ω. The ambient temperature is -15°C.

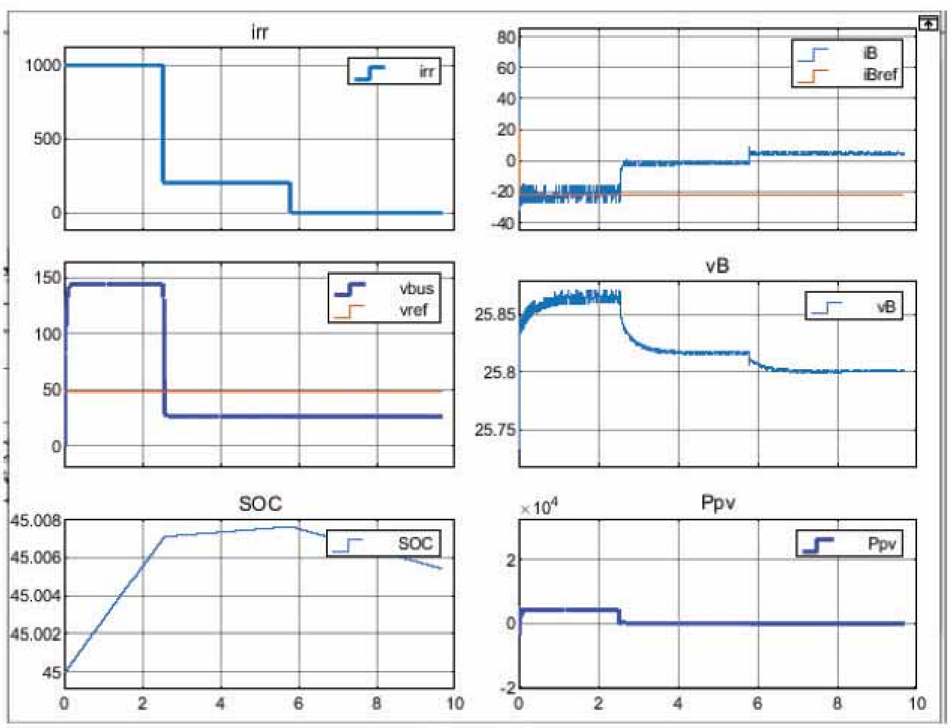

Figure 12

4. CONCLUSION

Simulink is a software module for modeling, simulating, and analyzing dynamic systems. It supports linear and nonlinear systems, continuous-time models, discrete-time models, or any hybrid of the two. In Simulink, systems are drawn on the screen as block diagrams. A wide variety of block diagrams are possible, such as transfer functions, summators, and virtual input and output elements such as function generators and oscilloscopes. Simulink provides a graphical user interface (GUI) for system modeling in a drag-and-drop environment. Simscape Electrical helps develop control systems and test system-level performance. You can parameterize models using MATLAB variables and expressions, and design control systems for electrical systems in Simulink. You can integrate mechanical, hydraulic, thermal, and other physical systems into the model using components from the Simscape product family.

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