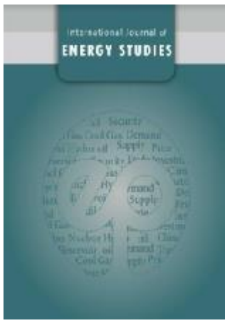
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article

Int J Energy Studies, 2020;5(2):107-131

Received: 27 July 2020
Revised: 22 Oct 2020
Accepted: 26 Oct 2020

The Impact of Supercapacitor on a DC Machine Operation in Stand-Alone Photovoltaic System with a Hybrid Battery-Supercapacitor Storage System

Yvon Gotran Koyi-Boukila [a,*], Muhammed Fahri Unlersen [b]

[a] *Department of Electrical and Electronics Engineering, Faculty of Engineering and Architecture, Necmettin Erbakan University, 42090, Konya, Turkey, 0000-0003-2534-7134*

[b] *Department of Electrical and Electronics Engineering, Faculty of Engineering and Architecture, Necmettin Erbakan University, 42090, Konya, Turkey, 0000-0001-7850-6712*

*(*Corresponding Author:koyiyvon92@gmail.com)*

Highlights

- Energy storage at an insulated grid location becomes an important element to ensure the production of energy continues.
- The concept of energy storage ensures the resources management properly.
- The hybrid storage system with a supercapacitor in a solar energy system reduces the battery deep discharges and its stress at least 15%.

You can cite this article as: Koyi-Boukila, Y. G, Unlersen, M. F. "The Impact of Supercapacitor on a DC Machine Operation in Stand-Alone Photovoltaic System with a Hybrid Battery-Supercapacitor Storage System", *International Journal of Energy Studies* 2020;5(2):107-131.

ABSTRACT

In this study, a hybrid battery-ultracapacitor storage system of a stand-alone photovoltaic energy system with a DC machine was examined. The effects of an ultracapacitor in the operation of a DC machine in a system powered by a stand-alone photovoltaic energy system were duly investigated in the study. In this context, the permanent production of the necessary energy for its operation is generated by the hybrid battery-supercapacitor storage system. Firstly, the operation of the DC machine is observed when the charge of the battery and the nominal voltage of the supercapacitor is zero. After that, the operation of the DC machine is observed when the charge of the battery is zero, while the nominal voltage of the supercapacitor is greater than zero. Finally, the operation of the DC machine is observed when the charge of the battery and the nominal voltage of the supercapacitor are greater than zero. Our results were obtained by simulation to confirm the contribution of the supercapacitor's performance and its advantages to the global system. The simulation circuit is attached, and the supercapacitor's contribution is extensively discussed in the main text.

Keywords: Photovoltaic Energy, Supercapacitor, Battery, DC Machine, Hybrid Energy Storage

1. INTRODUCTION

A survey of the literature on recent studies has shown that the main purpose of most of the studies is centered on how to reduce global greenhouse gas emissions caused by fossil energy sources. The solar energy system can be a suitable alternative for fossil energy sources. The concept of energy storage is considered important to ensure that available resources are managed appropriately.

When solar energy production is zero, energy storage at an insulated grid location becomes an important element as far as the sustainability of energy production is concerned. For example, in the case of a solar panel in the absence of sunlight, the storage of renewable resources is necessary to ensure power sustainability in areas with high fluctuation in production to ensure better management of the grid[1][2].

In 2014, solar energy production has grown eight times bigger than it used in 2009 from 20.4GW to 177GW. Thus is representing approximately 1% of the production of global electricity [3]. In Europe for example, to be precise in France, people buy the electricity produced from photovoltaic systems for 0.10€/kWh and while electricity companies sell at 0.60€/kWh. Looking at the high difference in prices, it is therefore important to encourage the public to install Photovoltaic (PV) systems. Also, some systems are connected to the normal grid by a solar inverter that is actually made up of a DC-DC converter (Boost) for maximum power point tracking. Hybrid Energy Storage System (HESS) which is advanced in energy storage systems with a lower installation cost is an efficient and economical solution. And batteries are used to ensure the autonomy of the system [3]. Inappropriate selection of battery size will increase the size of our system. Supercapacitors should therefore be used to support the batteries to meet the global energy demand of systems in power phases[4]. The addition of the supercapacitor (SC) to the hybrid system allows the storage system to compensate for the fluctuations due to the variation in the irradiation undergone by the PV. Hence, the contribution of SCs with a high power capacity is to balance the fast fluctuations due to the sun, while the battery is useful to balance the fluctuations of the solar panels in the long term[5].

In this study, we set up a photovoltaic system that has a hybrid storage system associated with batteries, supercapacitors, and a DC Machine. The diagram has the peculiarity that follows the output characteristics of the PV, the boost converter, the hybrid storage system (battery and supercapacitor), and the DC Machine associated with a Maximum Power Point Tracking (MPPT) algorithm to extract the maximum power points of our solar panel. The experiment was carried out and a comparison to a photovoltaic system was made using batteries and supercapacitors as energy storage. Also, a hybrid storage system with certain characteristics of the battery and the supercapacitor were used. To evaluate our system, simulations were carried out with MATLAB/Simulink environment.

2. PV ARRAY and MODEL ARCHITECTURES

- **PV model**

These solar panels consist of several modules; the modules are composed of cells that are in series or in parallel to provide a voltage and current. Solar cells transform light energy into electrical energy.

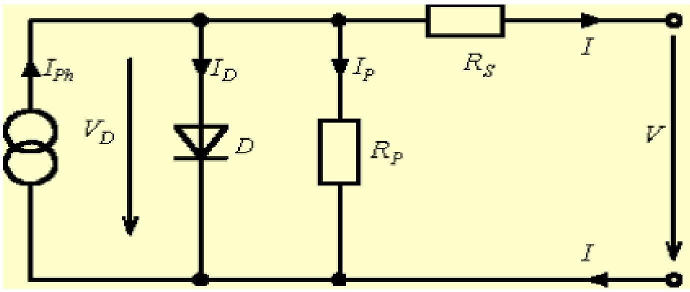


Figure 1. Photovoltaic cell diagram

The equivalence of the model of the circuit of a solar panel can be represented in Figure 1. It consists of an ideal source producing a current I_{Ph}, proportional to the irradiation and it is in parallel with a diode D. The shunt resistance R_P represents the effect of current leakage. The model, therefore, contains a current source I_{Ph} (represents the irradiation photocurrent), a series resistance Rs (the internal resistance of each cell), and a diode. The net output current of the solar cell is the difference between the photocurrent Iph, Ip, and the current I_D of the diode as described by the following[6]:

$$I = Iph - I_D - Ip \tag{1}$$

$$Iph = I_{ph-T1}\big(1 + K_0(T - T_1)\big) \tag{2}$$

$$Ip = \frac{V_D}{R_P} = \frac{V + I.R_S}{R_p} \tag{3}$$

$$I_D = Is\left(\exp\left(\frac{V_D}{V_T}\right) - 1\right) \tag{4}$$

Finally:

$$I = Iph - Is * \left(\exp\left(\frac{V + I.R_S}{m.V_t}\right) - 1\right) - \frac{V + I.R_S}{R_p} \tag{5}$$

Where

$\boldsymbol{I_{Ph\_T1}}$ = current proportional both to short circuit at temperature $\boldsymbol{T_1}$ and the ratio between irradiance at $\boldsymbol{T_0}$ and nominal irradiance

$\boldsymbol{K_0}$ = coefficient of dependence on temperature

$\boldsymbol{I_S}$ = cell reverse saturation current

$\boldsymbol{V_T}$ **= kT/q**

K = Boltzmann's Constant (1.380649×10^{-23} J · K^{-1})

T = temperature

Q = electric charge

- **The topology of the proposed MPPT algorithm**

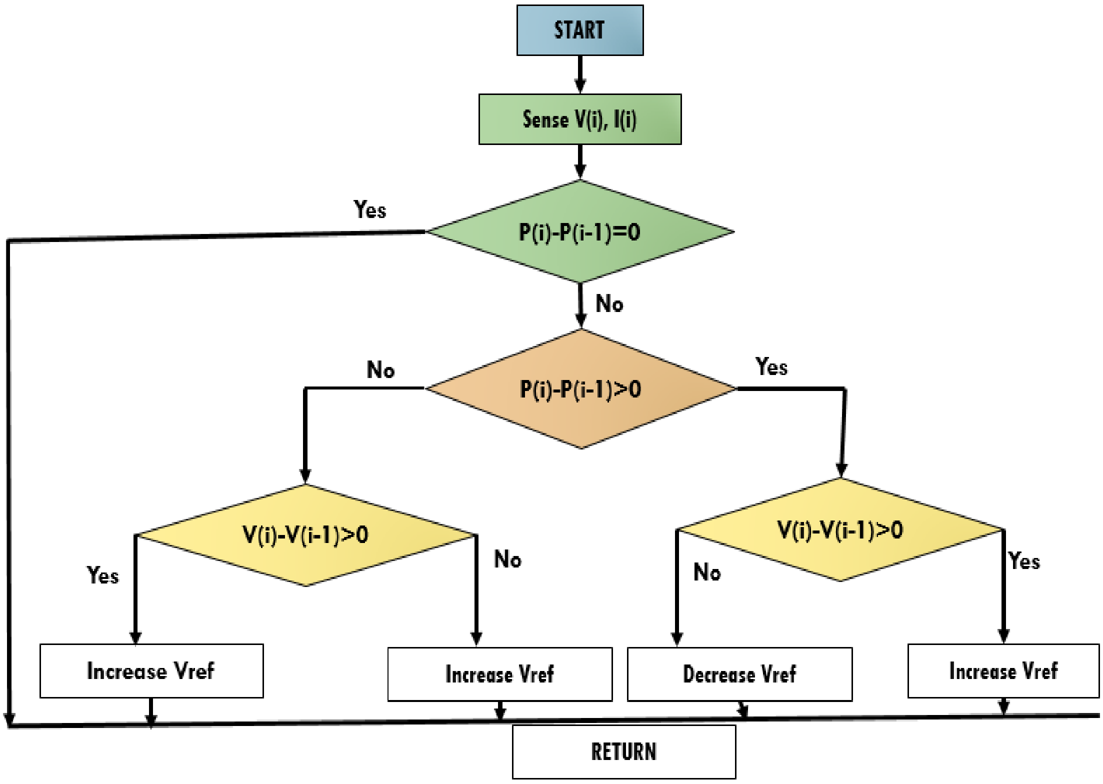


Figure 2. MPPT Algorithm model

Repel from Matlab/Simulink Library, the proposed algorithm optimally utilizes the charge of the supercapacitor which requires a power flow controller between the two energy storage systems (SC and battery). Battery stresses are definitely minimized. Therefore, the flow of power through the supercapacitor is controlled by the pulse-width modulation (PWM).

- **Battery Model**

The batteries have very high power, energy density, and a long-life cycle. The total number of charge-discharge cycles or life cycle is highly dependent on the depth of discharge. After 200 to 1000 charge/discharge cycles, which can take around 4 to 5 years, the batteries lose a large part of their energy efficiency, thus reducing their lifespan[7].

The introduction of electrochemical batteries in solar energy storage systems is very important, especially lead-acid technology which is the most suitable. This is because it requires less maintenance and its cost is very low[4]. An RC configuration was made for our lead-acid batteries as an equivalent circuit model and illustrated in Figure3.

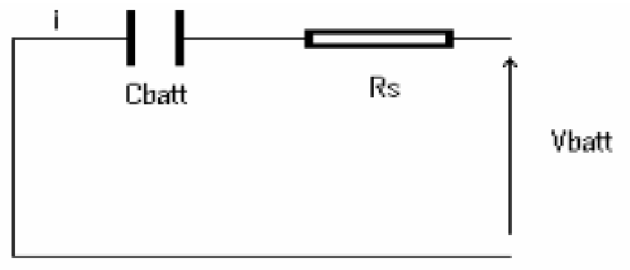


Figure 3. Lead-acid battery equivalent model

- **Supercapacitor model**

Supercapacitors are electrical storage devices made up of two identical electrodes, generally separated by an electrolyte. Unlike rechargeable batteries or accumulators, supercapacitors have a very high energy density of around 65kW/kg with 95% energy efficiency[8].

The electrical response of supercapacitors is similar to that of a normal capacitor: it can provide large current densities in a short time (high power). In an equivalent volume, they store 20 to 50 times less electrical energy than accumulators, but about 100 times more than other normal capacitors[7]. Figure 4 shows the equivalent circuit model predictions with measurements.

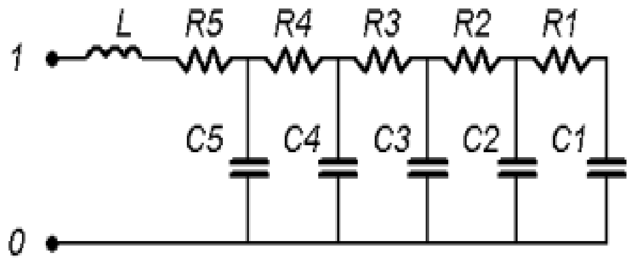


Figure 4. Supercapacitor equivalent model

- **The boost converter model**

A DC/DC boost converter connected to the battery and the supercapacitor gives us a lot of advantages.

i) The voltage of the supercapacitor can be different from that of the battery, this allows us a lot of freedom concept to the design of the battery and the supercapacitor.

ii) The output power can be much greater than the power source and the limit of the current of the battery.

iii) The voltage across the *V_OUT* can be kept relatively constant with a lower fluctuation than that of the source *V_IN*.

iv) Improving efficiency could be possible because the battery operates with lower currents which are generally lower losses, but the problem is the efficiency of the DC/DC converter.

v) The DC/DC boost converter can also be a battery charger or a controller[9].

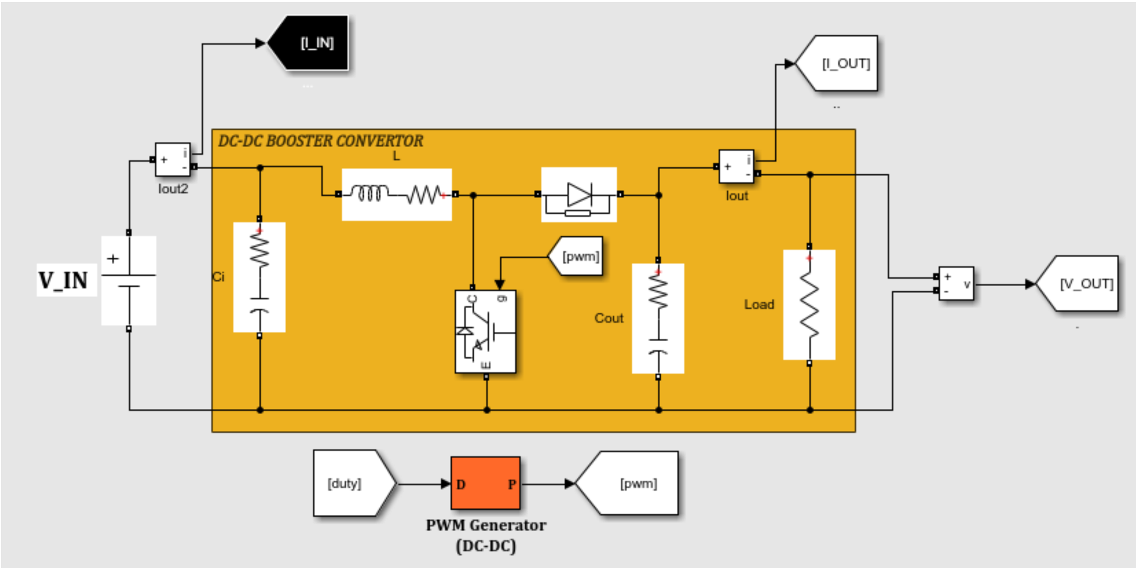


Figure 5. DC/DC Boost converter

3. SYSTEM DESCRIPTION and MODELING

Using a hybrid energy storage system with a supercapacitor and a battery is presented in Figure 6, which gives us a possibility to reduce the size of the battery, and a high State of Charge (SOC) can be maintained for a long time. The high-power density of the supercapacitor over that of the battery allows the supercapacitor to provide more power over a very short period of time. The battery also has a much higher energy density compared to that of a supercapacitor, and this allows it to store more energy and also releases it in a significant period of time. In Table 2 the battery and the supercapacitor are compared from various angles. In the proposed hybrid system, the fast peak power requirements of the DC machine are met by the supercapacitor and when powered, the battery ensures the continuous production of the power requirements [6], [10].

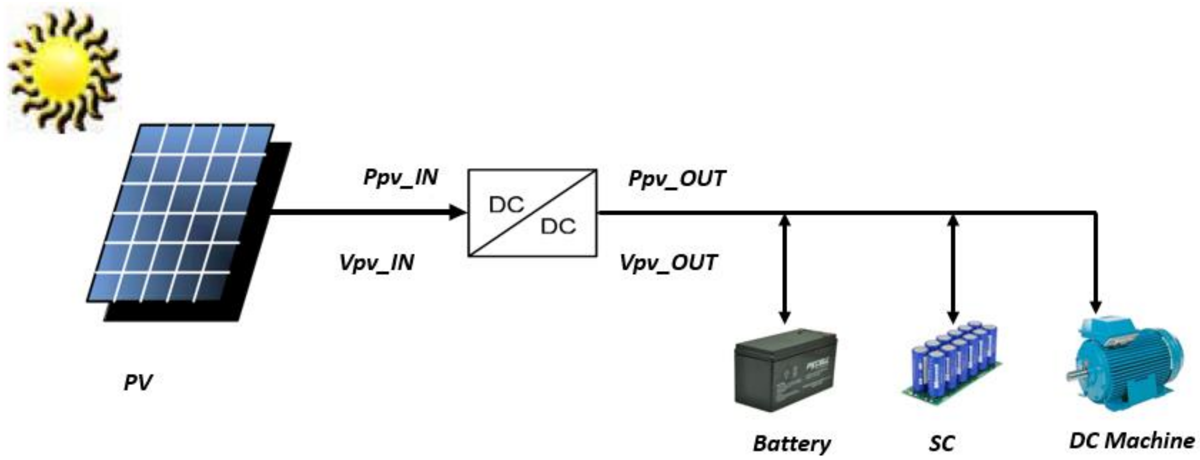


Figure 6. Photovoltaic system studied

Table 1. Battery and Supercapacitor performances

	Lead Acid Battery	Supercapacitor
Specific Energy Density(Wh/kg)	10 - 100	1 - 10
Specific Power Density(W/kg)	<1000	<10,000
Cycle Life	1,000	>500,000
Charge/Discharge Efficiency	70 - 85%	85 - 98%
Fast Charge Time	1 - 5h	0.3 - 30s
Discharge Time	0.3 – 3h	0.3 - 30s

The proposed system aims to optimize the storage system. The addition of the supercapacitor to the battery will enable us to reduce its size and also extend its lifespan by avoiding deep discharges.

The system controls the outputs of the solar panel, the battery, the supercapacitor, and the output of the DC machine across from the current, the voltage, the power, the speed, and the SOC. This allows us to estimate how the SOC of the battery and the supercapacitor optimize the energy of the photovoltaic panel and control the flow of energy in the system.

Table 2. Used modules parameters

PV Module: 1Soltech 1STH-215-P
• *$V_{oc,n} = 36.3V$; $I_{sc,n} = 8.21A$*
• *$R_s = 0.221\Omega$; $R_p = 313.3\ \Omega$; $a = 0.98$; $N_s = 60$*
• *$T_n = 25^oC$; $G_n = 1000W.m^{-2}$*
• *$K_i = 0.102A.C^{-1}$; $K_v = -0.3609V.C^{-1}$*
A generic Supercapacitor model
• *$V_{uc,n} = 240V$; $R_{uc} = 8.9m\Omega$; $C_{uc} = 99.5F$*
• *$N_s = 48$; $N_p = 1$*
Lead-Acid battery model
• *$V_{b,n} = 240V$; $C_{b,n} = 16.2A.h$*
DC Machine model
• *$R_{ar} = [0.6\Omega\ \ 0.012\Omega]$; $L_{ar} = 1.8H$; $R_f = [240\Omega\ \ 120\Omega]$*
• *$L_{af} = 1.8H$; $J = 1\ kg.m^2$; $B_m = 0\ N.m.s$; $T_f = 0\ N.m$; $t_e = 1rad/s$*

4. SIMULATION and RESULTS

The entire system was implemented in the Matlab/Simulink software environment. The representation of the functional diagram studied is illustrated in Figure 7.

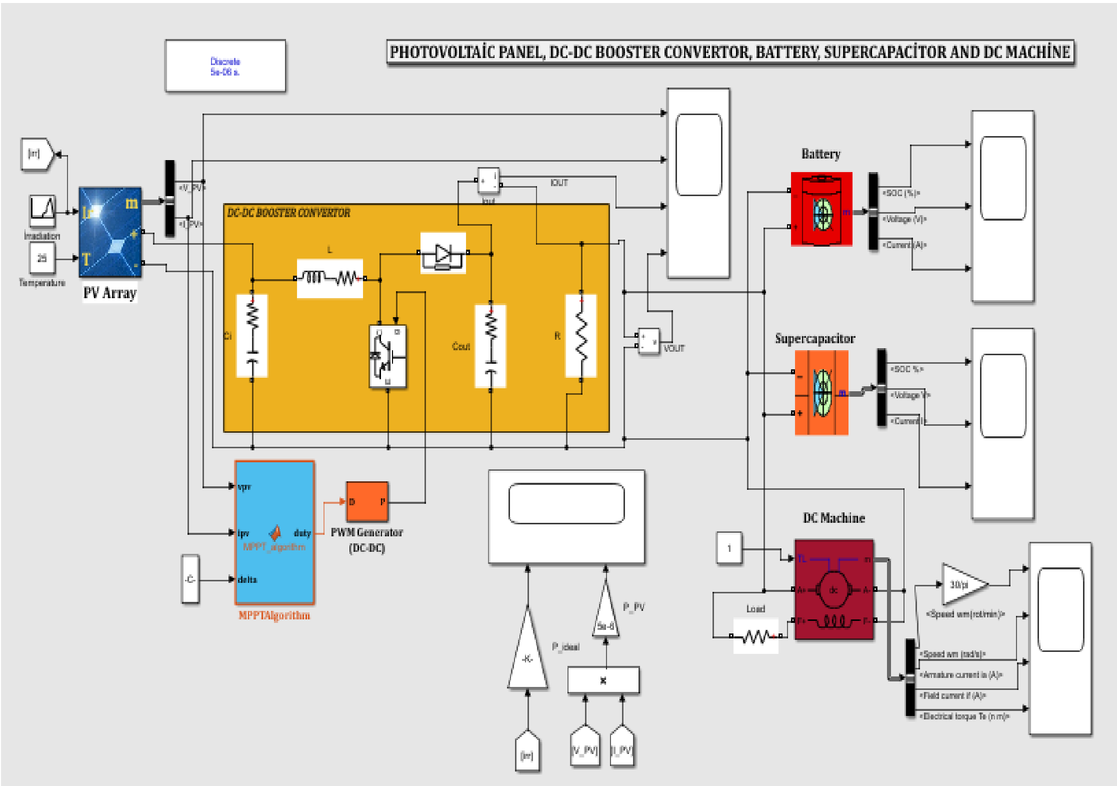


Figure 7. Simulink block study system.

The equivalent electrical circuit of the photovoltaic cells of Figure 1 is included in the system "*PV Array*". The multi-branch circuit of Figure 4 is placed in the system under the name of "*Supercapacitor*". The open block in Figure 3 of the lead-acid battery is considered in the Simulink diagram under the name "Battery". We have made some readjustments on the DC/DC boost converter, Figure 5, already validated in a previous study[9] as well presented in our Simulink diagram. All accompaniment in an MPPT algorithm according to Figure 2 allow us to track the highest power points of our solar panel.

The model data is presented in Table 2. The number of storage units is chosen to correspond to the nominal voltage and current of the DC machine[11]: Vm,n = 240V, and Im,n = 16.2A. Therefore, a lead-acid battery with a nominal voltage Vb,n = 240V, and a nominal capacitance Cb = 16.2A.h, and a generic supercapacitor with a nominal voltage Vuc,n = 240V, the whole constitutes our hybrid storage system. A module of five photovoltaic panels with three in series and two in parallel of type 1Soltech 1STH-215-P is taken (Voc,n = 36.3V, and $I_{sc,n}$ = 8.21A). The DC machine characteristics are: P_{en} power = 3731W = 5.0HP, rotating speed ω_n = 1220 rpm and torque $T_{e,n}$ = 29.2N.m the torque Te proportional to the speed of rotation ω. Starting in three stages (t_0 + 2.8s/4.8s/6.8s) with a resistance of 1Ω to protect the motor.

The discharge of the supercapacitor at t_0 when the engine starts ensures the power demand of the engine reaches its nominal speed.

In this study, only one irradiation prediction was created for the results as presented in Figure 8.

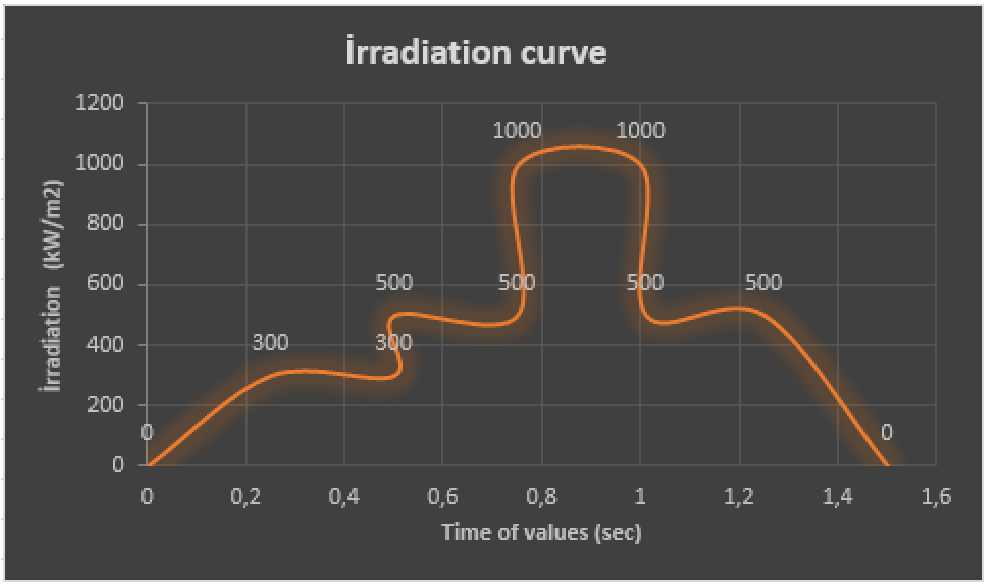


Figure 8. Irradiation waveform created

4.1. Battery charge is 0% and Supercapacitor nominal voltage is 0V

The circuits were simulated with different circumstances of battery and supercapacitor state of charge and voltage respectively. The obtained results were discussed above.

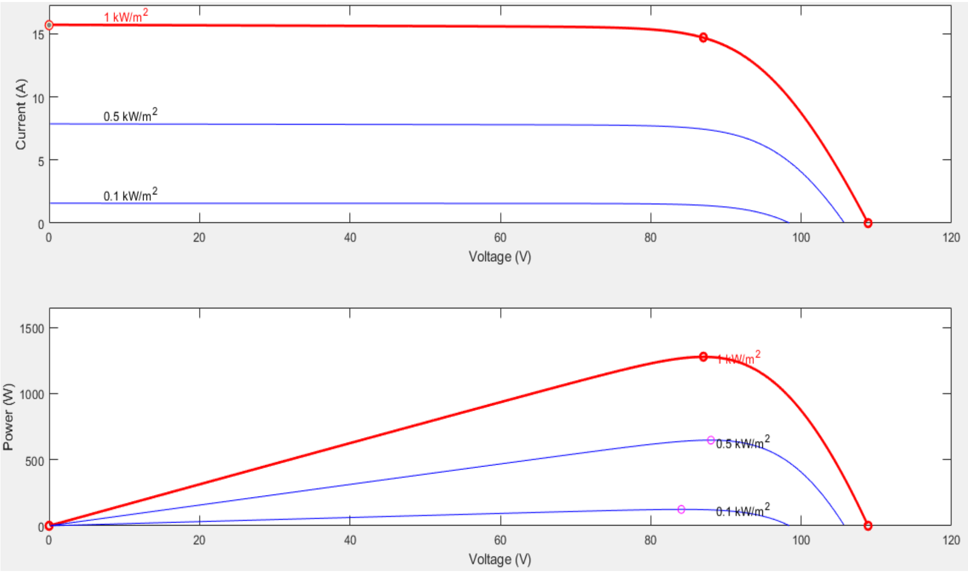


Figure 9. PV power, voltage, current, and specified irradiances characteristics.

The terminal voltage and current waveform of the solar panel and their outputs after the boost converter are shown in Figure 10. The voltage value is changed but based on the proposed MPPT algorithm. The step-size of the algorithm is set at 6s which means that a refreshed voltage reference is given per 6s and as a result the voltage waveform is stair-like.

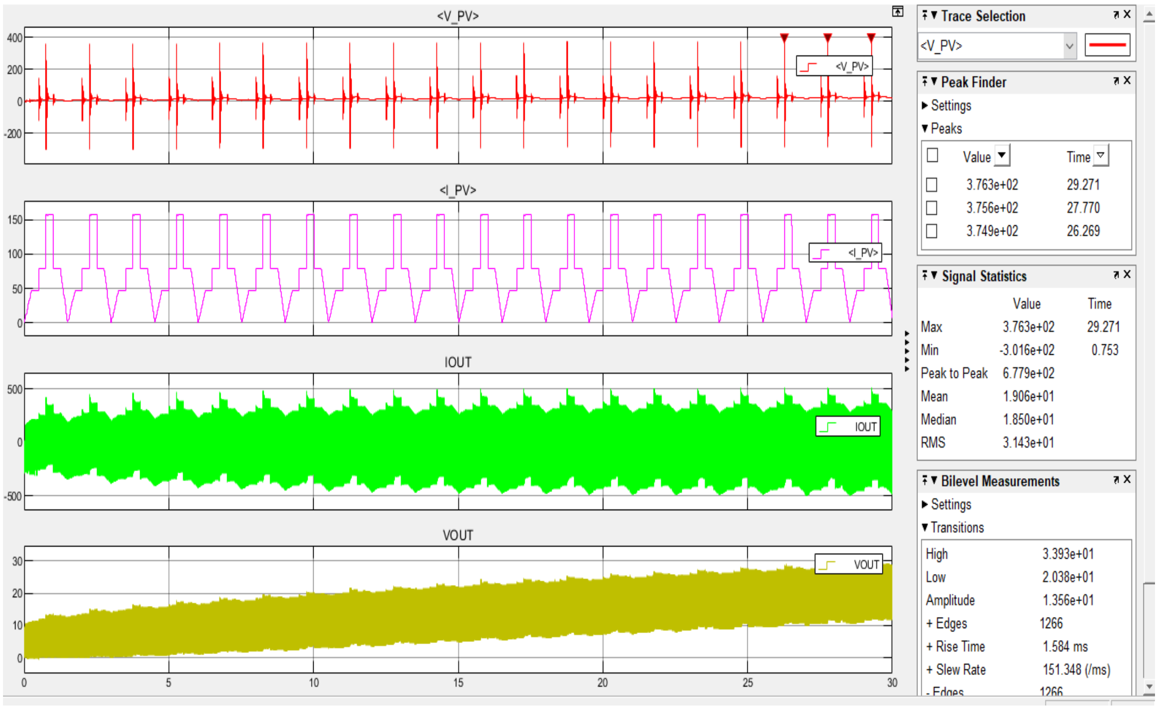


Figure 10a. PV voltage and current out characteristics

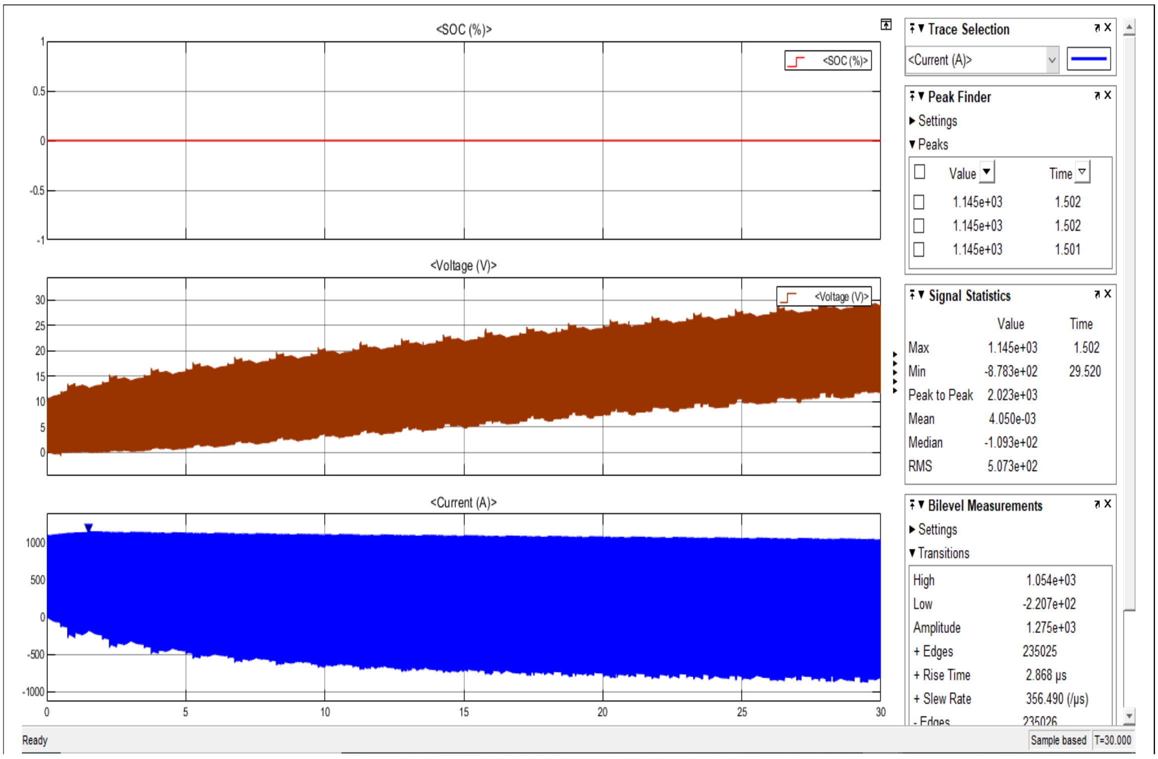


Figure 10b. Battery output characteristics

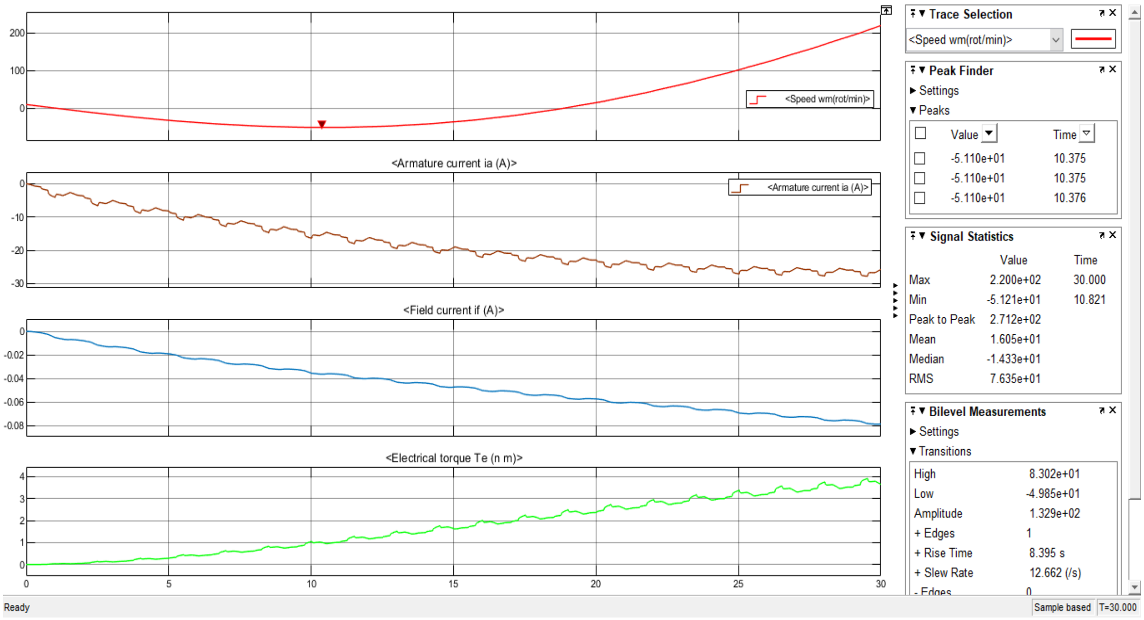


Figure 10c. DC Machine output characteristics

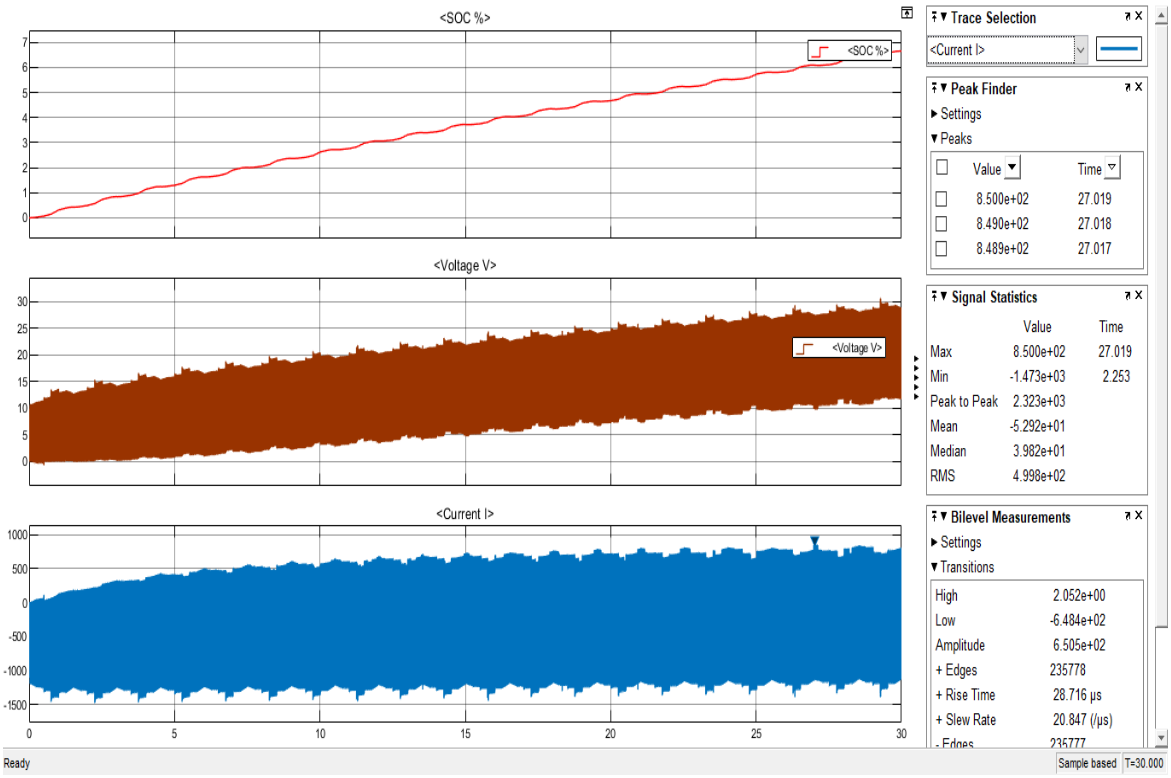


Figure 10d. Supercapacitor output characteristics

First, the battery and the supercapacitors have been connected in parallel as shown in Figure 6. The DC/DC boost converter is supposed to be ideal without losses. The DC-bus voltage V_OUT approximately increases with a noise thickness of 10V and an approximate speed over time by 1V/s. At 30s, V_OUT is approximately 30V in figure 10a. In this condition of very weak and interfering voltage, the battery cannot be charged and the SOC of the battery stays at 0%. The battery's power system does not charge as seen in figure 10b. In figure 10c, the machine's speed goes below zero since the minimum operating voltage of the machine is neither satisfied by the battery nor by the supercapacitor, hence an output V_OUT is interfered with and weakened. But after the 17-18th second the machine's speed starts to take off. After 30s, the speed of the machine passes 200RPM and this is because the DC/DC boost converter works as a generator. Finally, in Figure10d, the supercapacitor's current Isc starting in negative range indicates the boost mode was active as Dennis Carreira and others proved in 2014, the supercapacitor is trying to supply the load but not sufficiently because of low tension. And in the other way, the supercapacitor's charge begins to increase despite a low and scrambling voltage at the output V_OUT of the DC/DC boost converter. With a voltage rated at 240V the supercapacitor, therefore, absorbs any voltage available in the grid and gets charged by 6.5% in 30s.

In this part, it is concluded that the DC/DC boost converter, when the hybrid energy storage system does not meet the energy demand of the machine, plays the role of an energy supplier. But it can be said that its energy supply is insufficient because the photovoltaic source is fluctuating and not stable.

4.2.Battery charge is 100% and Supercapacitor nominal voltage is 0V

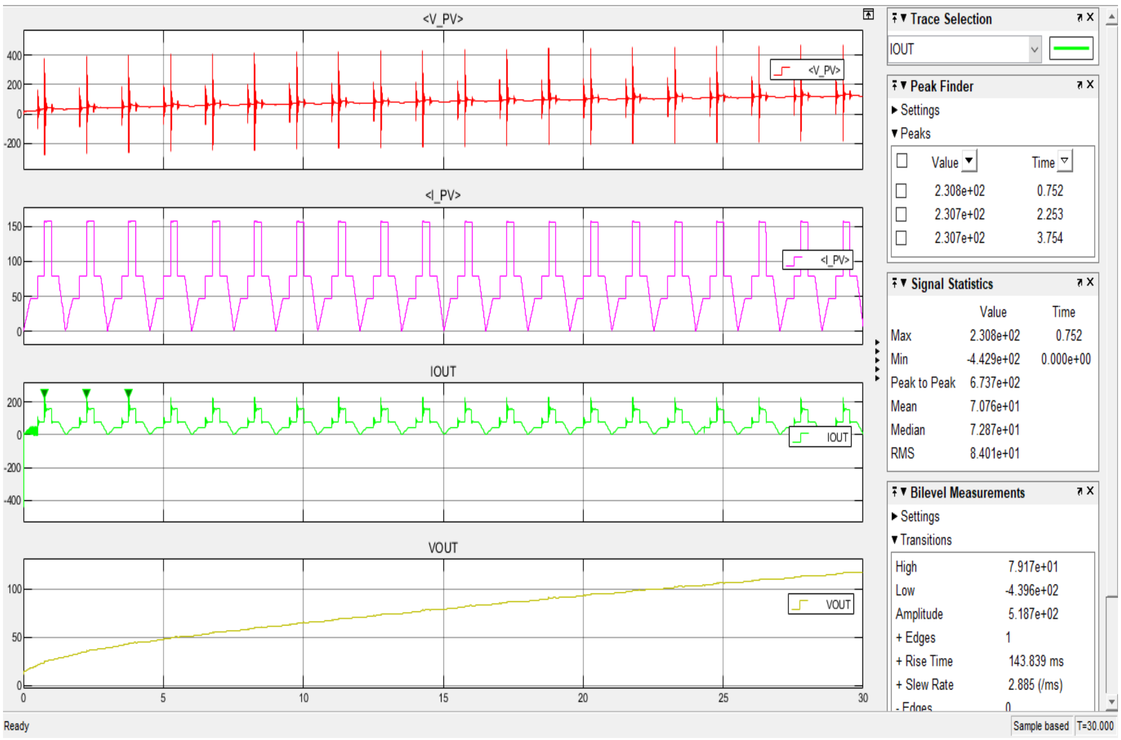


Figure 11a. PV voltage and current output characteristics

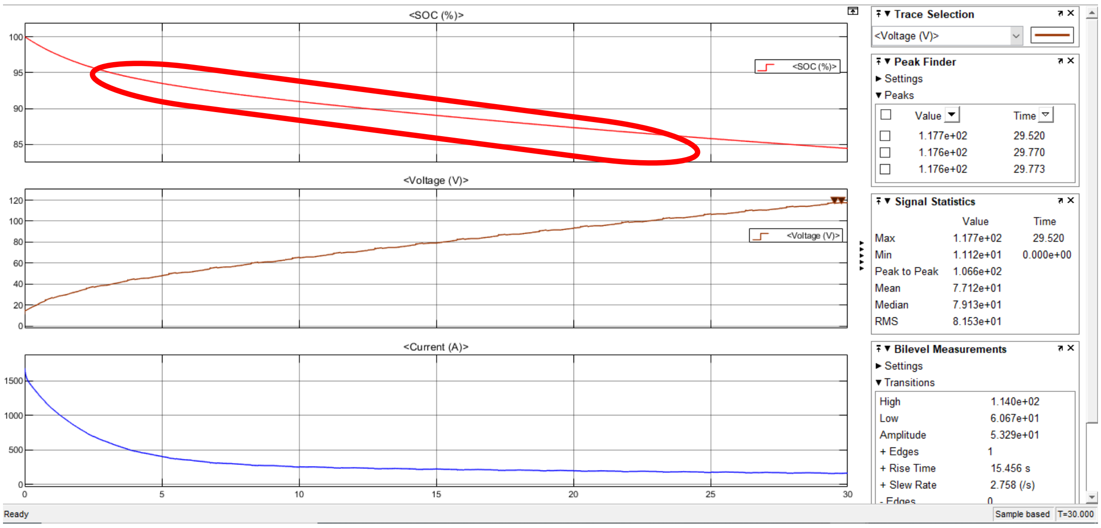


Figure 11b. Battery output characteristics

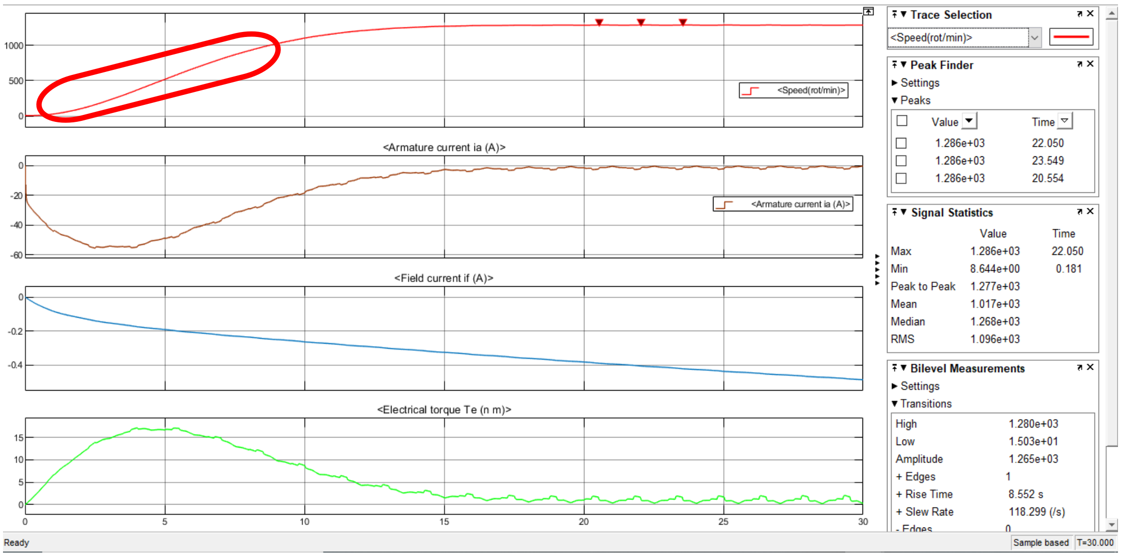


Figure 11c. DC Machine output characteristics

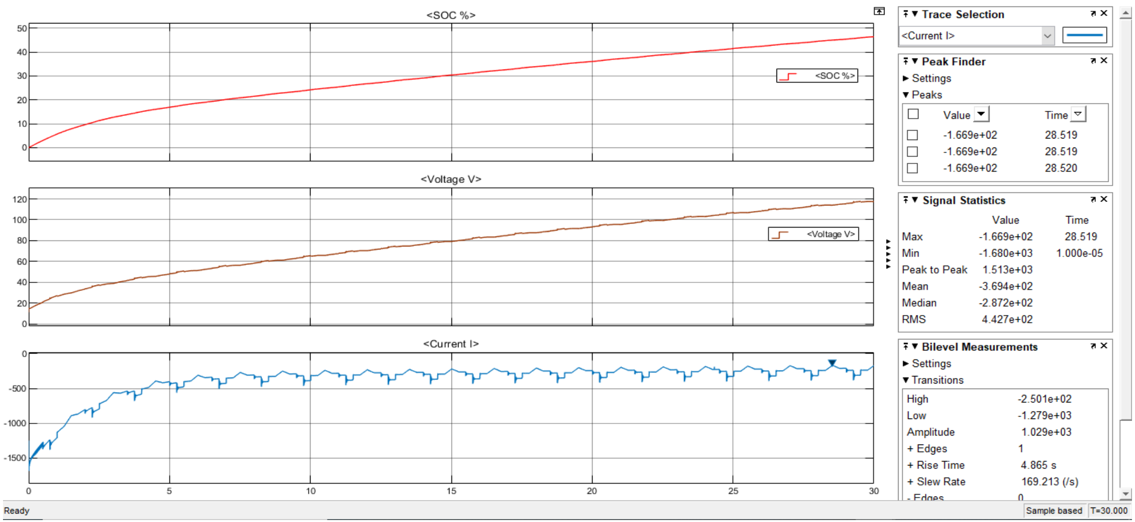


Figure 11d. Supercapacitor output characteristics

The PV panel is operated in maximum power point tracking (MPPT) mode with S=1kW/m^2 at maximum in Figure 11a, b, c, and d. Figure 11a shows the PV outputs and the system's output voltage (V_OUT). From t = 0s to t=30s, the V_OUT is approximately increased from 10V to 110V. With our previous irradiation as seen in Figure 8, the PV panel supplies and the DC/DC boost converter increases the outputs at that period because of a sudden battery recharge demand. V_OUT is increased to 110V from 10V when the PV system is acting alone, that is, the energy storage system as shown in Figure 11a. In Figure 11b, in an interval of 1 to 30seconds, the state of charge of the battery decreases very quickly from 100% to 85%. Despite that, its voltage increases due to the increasing voltage which comes from the source moving from 18V to almost 120V. In this case, the battery is therefore the main source supplying the necessary operating energy to the machine because of its discharge speed. In a part of Figure 11c, we can observe that the machine reaches its nominal speed between 20 and 25 seconds. A speed that goes from 0 to 1286RPM between 1 and 25 seconds. It has a very slow start since the nominal speed is reached after 20 seconds. This can be justified because of the small power density of the battery. The battery is observed as a source of operating energy for the machine in this part. In Figure 11d, the supercapacitor does not energize the machine when its starting nominal voltage is zero and at time t = 0s. Suddenly the supercapacitor charges normally passing from 0 to almost 48V between 0 and 30s. With a nominal voltage of 240V, the full charge is therefore estimated after approximately 200s.

A brief conclusion that can be drawn from this part is that when the battery is charged, it can meet the energy needs of the machine autonomously for a time. However, a very slow starting of the machine is observed.

4.3.Battery charge is 0% and Supercapacitor nominal voltage is 240V

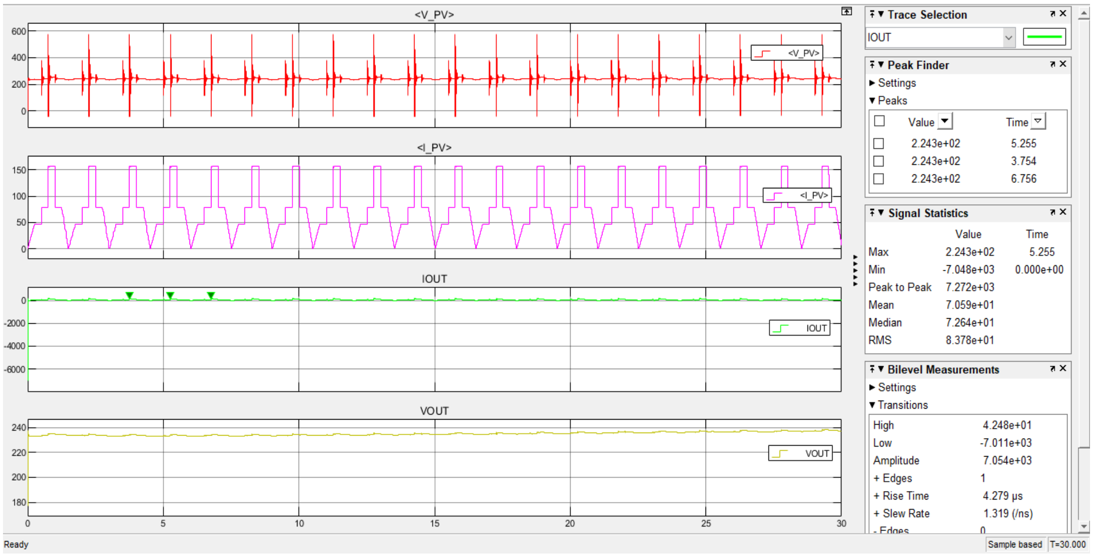


Figure 12a. PV voltage and current output characteristics

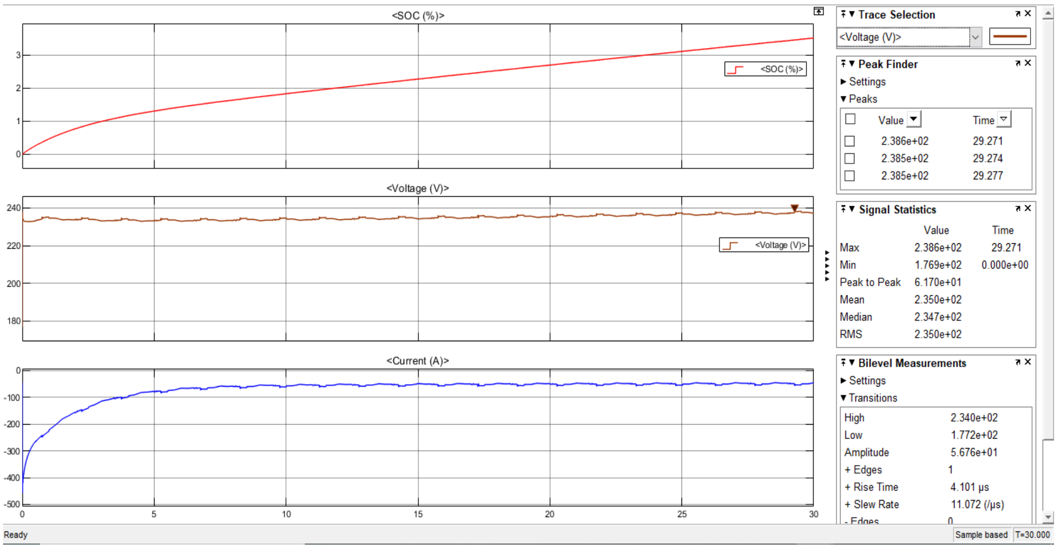


Figure 12b. Battery output characteristics

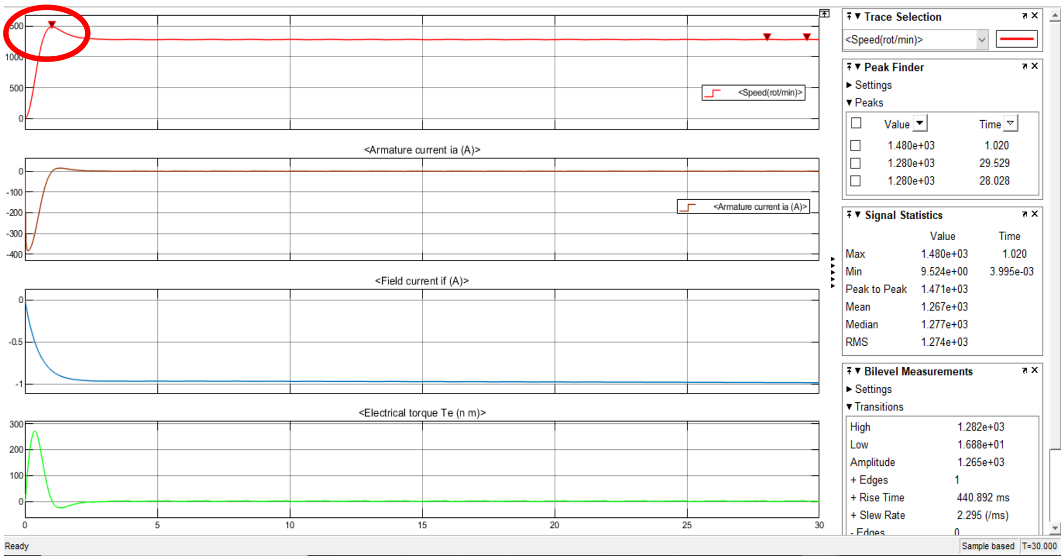


Figure 12c. DC Machine output characteristics

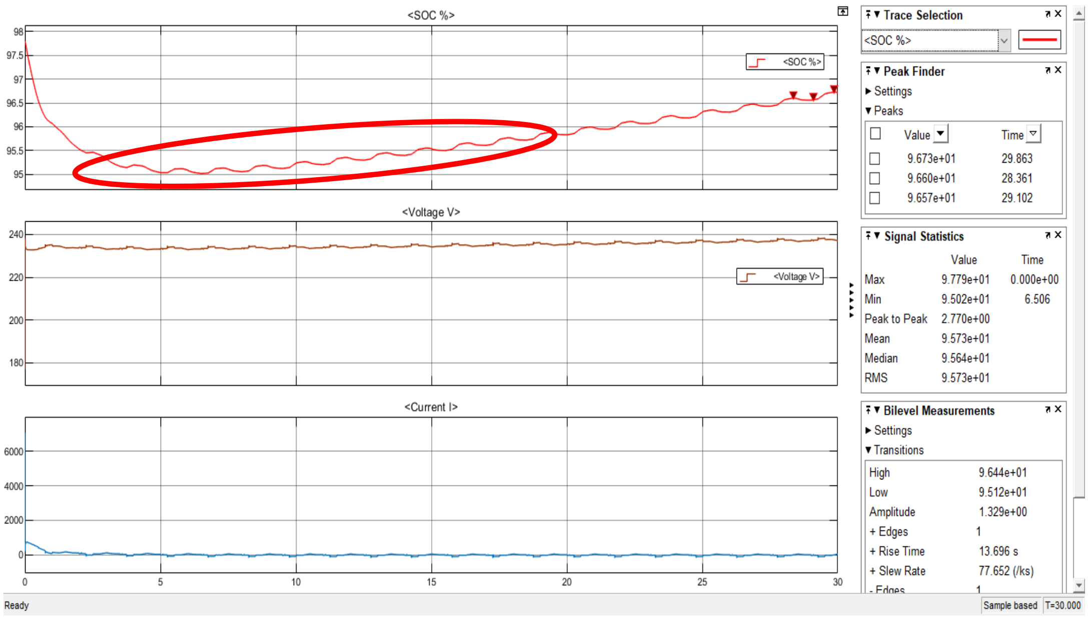


Figure 12d. Supercapacitor output characteristics

The PV panel is operated in maximum power point tracking like previously formulated. Figure 12a shows the PV output and the system's output voltage (V_OUT). A small increase in the slope of V_OUT is observed between t=0s and t=30s that is from 236V to 239V. This means the DC/DC boost converter works normally by supplying the battery. In Figure 12b the battery is charged normally without being discharged. Thus, the charge gradually increases from 0% to almost 3.5% between t=0s and t=30s which can take to a complete charge after 1000s at most. In Figure 12c, the starting of the machine was carried out very quickly, and a speed above 1480RPM is reached with only 1s. Thus, the machine rotates at its nominal speed 1280RPM in a second. Optimal operation desired with a very fast start-up and nominal speed was obtained after 2s. In terms of

Figure 12d at start-up, a very rapid discharge of the supercapacitor is observed between t = 0s and t = 5s until its charge rate decreases to 95%. Then at the end of the 7th second, a normal recharge rebound takes place because the system is always supplied via the output of the DC/DC boost converter. This rapid discharge therefore satisfies the very rapid high demand for the energy density of the DC machine at start-up to reach its nominal speed very quickly.

In this part, it is concluded that the supercapacitor is the ideal element to satisfy the very fast demand of high-density energy of the DC machine at the starting point even when the battery is completely discharged. The supercapacitor with its capacity to contain a high-power density and a possibility of very fast discharge answers exactly the demand of the DC machine. At the start-up of the machine, a fast nominal speed is reached.

4.4. Battery charge is 100% and Supercapacitor nominal voltage is 240V

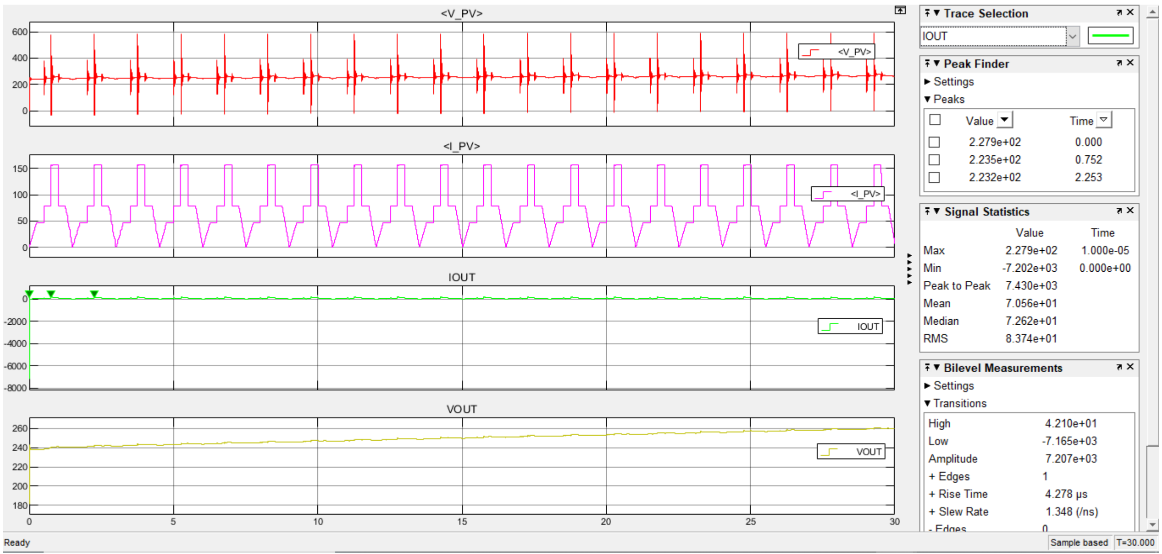


Figure 13a. PV voltage and current output characteristics

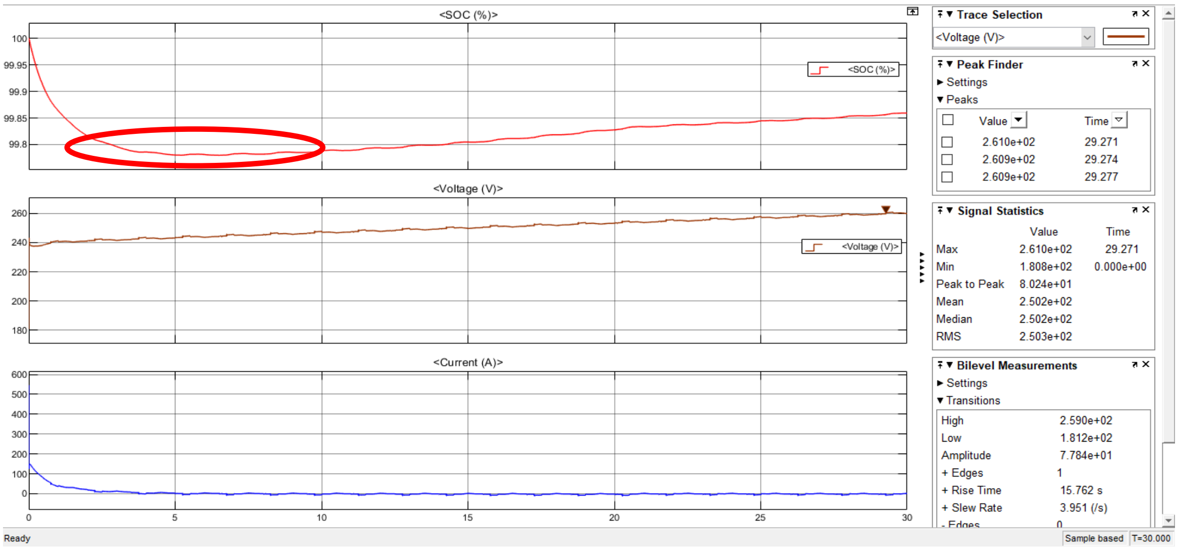


Figure 13b. Battery output characteristics

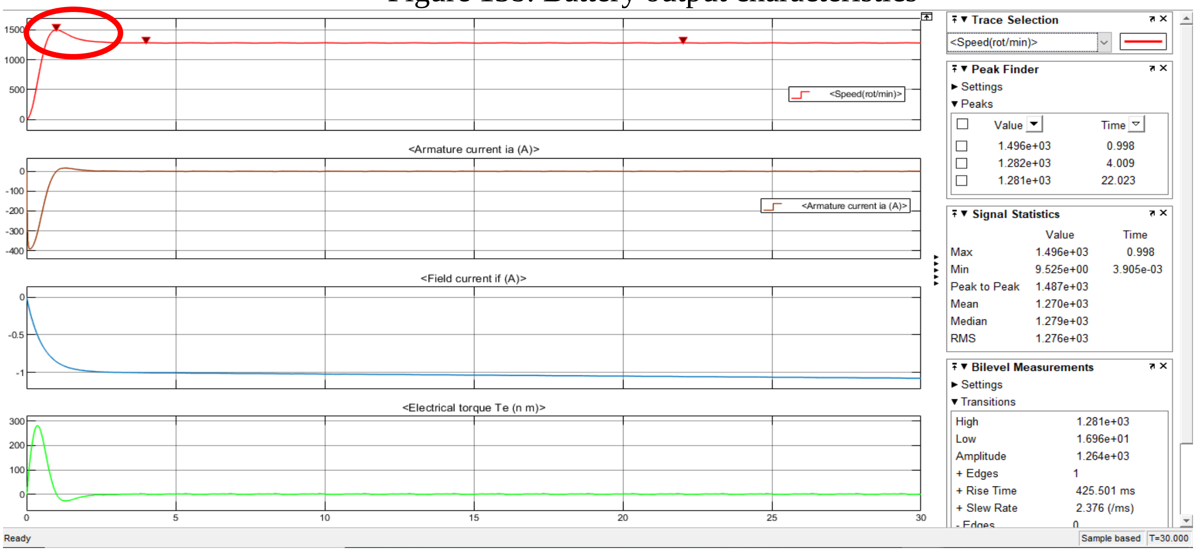


Figure 13c. DC Machine output characteristics

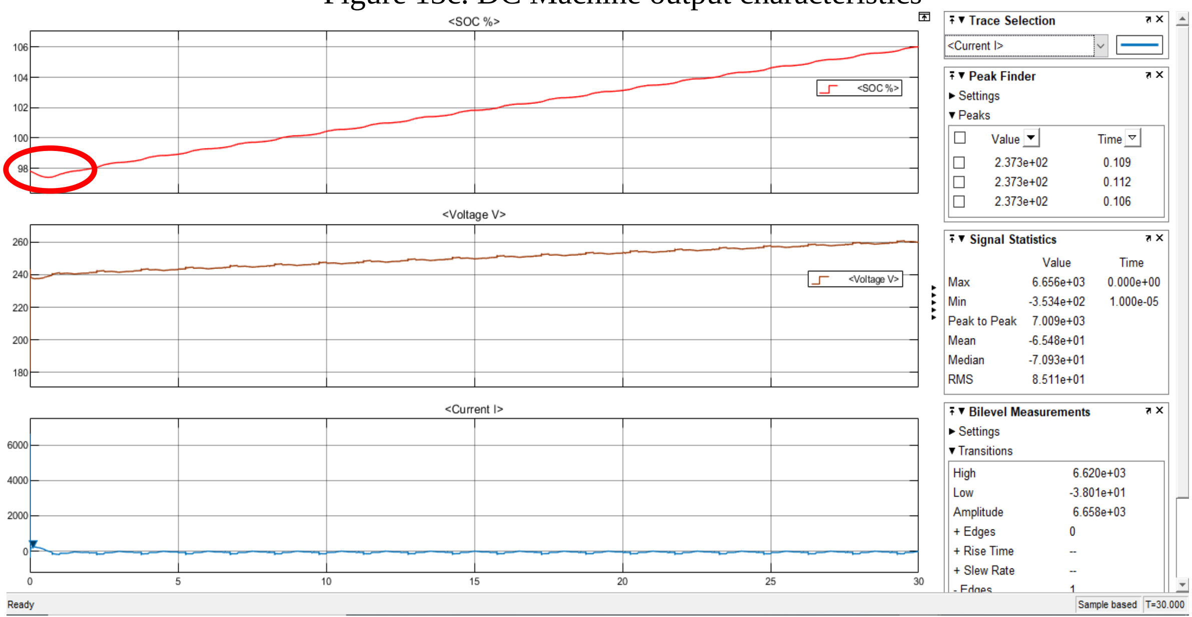


Figure 13d. Supercapacitor output characteristics

The PV panel is operated in maximum power point tracking (MPPT) like previously defined. In Figure 13a the PV output and the system's output voltage (V_OUT) are shown. An increase in the slope of V_OUT is observed between t=0s and t=30s from 240V to 260V. That increase explains that the DC/DC boost converter normally works by supplying the battery and the supercapacitor in a new recharge demand. In Figure 13b a small decrease in the battery charges was observed between t=0s and t=6s that is from 100% to almost 99.76% and the charging gradually restarts between t=6s and t=30s. In Figure 13c the starting of the machine was carried out very quickly and a speed above 1496rpm was reached before 1s. Thus, the machine rotates at its nominal speed 1280rpm in the first second. Optimal operation desired with very fast start-up and nominal speed is obtained in 1s. In terms of Figure 13d at start-up, a very rapid discharge of the supercapacitor is observed between t = 0s and t = 1s until its charge rate decreases to 97%. Then at the end of the 2nd second, a normal recharge rebound takes place because the system is always supplied for recharging via the output of the DC/DC boost converter. This rapid discharge, therefore, satisfies the very rapid high demand for the power density of the DC machine at startup to reach its nominal speed very quickly.

In this part, the conclusion is that the supercapacitor is the ideal element to satisfy the very fast demand of a high-power density demand of the DC machine at startup. And the battery is suitable for the long-term functioning of the DC machine. The supercapacitor and the battery when supplied together, the DC machine's optimal functioning is obtained quickly. And the supercapacitor with its capacity to contain a high-power density and a possibility of very fast discharge becomes suitable for the fast start-up demand of the DC machine. Besides, a nominal speed is reached in record times thus providing a solution for the deep discharge of the battery at the start-up of the DC machine.

5. CONCLUSION

The fundamental part of this work focuses on analyzing the improvement of a supercapacitor in HESS which is supplied by a stand-alone solar panel that is connected to a battery, a supercapacitor, and also a DC machine. The desired results were reached. When the hybrid energy storage system does not meet the energy demand of the machine, the DC/DC boost converter plays the role of an energy supplier. However, we can say that its energy supply is insufficient because the photovoltaic source is fluctuating and not stable. The battery when charged can meet the energy needs of the machine autonomously for a time. Although, a very slow starting of the machine is observed. The supercapacitor is the ideal element to satisfy the very fast demand for a high-power density demand of the DC machine at the starting point even when the battery is completely discharged. The supercapacitor with its capacity to contain a high-power density and a quick discharge rate becomes suitable for the fast start-up demand of the DC machine and a nominal speed is reached in record times. The different signals obtained by simulation: the supercapacitor voltage curves, the battery charge state curves, and the machine speed curves have shown that adding a supercapacitor in a solar energy system of which the only energy storage system is the battery enables to reduce its deep discharges and its stress at least 15%. This is proven by comparing the state of charge signals of the battery obtained in a solar energy system of which the only energy storage system is the battery where the battery is stressed compared with that of which the energy storage system is hybrid battery-supercapacitor where the battery is less stressed. It is thus advantageous to reduce the dimensions of the batteries. However, the fact that ultracapacitors cannot store a lot of energy means that they cannot be used without batteries. When combining the supercapacitor and the battery, the DC machine's optimal functioning is obtained quickly. Therefore, by the supercapacitor's activity, the battery's life-cycle is extended due to less current constraints by limiting their discharge current.

Lastly, only the load and empty conditions of both energy storage devices were taken into account for the output voltage in this study. However, it is not the only parameter that can be considered. Future studies can cover how a supercapacitor in HESS can improve the life span of a battery with a focus on more suitable parameters like the proper size of the supercapacitor and the battery, and those of the full energy storage system in stand-alone solar panel applications.

Declaration of Ethical Standards

We wish to draw the attention of the Editor to the following facts, which may be considered as potential conflicts of interest, and to significant financial contributions to this work:
No conflict of interest exists. We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.
All of the sources of funding for the work described in this publication are acknowledged below:
No funding was received for this work.
We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing

of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We further confirm that any aspect of the work covered in this manuscript. That has involved human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript. IRB approval was obtained (required for studies and series of 3 or more cases). Written consent to publish potentially identifying information, such as details or the case and photographs, was obtained from the patient(s) or their legal guardian(s).

The International Committee of Medical Journal Editors (ICMJE) recommends that authorship be based on the following four criteria:

1. Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND
2. Drafting the work or revising it critically for important intellectual content; AND
3. Final approval of the version to be published; AND
4. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

All those designated as authors should meet all four criteria for authorship, and all who meet the four criteria should be identified as authors. For more information on authorship, please see http://www.icmje.org/recommendations/browse/roles-and-responsibilities/defining-the-role-of-authors-and-contributors.html#two.

All listed authors meet the ICMJE criteria. We attest that all authors contributed significantly to the creation of this manuscript, each having fulfilled criteria as established by the ICMJE.

We believe these individuals should be listed as authors because: We confirm that the manuscript has been read and approved by all named authors. We confirm that the order of authors listed in the manuscript has been approved by all named authors.

The Corresponding Author declared on the title page of the manuscript is: **Yvon Gotran KOYI BOUKILA.** This author submitted this manuscript using his/her account in EVISE. We understand that this Corresponding Author is the sole contact for the Editorial process (including EVISE and direct communications with the office). He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that the email address shown below is accessible by the Corresponding Author, is the address to which Corresponding Author's EVISE account is linked, and has been configured to accept email from the editorial office of International Journal of Energy Applications and Technologies: **koyiyvon92@gmail.com**

We the undersigned agree with all of the above.

REFERENCES

[1] J.-C. L. de récherche/ C. A. C. plateforme d'éssai/France) Christian SARRAZİN(DGA/DRET) *et al.*, "Accumulateurs d'énergie," *Tech. l'ingénieur*, p. 84.

[2] Akram,U., Khalid, M., Shafiq, S., "An Innovative Hybrid Wind-Solar and Battery-Supercapacitor Microgrid System—Development and Optimization," *IEEE Access*, 2017:5;25897-25912.

[3] Perdana, Y. S., Muyeen, S. M., Al-Durra, A., Morales-Paredes, H. K., Simoes, M. G., "Direct connection of supercapacitor-battery hybrid storage system to the grid-tied photovoltaic system," *IEEE Trans. Sustain. Energy*, 2019:10(3);1370-1379.

[4] Singo, T. A., Martinez, A., Saadate, S., "Using ultracapacitors to optimize energy storage in a photovoltaic system," *SPEEDAM 2008 - Int. Symp. Power Electron. Electr. Drives, Autom. Motion*, 2008;229-234.

[5] Argyrou, M. C., Christodoulides, P., Marouchos, C. C., Kalogirou,S. A., "Hybrid battery-supercapacitor mathematical modeling for PV application using Matlab/Simulink," *Proc. - 2018 53rd Int. Univ. Power Eng. Conf. UPEC 2018*, 2018;1-6.

[6] Glavin, W. G. H. M.E., Paul K.W. Chan, Armstrong, S., "A Stand-alone Photovoltaic Supercapacitor Battery Hybrid Energy Storage System," *13th Int. Power Electron. Motion Control Conf.*, 2008:60(5);1688-1695.

[7] Babazadeh, H., Gao, W., Lin, J., Cheng, L., "Sizing of battery and supercapacitor in a hybrid energy storage system for wind turbines," in *Proceedings of the IEEE Power Engineering Society Transmission and Distribution Conference*, 2012.

[8] Simon, P., "SUPERCONDENSATEURS : Principes et Evolutions," Toulouse, 2011.

[9] Gao,L ., Dougal, R. A., and Liu, S., "Active power sharing in hybrid battery/capacitor power sources," *Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC*, 2003:1;497-503.

[10] Rout, T., Maharana, M. K., Chowdhury, A., Samal, S., "A Comparative study of Stand-alone Photo-Voltaic System with Battery storage system and Battery Supercapacitor storage system," *Proc. 4th Int. Conf. Electr. Energy Syst. ICEES 2018*, 2018:i;77-81.

[11] Camara, J. F. D. M. A., Djellad, A., Logerais, P. O., Riou, O., "Modeling of A Hybrid Energy Storage System Supplied by a Photovoltaic Source to Feed a DC Motor," *Int. J. Renew. Sustain. Energy*, 2013:2(6);222.