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Control Strategy for an Off-Grid Photovoltaic System in Haiti

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Abstract: This paper proposes a control system for an off-grid photovoltaic system, which can be used to improve the electricity access in poor or developing countries. The PV system is composed of three independent closed-loop converters, connected to a common dc voltage bus. The objective of the proposed control system is to adequately control the power flow through these converters and the dc bus independently on the solar irradiation and the charge/discharge of the battery-bank while providing the power to the ac loads. To achieve this goal, the power injected to the dc link is monitored by using two integrated control loop that compute the difference between the input and output power levels to inject or to extract it from the battery bank under distinct operating points. Simulation results are included for an 1.6 kW PV system to validate the proposed control strategy.

Keywords: Off-Grid Photovoltaic systems, Control system.

1. INTRODUCTION

Since last decades, electric energy has been one of the world's concerns because it reflects the economic development and technological progress in all areas. Different types of electric power generation systems have already been developed to meet the increasing demand. The generated power come from primary energy sources that are either exhaustible (e.g., fossil fuels.), which have a direct impact on the ecosystem by releasing greenhouse gases, or that are either renewable (hydraulic, wind, marine, geothermal, solar energy, etc.) which have no negative impact on the ecosystem (Bentarfa. e al., 2019).

However, despite the evolution of technology, undeveloped countries have suffered from an unreliable availability of electricity due to some limitations such as the decrease of the oil reserves and low economic indices. At the same time, for the majority of the developed and undeveloped countries the sun represents an important resource in the renewable energy chain (Shenawy e al., 2017).

On the other hand, a lot of research has already been to exploit some of renewable resources into electricity at an affordable cost and also to minimize the releasing greenhouse effect. Indeed, solar photovoltaic (PV) energy has receiving increasing attention, because it presents low impact on the environment, low operating cost and it is easy to implement (Shenawy et al., 2017; Cândido et al., 2009).

Different solar PV systems have been developed to meet specific needs, including grid-connected systems, hybrid systems and others independently of the power grid. Off-grid PV systems have wide application in remote isolated areas, where utility grid is not available to meet the essential electric load or when its extension is not economically viable (Schuch, 2001; Walker et al., 2004; Cândido et al., 2010; Bellinaso, 2011; Priyabrata et al., 2016; Bellinaso et al., 2014). These off-grid PV systems should include battery-bank storage system, as solar energy generation tends to be intermittent due to diurnal cycle of solar geometry and clouds. The battery bank improves the reliability of these systems because the excess energy is stored in the battery bank, and this energy is provided to the load when there is increase in load power or reduction in source power. Several off-grid PV system configurations have already been developed, with emphasis to the use of a conventional bi-directional dc/dc converter as a battery bank converter interface to control the battery charge and discharge (Rosemback, 2004; Cândido et al., 2009; Cândido, 2010; Bellinaso et al., 2014).

This paper deals with an ac off-grid PV system, for houses isolated from conventional electricity production centers in underdeveloped countries. The case study is focused on the country of Haiti, which is located in Central America and is situated between the latitude of 18°02' and 20°06'north; 71°41'and 74°29' west longitude. Due to its geographical situation, this country has a good solar potential to generate the electricity to the entire country. However, the country suffers a precarious energy deficiency. Electricite d'Haiti (EDH) is a state-owned company that is responsible for the production, transmission and sale of the energy. EDH's mini-thermal power plants are located only in urban areas and provide energy to the urban areas for an average 20-40% of the population (Richard et al, 2018). The majority of Haitian population lives in rural areas with a significantly low gross domestic product per capita and have no access to electric energy (Bureau des Mines et de l'Energie Electricité d'Haïti, 2007-2017; Richard et al, 2018). The inaccessibility to the electric energy in these rural areas impacts social, educational and health development.

Based on these facts, the main objective of this paper is to present an off-grid PV systems with lead-acid battery for rural residential applications in Haiti while addressing the economic level of the target population to mitigate the basic need for electrical energy. The configuration under study employs three closed-loop converters and a new control system is proposed to adequately control the power flow under distinct operating conditions.

2. DESCRIPTION OF THE OFF-GRID PV SYSTEM

The configuration of the off-grid PV system under study is shown in Figure 1. This system is comprised of three power converters to control the power flow among the PV modules, a battery bank and ac loads which are:

- a dc-dc boost converter for extracting the dc power from the PV modules to the dc bus, operating under a maximum power point tracking (MPPT) algorithm (Bellinaso et al, 2014; Kim et al., 2006);
- a two-leg interleaved bidirectional dc-dc battery-bank interface converter, presented in Figure 2, to charge/discharge the battery-bank through the dc bus (Ahmed et al., 2016; Melo et al., 2014);
- a dc-ac single phase full-bridge converter to generate an output sinusoidal waveform for the ac loads.

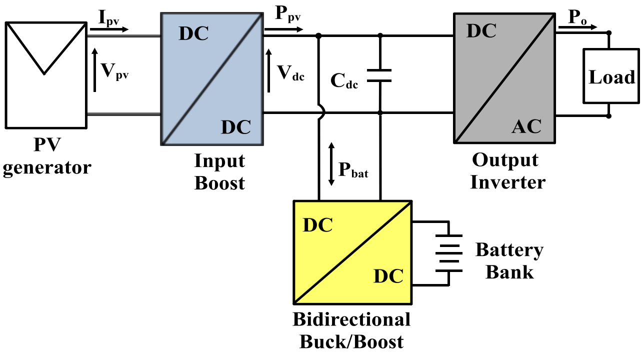

Fig. 1 Off-grid PV system

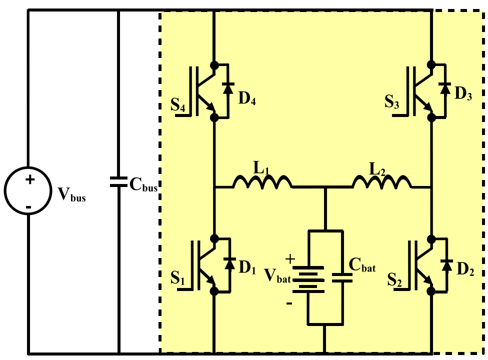

Fig. 2 Interleaved battery-bank converter interface with two power modules.

A control strategy has been established to manage the power of the system. This control strategy takes into account the extraction of the maximum power from the PV modules to transfer it to the DC bus via the dc/dc input boost converter, the control of the power flow of the battery bank in both direction via the interleaved bidirectional dc/dc converter (IBDC) and finally an dc/ac loop control take account of the ac output voltage.

3. OPERATION MODES

The control strategy of the system consists to maintain a balance between the input photovoltaic power, the injected/extracted power of the battery-bank and the output power of the loads. The power from batteries and photovoltaic system are processed by power converters as shown in figure 1. The power balance equation described in (1) must be respected continuously to have to have a good power regulation of the system.

$$P_{dc} = P_{pv} \pm P_{bat} - P_L = 0 \tag{1}$$

Where P_{dc} is the power flow on C_{dc}, P_{pv} is the power processed by the boost converter, P_{bat} is the power extracted (+) or injected (-) into the battery bank and P_L is the system load demand. Therefore, to ensure the power balance of the off-grid PV system, there are three degrees of freedom: P_{pv}, P_{bat} power control, and loads management. For the dc bus voltage remains stable, it is necessary that the sum of the powers is equal to zero (Cândido et al., 2010; Schwertner et al., 2013; Bellinaso, 2017).

However, to obtain $P_{dc} = 0$, a supervisory control strategy must be implemented to coordinate the power flow between the DC bus and the other converters interfacing the dc link (Cândido et al., 2010; Bellinaso, 2017). This control strategy controls the dc bus voltage by using the input dc-dc boost converter that can operate in three different modes as: MPPT mode, dc Bus Voltage Regulation (DCBVR) mode and OFF mode. Moreover, the interleaved bidirectional battery-bank converter can also operate in three different modes: the buck/boost mode that process the injection/extraction power at the battery-bank, the buck/boost DCBVR mode to regulate the power injected/extracted of the battery and the OFF mode. The control system modifies the operating mode of each converter instantaneously to ensure the power balance given in (1), resulting in the following operation modes.

3.1 Operation modes for each converter

3.1.1. Input Boost converter

The extraction of the power from PV modules to the common dc link is responsible accomplished by the input Boost converter. This converter can have different modes operation, such as: i) The MPPT mode to extract the maximum power through the Perturb and Observe (P&O) algorithm that generate a reference voltage. This converter behaves as a current source. ii) The DCBVR power mode, which is used to regulate the dc bus to continuously satisfy the power balance of the system. iii) Off mode, which is used when there is no enough power generated by the panels, and the converter is turned off.

3.1.2. Interleaved DC-DC Bidirectional Battery-Bank Interface converter

The interleaved bidirectional battery-bank interface converter is responsible for the injection/extraction of the power to/from the battery-bank. Normally, it's can operate as: i) Buck mode, to recharge the battery when the input power is higher than the output load demand ii) DCBVR mode, to regulate the power injected in the battery while activated the fluctuation mode, iii) Boost mode, to provide the power already stored at the battery when the input power is lower than the output load demand and also to maintain the dc bus regulation. iv) Off mode, to avoid total discharge/overcharge of the batteries.

3.1.3. The Full Bridge Inverter

This converter must supply power to the load, synthesizing an ac voltage with low harmonic distortion. It can operate either in ON mode, when there are some loads connected, or in OFF mode.

3.2. Operation Modes of the Global System

The real time operation of the global system depends on some variables, such as: the input power (P_{pv}), the state of charge of the battery (SOC) and the load connected at the output (P_L). Each of these variables is managed by one of the converters to have an adequate power balance. Thus, a control system has been established to guarantee an adequate operation of the system. The operating modes are described:

3.2.1. Mode 1

As the priority of this system is the load, when the power generated by the PV panels is exactly that required to meet the power demand of the load. The input boost converter is operated in MPPT mode, the inverter is ON to supply the load and no matter the state of charge of the battery the IBDC is OFF.

3.2.2. Mode 2

In the situation where the power generated by the PV panels is less than the load demand, the input boost converter still operates at the MPPT. At this time, the interleaved bidirectional converter must be activated in boost mode to provide power need for the load if the state of charge of the battery is adequate (middle or full charge.). If the state of charge of the battery (SOC) is less than the minimum value, the bidirectional battery-bank converter must be turned off to avoid a battery damage while switching the mode OFF to the inverter to ensure that DC bus voltage does not collapse.

3.2.3. Mode 3

If the system does not have load at the output, the output ac current is zero. The input boost converter operates at the DCBVR mode to regulate the dc bus while power is injected at the battery if battery SOC is not at the maximum value. Otherwise, the fluctuation mode of the IBDC is activated to compensate the self-auto discharge of the battery.

3.2.4. Mode 4

In the situation where the power generated by the PV modules is higher than the load demand, the inverter is ON. The input boost converter operates at the MPPT mode. Dc bus is regulated by using the exceeding power to charge the battery bank while activated the buck mode of the IBDC.

3.2.5. Mode 5

This mode occurs when the power generated by the PV panels is approximately zero (situation at the night or cloudy.) and there are connected loads. At this time, the input boost is turned off. If the state of charge of the battery is less than the minimum value, The IBDC is turned off and the loads are also turned off. If the state of charge is higher than the minimum value, the IBDC operates at the boost mode to transfer the power already stored at the battery for the loads.

4. CONTROL SYSTEM STRATEGY

The control strategy of the system takes into account certain assumptions, such as: tracking the maximum power of PV module, the regulation of the power dc bus and also the injected or extracted power at the battery bank. For this purpose, the input boost converter and the bidirectional battery-bank converter must be monitored by means of control. The operation modes are defined from the actual state of the variables P_{pv} , P_{bat} , and P_{Load} .

Figure 3 shows the proposed control structure for the off-grid PV system. This control system operates automatically according all events and for different operation modes.

4.1. Maximum power point tracking mode

The MPPT mode is used to extract the maximum power of the PV modules throughout the implementation of Perturb and Observe algorithm that generate a reference voltage (Walker et al., 2004; Bellinaso et al., 2014). This reference voltage is compared with measured PV voltage seen, and this voltage error is input of a PI controller that generates a reference current. This reference current is multiplied by the PV voltage to obtain the power at the maximum point operation $P_{pv,\max}$. This power pass through a limiter block to results in a boundary between zero and $P_{pv,\max}$. In the saturation of the $P_{pv,\max}$, the MPPT mode must be disabled and the DCBVR mode is enabled to regulate the dc bus voltage.

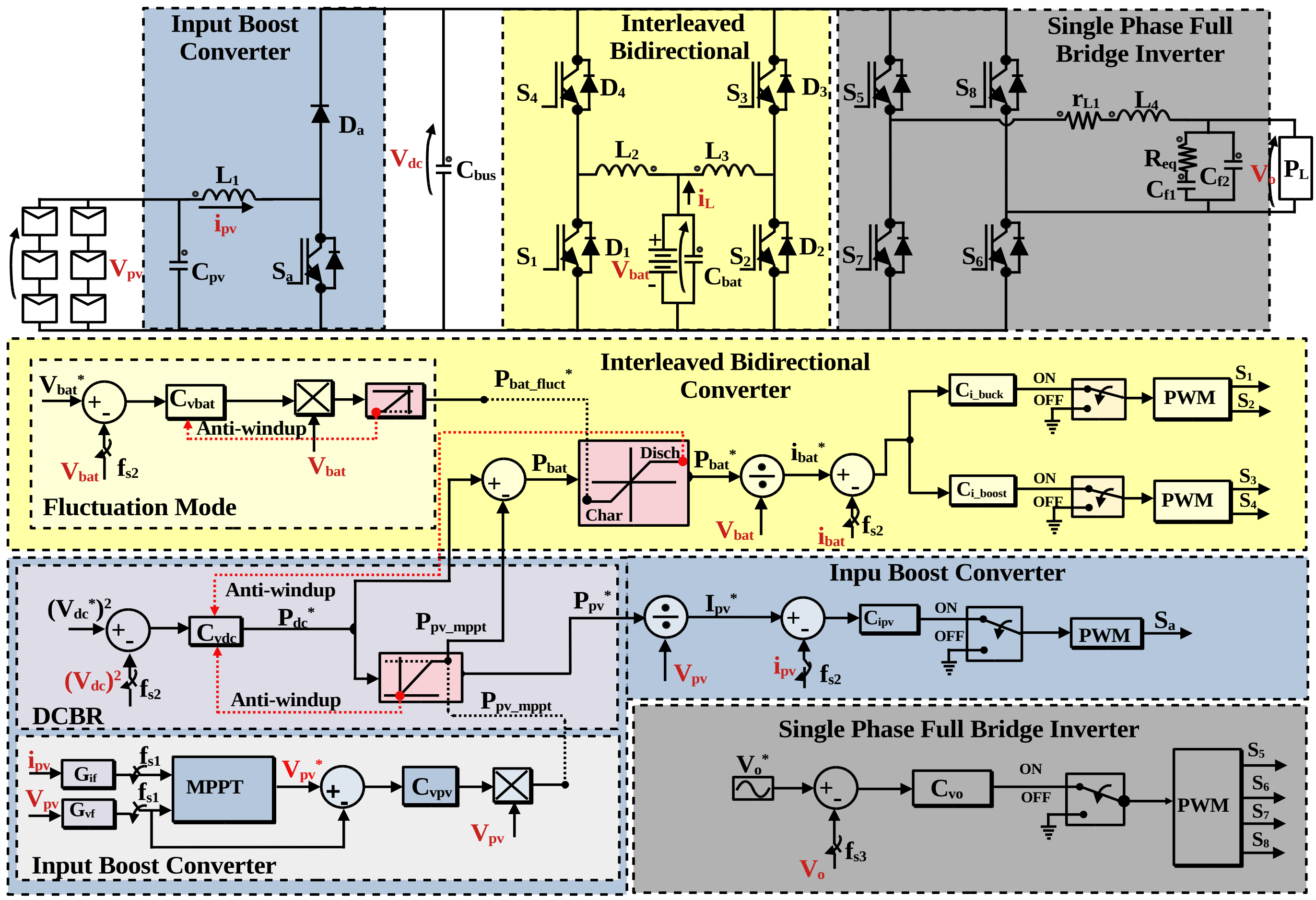

Fig. 3 Block diagram of the proposed control strategy for the off-grid PV system.

4.2. DC bus regulation mode

This mode is used to control the power at the bus. The square value of the dc bus reference voltage and the measured dc bus voltages are considered, and the resulting error is the input of a controller to generate the reference power of the dc P_{dc} .

To monitor the power injected from the PV modules at the dc bus and to inject or extract the power of the battery bank, the subtraction action of the $P_{pv,\max}$ and the reference bus power P_{dc} is done to obtain the P_{bat} as shown in the (2). This technique uses a single loop control that can regulate the power from the input boost converter, and the power flow to the bidirectional battery-bank converter in both directions.

$$P_{bat} = P_{dc}^{*} - P_{pv,\max} \qquad (2)$$

The resulting battery power P_{bat} is the input of a limiter block to result in a power boundary with a maximum recharge power, which is considered 28% ($P_{bat} = 450W(-)$) of the nominal system power. At this time, the bidirectional converter operates in buck mode. Moreover, the limiter results in a boundary with a maximum discharge power of the battery, which is the nominal power of the system ($P_{bat} = 1.6kW(+)$). At this time, the bidirectional converter operates in boost mode converter. The output of this limiter block gives a reference power for the battery, and this reference power of the battery (P_{bat}^{*}) divided by the battery voltage (V_{bat}) results in the reference current (i_{bat}^{*}). This reference current is compares with the measured current, which generate an error for each current loop of each operation mode (Buck/Boost) for the bidirectional converter. This error is the input of two PI controllers, which generate the PWM signal for each operation mode, as illustrated in Figure 3.

In addition, anti-windup compensation techniques are considered to improve the performance of the integral action under saturation for both limiters. Firstly, when the $P_{pv,\max}$ is saturated at zero the integral action of the PI bus power is set to zero. Secondly, when the power extracted at the battery is saturated at one (1), the integral action of the PI controller of the bus power must be stopped. Finally, when the power injected at the battery is saturated at minus one (-1), the equation that make the difference of the $P_{bat} = P_{dc}^{*} - P_{pv,\max}$ must be disabled in order not to inject more power to the

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battery. At this time, the system does not operate at the MPPT point, but the DCBVR is activated automatically to regulate the dc bus voltage.

When the injected power at the battery is saturated, the loop control of fluctuation mode of battery bank must be activated to compensate the self-auto discharge of the battery. This loop has an anti-windup compensation action to increase the performance of this control and to avoid instability. By using this method, the overcharging is avoided, and the battery must be disconnected at the level of the minimal voltage (42V) to avoid a deep discharge of the battery as shown in Table 1.

Table 1. Reference voltage for battery bank.

Reference voltage of Battery-Bank		
Voltage	**Value**	**Step of Charge**
$V_{bat,\min}$	42V	Bulk charge
$V_{bat,\,float}$	55.2V	Float charge
$V_{bat,\max}$	58.8V	Over charge
$V_{bat,nom}$	48V	Nominal Voltage

Finally, battery bank should never be discharged if the PV source can provide independently the energy demanded by load. Moreover, batteries should be charged if they are not fully charged.

Table 2. Parameters of the PV off-grid system.

Converter/stage	Parameter	Value
--	**Total input power**	**1.6kW**
Input Boost Converter	Input PV power (P_{pv})	1.6kW
	Switching Frequency (f_{s_1})	40kHz
	Input PV Capacitor (C_{pv})	100uF
	Inductor (L_1)	530uH
Interleaved Bidirectional Converter	Buck Power	450W (-)
	Boost Power	1.6kW
	Switching Frequency (f_{s_2})	40kHz
	Inductor (L_2, L_3)	246uH
	Capacitor of Batt (C_{bat})	185uH
	Capacitor of DC link (C_{dc})	5.36mH
	Current ripple (Δ_{I_L})	15%
Voltage–Source Inverter	Inverter Power	1.6kW
	DC bus voltage level (V_{dc})	200V
	Output AC voltage (V_{ac})	120Vrms
	Switching Frequency (f_{s_3})	45kHz
	Filter Capacitor (C_1)	1.2732uF
	Filter Capacitor (C_2)	1.9098uF
	Filter of Inductor (L_4)	98.22uH
	Equivalent resistance (R_{eq})	8Ω
Battery-Bank	Max. current charging	8.32A
	Max current discharging	33.35A
	Ripple current	2.96A

5. SIMULATION RESULTS

Some simulations are shown in this section to analyze the operation modes and also to verify the performance of the proposed control system. These are two parameters that can present some variations, which are: the solar radiation and the output loads. As already described in subsection 3.2, some transition modes of this system, it is important to verify the behavior of the operation modes of the system under distinct parameters. Table 2 shows the specifications of the system. This PV system was implemented by considering a variable irradiation from a maximum value ($1000W/m^2$) to a minimum value ($100W/m^2$), and a constant temperature equal to $25°C$. The nominal load is 1.6kW and the nominal dc bus voltage is 200V. Moreover, the series association of four (4) 12V /150Ah lead-acid batteries is considered and the maximum injected power by the battery must be limited around 28% of the nominal power system (450W (-)), as highlighted in the previous section. The simulation results were obtained by using the software PSIM.

Firstly, the system operates with no load and with $1000W/m^2$ solar irradiation (*mode 3*). In Figure 4, the variables V_{dc}, P_{pv}, P_{bat}, P_L, i_{pv}, i_{L1bat}, i_{L2bat}, V_{ac}, i_{ac} are shown to validate the control system. From of 0 to 0.2s, the control system must extract only the power to recharge the battery bank ($450W(-)$) and then, this power must be limited if the SOC of the battery is maximum. As can be seen in the i_{pv} current, the input power of the boost converter is not operated at the MPPT point. The sum of the interleaved currents i_{L1bat}, i_{L2bat} is done to obtain the current that must be injected or extracted from the battery while resulting in a low current ripple. At 0.2s, one third of the nominal power ($533.33W$) is connected, as we can see in the same Figure 4, resulting in mode 4. The input power is increased to supply the load power demand, as the input power is higher than the load power demand, and injected power at the battery bank is maintained as can be observed in P_{bat} curve. According the first simulation, one can verify that control system regulates adequately the dc bus voltage for distinct input and output operating points.

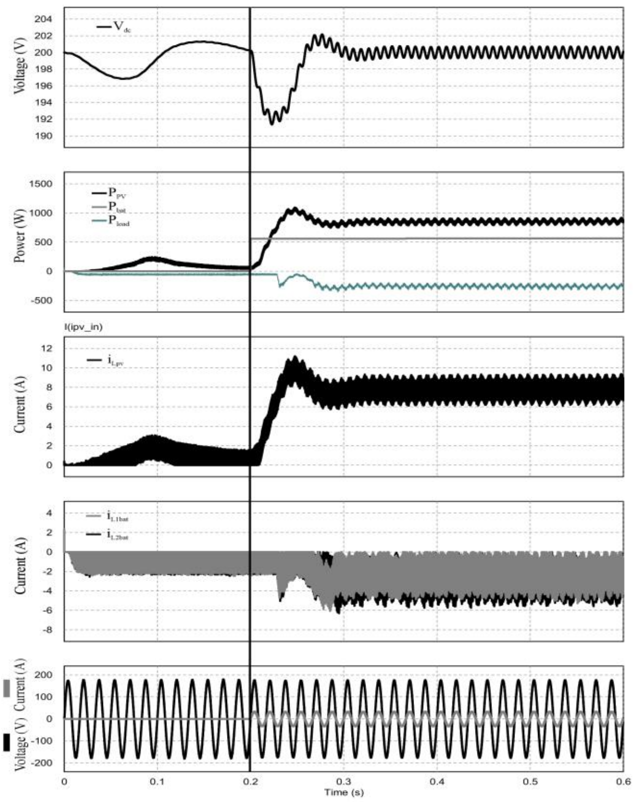

Fig. 4 Simulation results for Buck mode operation under load variation.

Figure 5 shows a simulation result when the system operates at $1000W/m^2$ and from 0 to $0.1s$ $450W$ is connected firstly. After the initial transition, the dc bus voltage is adequately regulated. At 0.4 s, the output power is reduced to about 257W, and the control loop of the P_{dc} power acts automatically to regulate the bus power, at the same time the control loop of the fluctuation mode of the battery is activated to limit the injected power at the battery. One can see in Figure 5, with the help of the indication of the $P_{pv}\_Saturation$ and $P_{bat}\_Saturation$ all operation modes of the system. It is worth to mention that if $P_{pv}\_Saturation$ is equal to 1, the input boost converter does not operate at the MPPT point, otherwise the MPPT is activated and the $P_{bat}\_Saturation$ at -1, the equation $P_{bat} = P^*_{dc} - P_{pv,\max}$ must be disabled to activate the fluctuation mode of the battery while the bidirectional converter still operates in the buck mode. Otherwise, the $P_{bat} = P^*_{dc} - P_{pv,\max}$ must be maintained to inject the power necessary to recharge the battery.

In Figure 6, the system is operated firstly at $1000W/m^2$. At 0.15 second, half of the nominal power ($800W$) is connected, as observed the system is perturbed. As the input power is higher than the output power, the bidirectional operates in buck mode to recharge the battery. At 0.4 s, the irradiation changes from $1000W/m^2$ to $100W/m^2$, then bidirectional converter switches from buck mode to boost mode to extract the power from the battery bank. When there is a perturbation of the bus power, the control system tries instantaneously to switch the operation mode. As a results, the proposed control system can operate under different irradiation levels.

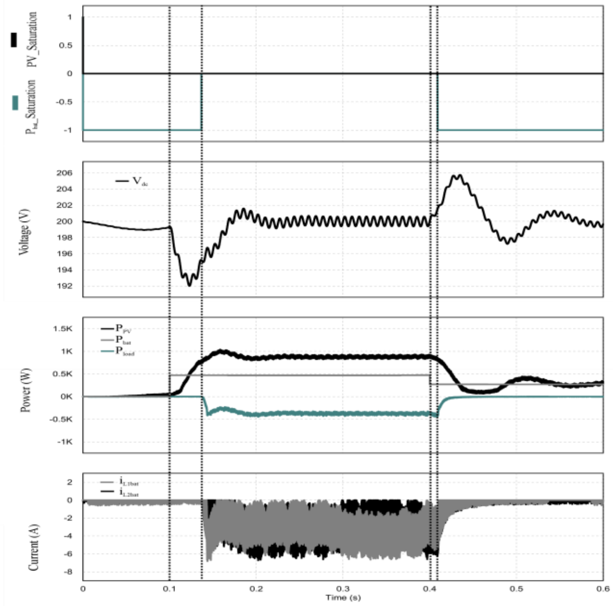

Fig. 5 Simulation results shows both saturations of the system under loads variation while operating in Buck.

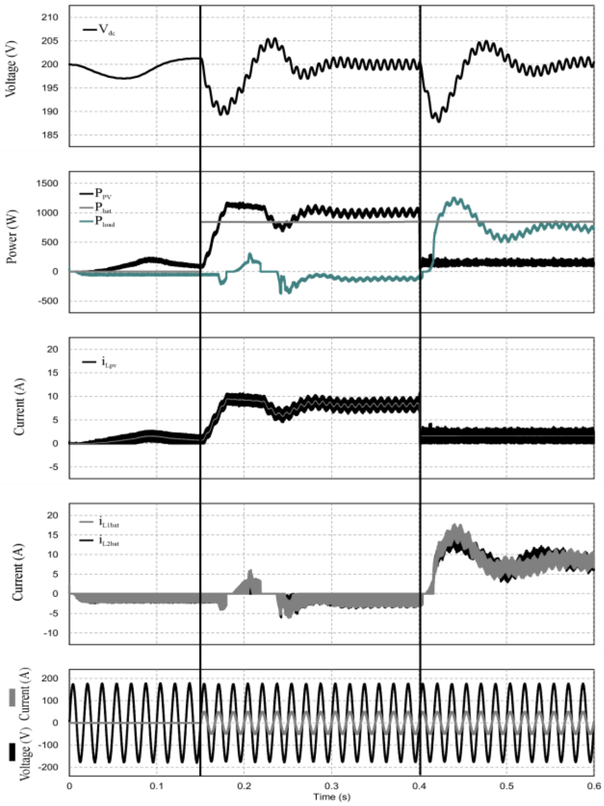

Fig. 6 Simulation results for transition modes from Buck to Boost modes under loads and irradiation variations

6. CONCLUSION

This paper proposed an off-grid PV system to provide the electrical energy in rural areas in Haiti. This system relates the use of an interleaved bidirectional converter with two power modules. The proposed control system is managed by the control of the power flowing which are: the input power from the PV module according the implementation of algorithm P&O, the power at the bus and the power injected/or extracted at the battery bank. The control is designed to regulate the dc bus of power via the input boost converter and the interleaved bidirectional battery-bank converter that interact together with a single loop control that regulate the power of them. The interleaved bidirectional is used to inject/or extract the power at the battery by using the UI method that can maximize the lifetime of the battery bank. It's worth to mention that, the output load is uncontrollable, then the regulation of the DC bus power is doing continuously for the input bus converter and also for the buck/ or boost mode of the interleaved bidirectional in order to have a good regulation of the power.

The simulation results validate the operation of the system by considering all operation modes described in the previous sections and can be extend to other remote areas where the electrical energy is weak.

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REFERENCES

Ahmed, M., Orama, M., Sleptsoy, (2016). Bidirectional Interleaved DC/DC Converter for Electric Vehicule Application. *IEEE, 11th International Forum on Strategic Technology (IFOST).*

Bellinaso, L. V. (2011). Controle Digital Aplicado a um Sistema Fotovoltaico Multistring Autônomo. Page 95, Trabalho de conclusao de curso (TCC), Universidade Federal de Santa Maria.

Bellinaso Lucas Vizzotto (2017). Inversores fotovoltaicos Conectados a Rede Com Armazenamento de Energia – Classificaçao, Recomendaçoes Tecnicas e Gerenciamento. P. 325**.** *Tese de Doutorado, Programa de Pós-Graduação em Engenharia Elétrica - PPGEE/UFSM,*

Bellinaso. L. V, Vieira. R. P., Gründling H. A., and Leandro. M, (2014). Adaptive control of PV boost converter for minimal passive components and fast maximum power point tracking. *IEEE Trans. Power Electron., vol. 4.*

Bentarfa D, Channouf N, Bensari H, Sekirifa M. L. (2019) The sizing of the isolated photovoltaic system (Domestic self-consumption) and economic comparison between the cost of this energy (price of KWh) and different sector). *IEEE, The 10th International Renewable Energy Congress (IREC).*

Bureau des Mines et de l'Energie Electricité d'Haïti (2007). Haiti: Plan de Développement du Secteur de l'Energie 2007 - 2017**.**

Cândido, D. B., Zientarski, J. R. R., Beltrame, R.C., Pinheiro, J. R., Hey, H. L., (2009*). Implementation of a Stand-Alone Photovoltaic System Based on Decentralized DC-DC Converters*. *Congresso Brasileiro de Eletrônica de Potência, COBEP, Bonito, Ms, Brasil*.

Cândido, D. B., Zientarski, J. R. R., Beltrame, R.C., Pinheiro, J. R., Hey, H. L (2010). Integrated Controlo of a Stand-Alone Photovoltaic System Based on Decentralized DC-DC Converters*. IEEE International Symposium on Industrial Electronics, ISIE, Bari, Italia. (Submetido).*

Cândido, D B., (2010). Desenvolvimento de Sistemas Estaticos Distribuidos –'Multistring', para Aplicaçao em Sistemas Fotovoltaicas Autonomos. p. 149. *Dissertação de mestrado apresentada ao Programa de Pós-Graduação em Engenharia Elétrica - PPGEE/UFSM*

Kim. I and M. Youn, (2006). New maximum power point tracker using sliding mode observer for estimation of solar array current in the grid-connected photovoltaic system. *IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1027-1035.*

Melo. R. R, Antunes F. L. M. and Daher S. (2014). Bidirectional interleaved dc-dc converter for supercapacitor–based energy storage systems applied to microgrids and electric vehicles*. IEEE, 16th European Conference on Power Electronics and Applications.*

Priyabrata S, Pradeep K. S, Sornnath M, Punit. K (2016). Modeling and Control of a Battery Connected Standalone Photovoltaic System. *1st IEEE International Conference on Power Electronics. Intelligent Control and Energy Systems (ICPEICES).*

Richard S, Jennifer H **(**2018). Assessement of Haiti's electricity sector.

Rosemback R. H, (2004*).* Conversor CC-CC Bidirecional Buck-Boost Atuando como Controlador de Carga de Baterias em um sistema Fotovoltaico, p. 139. *Dissertaçao apresentada ao Programa de Pós-Graduação em Engenharia Elétrica da Universidade Federal de Juiz de Fora*.

Schuch, L. (2001). Sistema CA/CC com um Conversor PWM Bidirecional para Interface entre o Barramento CC e o Banco de Baterias, p. 221, *Dissertação de mestrado apresentada ao Programa de Pós-Graduação em Engenharia Elétrica - PPGEE/UFSM*.

Schwertner C. D, Lucas V. B, Hélio L. H, and Leandro M. (2013). Supervisory control for Stand-Alone Photovoltaic System. 978-1-4799-0272-9/13/$31.00 *IEEE. Federal University of Santa Maria (UFSM,), Power Electronics and Control Research Group (GEPOC).*

Shenawy E. T. E, Hegazy A. H. and Abdellatef M. (2017). Design and Optimization of Stand-alone PV System for Egyptian Rural Communities**,** *International Journal of Applied Engineering Research ISSN* 0973-4562 Volume 12, Number 20 pp. 10433-10446.

Walker. G. R, Sernia. P. (2004). Cascaded DC-DC Converter Connection of Photovoltaic Modules. *IEEE Trans. on Power Electron.*, vol. 19, pp. 1130-1139, 2004.