

Insulated Hybrid Grid Based on PV System, Battery and Fuel Cell Car—A Case Study [†]

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Abstract: For insulated areas, careful exploitation of the available energy is a must. We are considering a scenario of an off-grid small resort, for which the electrical energy is available only from a photovoltaic (PV) system with a local battery (BAT) storage unit, while a supplementary energy source system could be considered: an electrical propulsion vehicle, i.e., a fuel cell (FC) car. This hybrid system is to be connected to the local three-phase microgrid used to ensure electric energy for in-house needs. This paper investigates through simulations the operability of this small microgrid, while its performances are evaluated to comply with the IEC 61000-2-2 standard in terms of voltage amplitude and current total harmonic distortion (THD).

Keywords: insulated smart hybrid grid; PV system; battery storage; fuel cell car

1. Introduction

For insulated areas where no electrical grid connection is available (for example, for a resort facility), the construction of a local microgrid is a must. Based on the available renewable resources, local microgrids can be put in place [1–4]. For the specific case where the main electrical energy needs are ensured via a photovoltaic (PV) system of 22 kW with its battery (BAT) storage capacity of 11 kWh, a possible extension of the energy availability can be obtained when considering an electric vehicle (EV) connected to the local microgrid via a bidirectional charging station [5]. More specifically, if the EV connected to the local grid is a fuel cell (FC) automobile, then through the consumption of hydrogen one can benefit from the necessary electricity during night periods or when even the BAT storage unit has a very low state-of-charge (SoC).

For isolated areas, like in our case, different renewable resources have been considered in the scientific literature, based on wind, solar, or hydropower, [3,4,6,7]. The same for the storage units [8–10]. In our case study, we have considered the common PV option, for which several techniques for maximizing the provided power are available (based on the PO-MPPT approach, using genetic algorithms, etc. [11,12]). Next, with respect to the storage unit to be attached to the PV system, a classic battery was considered, while for the EV, which can be connected to the grid, we have considered a fuel cell automobile since it offers the best autonomy among the electrified cars—which means that its energy can last longer in operation for our microgrid.

The goal of this study is to investigate the feasibility of such a microgrid. For this, we want to interconnect the “PV–BAT–FC car” hybrid system on a local grid of 22 kW, capable of ensuring the operability of a small resort at 230 V/50 Hz. A PO-MPPT [11,12] technique is employed for the maximization of the delivered power, while the following studied operation cases are considered: PV connected to grid, battery storage charging, battery connected to grid, and FC car connected to grid. The IEC 61000-2-2 standard will be evaluated in terms of voltage amplitude (± 10 V is acceptable) and the THD of the current's



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waveform (maximum 5%). For this, an appropriate 3-phase inverter connected to an LCL filter is used, while appropriate controllability is ensured via PI and PLL logic. The study and the validation of the research are made by means of simulated results.

2. The Designed Hybrid Smart DC Microgrid

The overall configuration of the studied system is given in Figure 1. Here, one can identify the PV system, which sends the appropriate voltage level by using a DC/DC boost converter (its controllability is ensured via the PO-MPPT technique). Next, we have the possibility to store the energy produced via the PV into a battery unit (BAT), which is included into the microgrid via a bidirectional DC/DC converter. To the same DC bus of the PV-BAT system's output, we have the fuel cell of an electric automobile. From this DC bus, we transfer the energy to the AC microgrid via a 3-phase inverter, which is controlled by using PI and PLL logic (for the axis currents and phase shift). Next, the inverter's output is filtered (with an LCL filter) and connected to our local grid of maximum 22 kW and 230 V/50 Hz. The overall logic for controlling the output AC power is depicted in Figure 2. Here, the PWM signals for the 3-phase inverter are generated based on PI current controllers and PLL for the phase shift calculation. The parameters used in the simulation are indicated in Table 1.

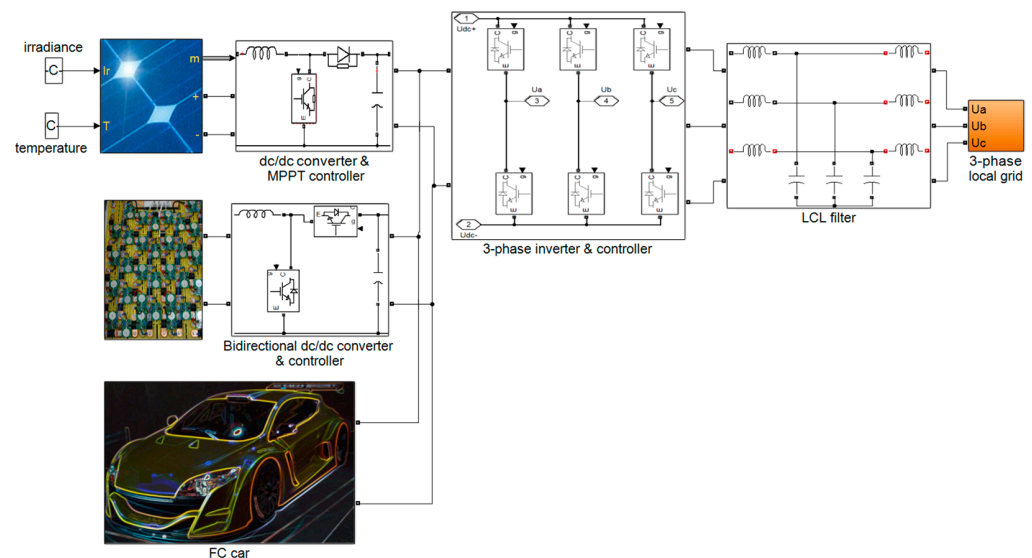


Figure 1. Overall structure of the local 22 kW/230 V/50 Hz microgrid, containing: a PV system, a battery storage unit, a fuel cell car, and the necessary electronic power converters and filter.

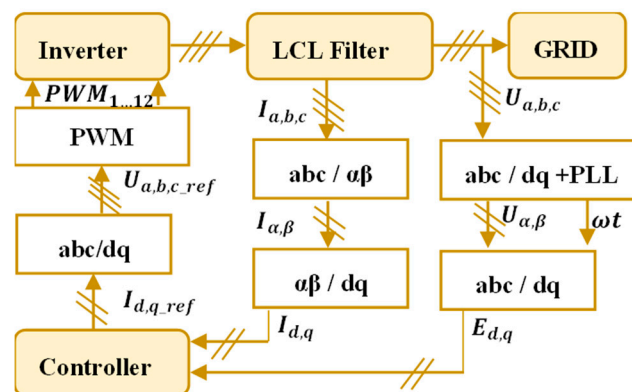


Figure 2. The logic for producing the PWM signals for AC power generation (22 kW/230 V/50 Hz).

Next, the simulation results of the analyzed system will be discussed to evaluate the feasibility of the local microgrid and the validation of the system for the given case study.

Table 1. Simulation parameters for the PV–FC–BAT system connected to the local microgrid.

Component	Parameter	Value and Unit
PV	Module SPR-445J-WHT-D	Matrix of 5 series and 10 parallel modules
	Output Power	22 kW
	Output voltage	380 VDC
BAT	Rated Voltage	240 V
	Rated Capacity	48 Ah
FC	Power	50 kW
	Output voltage	625 V
DC/DC converter	Boost Inductance	3.8 mH
	Boost Capacitance	49.154 μ F
LCL filter	Inductance	1.1 mH
	Capacitance	100 μ F
3-phase inverter and controller	Switching frequency	12 kHz
	Direct axis current coefficients	$K_p = 5/K_i = 5000$;
	Quadrature axis current coefficients	filter inductance 2.2 mH
	PLL	$K_p = 10/K_i = 20$; filter inductance 2.2 mH
		$K_p = 10/K_i = 50,000$

3. The Simulated Results of the Hybrid Microgrid

3.1. PV Connected to the Local Grid

First, we will evaluate the production of energy coming from the PV, while the IEC 61000-2-2 standard conditions will be verified (see Figure 3).

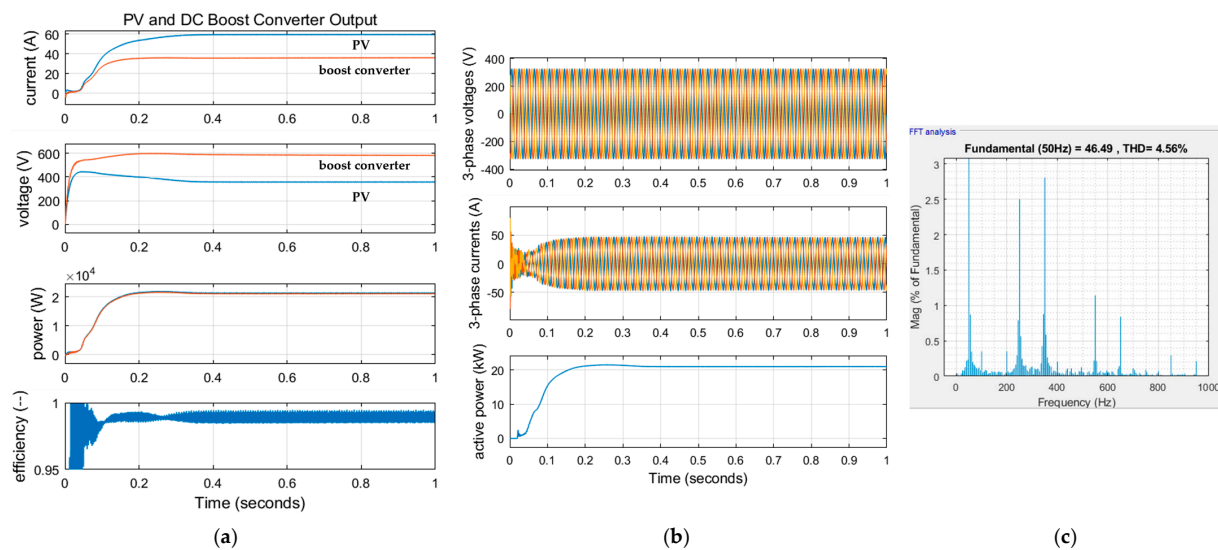


Figure 3. PV connected to local microgrid via electronic converters: (a) PV and boost converter characteristics; (b) grid characteristics; (c) THD for phase current.

In Figure 3, one can see the output voltage of the PV, which is next boosted to 600 V (Figure 3a), at the input of the inverter, which is now capable of ensuring the 230 V/phase voltage (Figure 3b), while the 22 kW power is offered to the grid. Thus, the AC electric power needs are ensured for our isolated resort facility. The quality of the produced energy is also proven, since the desired voltage amplitude was reached (230 V/phase), while the current THD is below 5% (4.56% to be more accurate).

3.2. PV Charging the Battery as a Local Storage Unit

The charging of the storage unit, the battery, is also investigated. We have accepted a higher current than the rated one (i.e., 60 A—which means that the charged power is

also more than the rated one of 11 kW) for the sake of presentation (or for a better state-of-charge evaluation). The electrical characteristics of the PV's output (Figure 4a) as well as the charging characteristics of the BAT (Figure 4b) are shown—here we have considered a 10% initial state-of-charge for the BAT. Thus, we have proven the operation of this scenario. Next, the battery–grid operability will be investigated.

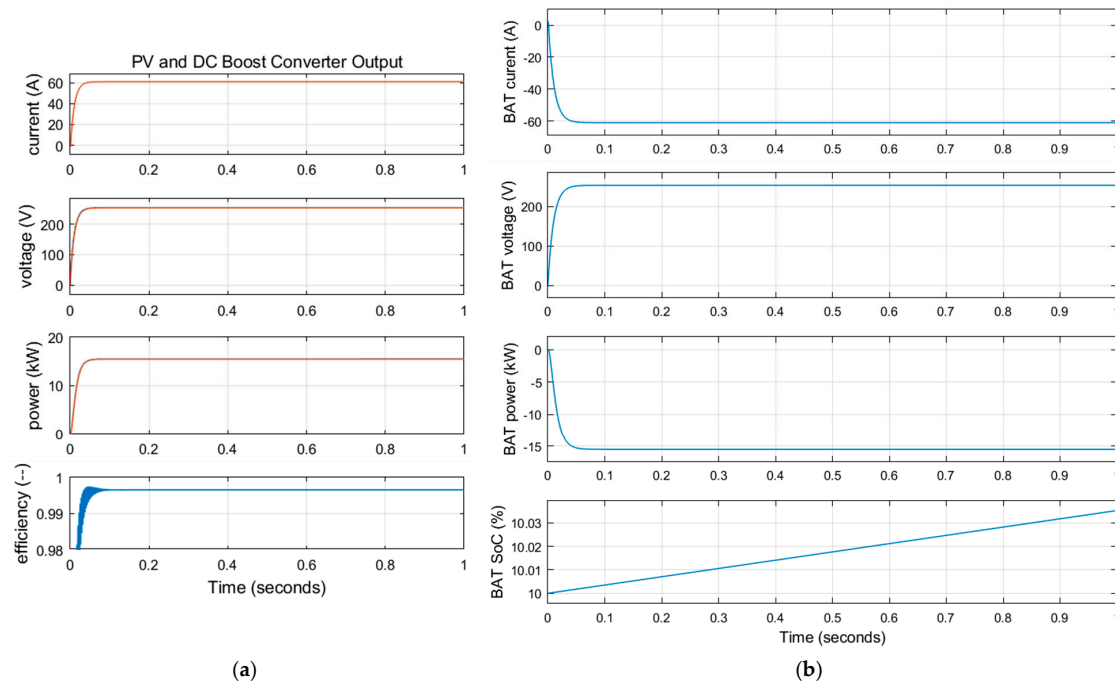


Figure 4. BAT charging via PV: (a) PV characteristics; (b) BAT characteristics.

3.3. Battery Connected to the Local Grid

For this scenario, the bidirectional DC converter is used to boost the voltage at the inverter's expected input, 600 V, relying on a voltage PI regulator with the following parameters: $K_p = 10^{-5}$, $K_i = 0.05$. In Figure 5a, one can see the grid electrical characteristics, with the expected output power, voltage amplitude, and RMS current. On the other hand, in Figure 5b one can see the THD of the phase current, which is, again, below the expected 5%—2.61 to be precise. Thus, this scenario is also validated.

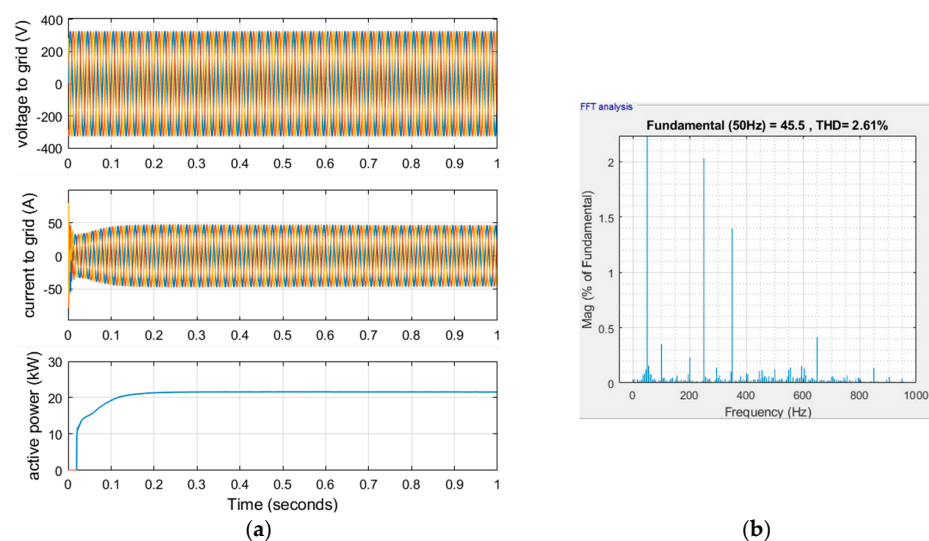


Figure 5. BAT connected to local grid via bidirectional converter and 3-phase inverter: (a) grid characteristics; (b) THD for phase current.

Therefore, we can next investigate the operation of the FC car connected to the local microgrid.

3.4. FC Car Connected to the Local Grid

For the last scenario, when our FC car is connected to the DC bus of the microgrid, the simulated results are shown in Figure 6. First, the characteristics of the FC, with a very good efficiency level of 65% at about 45% of load (the FC is of 50 kW), are shown in Figure 6a; next, the rated operating point of 22 kW-230 V/phase-50 Hz is depicted in Figure 6b, proving the fulfillment of the voltage criterion from the IEC 61000-2-2 standard; finally, in Figure 6c, one can see the THD of the generated grid current, which is at a very low level: 1.19%. Thus, based on the depicted simulated results, we can conclude that the good operation of the FC car to grid is also validated.

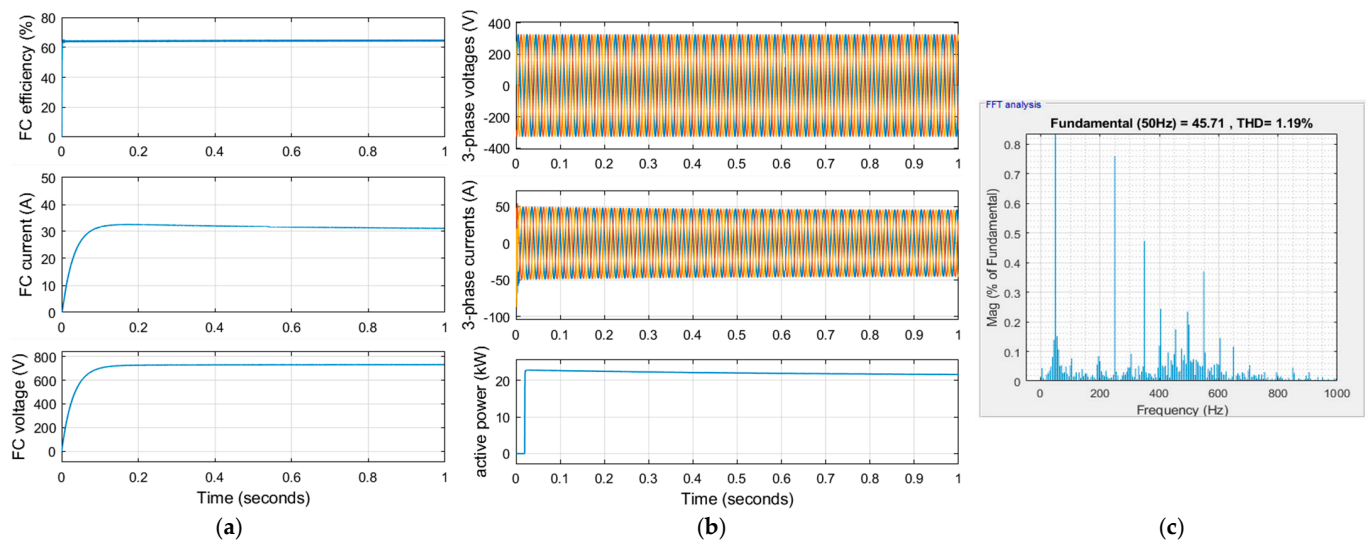


Figure 6. FC car connected to local grid via 3-phase inverter: (a) FC car characteristics; (b) grid characteristics; (c) THD for phase current.

Thus, the operation of all scenarios has been validated, and since the conditions of the IEC 61000-2-2 standard have been fulfilled, we can conclude that the study was numerically validated.

4. Conclusions

In the case of a small resort facility, separated from the wired AC grid, the authors have proposed the elaboration of a microgrid designed to work with a hybrid source system based on photovoltaics (PV), a battery (BAT), and a fuel cell (FC) car—the electric energy of the FC automobile being recovered with a bidirectional local charging station, while hydrogen is consumed by the FC car. The three subsystems are connected to the same DC bus, while several pieces of power electronic equipment were used: a DC/DC converter for the PV, a bidirectional converter for the BAT, a three-phase inverter, and an LCL filter for the electric energy transfer between the components and the AC microgrid. The simulation parameters of the components as well as of the controllers used to manage the energy transfer were given in the manuscript. Beside the demonstration of the operability of the proposed system, the authors were interested in evaluating the quality of the produced energy based on the IEC 61000-2-2 standard conditions: ± 10 V for the phase voltage and current's THD below 5% THD. In all studied scenarios, the voltage amplitude was attained, while for the PV-grid, BAT-grid, and FC car-grid cases, the current's THD was 4.56%, 2.61%, and 1.19%, respectively, proving the desired results.

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