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Optimized energy management of a residential microgrid: interconnected nanogrid system

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ABSTRACT

The use of renewable energy is essential to reduce the consumption of final energy used in the residential and tertiary sectors. For their effective integration in buildings, the main obstacles to be overcome are the design of multi-source systems (where renewable sources coexist with conventional sources), their design and their control - command. The objective is to obtain an optimal system from an economic and energy point of view. Because of the spread of the use of renewable energy to achieve energy self-sufficiency in remote areas, microgrids can lead to sustainable development of clean power systems but they pose challenges to a reliable energy supply because of its intermittent nature. This article presents a microgrid model including a PV. The purpose of the energy management system (EMS) is to provide a reliable and optimal generation from multiple sources in the microgrid. The idea is based on exchanging intermittent energy between the houses of a local community. Each house is equipped with an AC nanogrid including photovoltaic panels. These nanogrids are equipped with a network controller that the power can be exchanged between the houses on an external AC power bus. In this way, the fluctuations in response to demand are absorbed between nanogrid to improve reliability, energy management and complementarity nanogrids.

KEYWORDS;-Nanogrid, interconnected operation, microgrid, energy management, exchanging.

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I. INTRODUCTION

Energy production remains strategic in the long term, thus global energy consumption increases by around 2% per year while we are faced with a reduction in primary fossil resources. Furthermore, with regard to greenhouse gas emissions, it is recognized as being a major risk concerning the future of our planet. Under the Kyoto Protocol, the Bali plan, the Cancun agreements and certainly from what will emerge from the Durban conference, the use of a few conventional resources such as coal, oil, nuclear energy, etc. would be limited or discouraged for environmental reasons. Renewable energies such as wind energy, solar energy, hydroelectric power and biomass will have to play an increasingly important role. In this context, in September 2001, the European Union adopted the Directive relating to the promotion of electricity produced from renewable energy sources on the internal electricity market. The objective of this directive is the promotion and future exploitation of the potential of renewable energy sources. Renewable energy means energy from the sun, wind, heat from the earth, water or biomass. The sector studied in this thesis is photovoltaic solar energy. Solar photovoltaic (PV) energy has been growing rapidly for a few years because it is an inexhaustible source, non-polluting for the environment, silent and not disturbing for local residents. [1].

On the other hand, the topology of the electrical system has not changed since its creation in the early 20th century. At that time, a centralized architecture was implemented, the electricity being produced in very high-power plants, transported between regions by very high voltage networks and distributed to consumers by medium and low voltage networks [2].

This architecture was the one that best met the requirements of the time; it also ensured a rapid development of the network and quality of supply. However, in recent years, this system begins to be questioned in order to enable a broad liberalization of the electricity market and increasing the share of electricity generation from renewable resources by maintaining high-energy quality to final consumers [3].

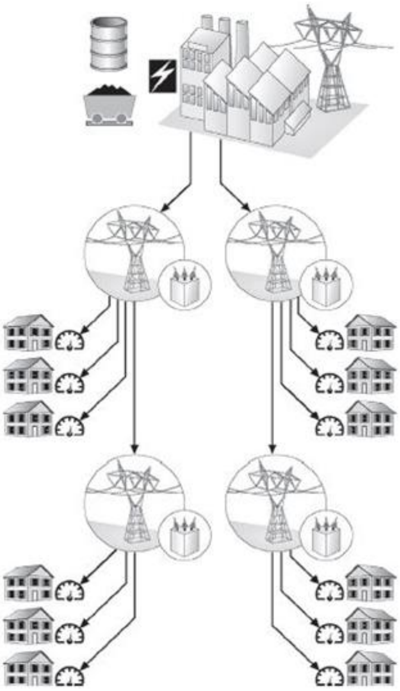

Figure1: Traditional Grid

In the current electrical system Figure 1, the generation of electricity is carried out rather in large power plants. These plants are supervised and controlled by the dispatch center of the transport network. The transmission system operator receives information for consumption from transformer stations and distribution network operators. The decentralized generation is perceived by the network operators as a passive (uncontrollable, sustained) charge of negative power, it is not controlled and the power generated is estimated solely on the basis of forecasts. Once the distributed generation exceeds in terms of power the consumption on a branch of the network, this can cause difficulties at the local level at all the other levels of the electrical system.

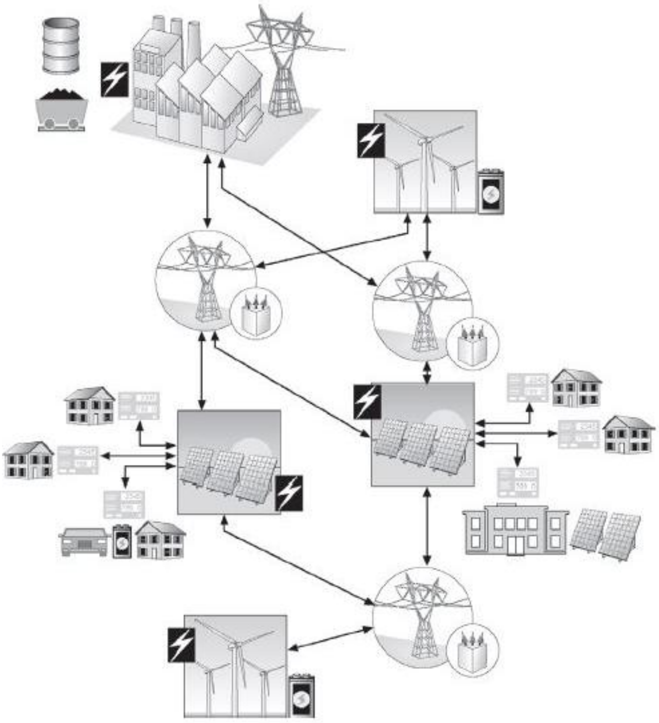

Figure2: Smart Grid

In the concept of "smart grid" Figure 2, distributed generation and consumption are controlled locally in an optimum manner, by central controllers and, in this way, each set of local decentralized generators, fillers and storage devices appear to the operator of the distribution network as a single entity that can act either as a consumer, either as an electric energy producer. In this way, it is easier to predict consumption and production with a small horizon and thus the information that the other actors of the electrical system receive would be more, which makes it possible to optimize the whole of the electrical system [4].

The microgrid energy management strategy comes down to judicious and efficient use of energy in order to maximize profits (minimize costs) and improve the competitive position. Management units requires a specific economic model to describe the operating cost, taking into account the power output produced. Such a model is naturally discrete and non-linear; therefore, optimization tools are necessary to reduce operating costs to a minimum level [9] - [10]. The management of the MG unit requires a precise algorithm to identify the operating cost and emission function taking into account the consumer's energy demand.

The microgrid concept (MG) has been proposed as a promising solution to recurring challenges in order to reduce the complexity of the system and improve the quality and reliability of power for local consumers. In fact, MG is using more control and management systems to monitor this transformation and respond effectively and sustainably to operation requirements such as stability, security, quality of energy in transit and continuity of service [11]. Recently, several researchers are an interest to propose control and management strategies to provide solutions to the problems posed by the massive integration of distributed resources, which offer more DGs integration capacity [12][13].

All this context, challenges / problems mentioned above, allows us to imagine a power system that is becoming increasingly complex and is not well controlled. Microgrids are sometimes called sustainable communities, because of the strong emphasis on energy management and the optimal use of renewable energy sources [14].

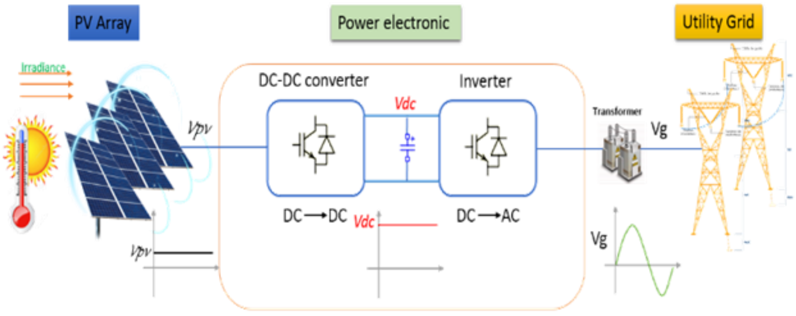

Figure3: PV system connected to Grid.

A nanogrid can be thought of as a small microgrid that generally has a single charge. Since it faces fewer technical and organizational obstacles than their microgrid counterpart does, an interesting deployment is already underway [15]. Therefore, a nanogrid, compared to the microgrid, is considered a bottom-up approach.

In the context of this article, we are interested in the study of autonomous microgrids dedicated to photovoltaic applications. The objective of this work is to propose a certain number of solutions allowing the creation of interface converters for high performance autonomous networks. The integration of the solar sector in the form of autonomous photovoltaic systems responds perfectly to a large number of applications such as the electrification of rural habitats, on-board applications, telecommunications, etc.

The energy produced is generally used on site, without losses due to transport. The minimization of the production-consumption distance makes it possible to minimize the harmful effect caused by the interactions between the impedance of the microgrid and the associated power electronics (stability problem).

The first session is devoted to describing and modeling study system that contains three nanogrids interconnected with each other and connected to the grid. The second session is to present the method based on an interconnection algorithm for communication between nanogrids. The last part presents the Matlab simulation results of the studied system.

II. DESCRIPTION AND MODELING OF THE STUDY SYSTEM

In this article, we describe a method of sharing energy in AC mode between houses by sharing consumption and production data in each house. As shown in Fig. 4, the energy-sharing framework can be described from the point of view of energy self-satisfaction. [16].

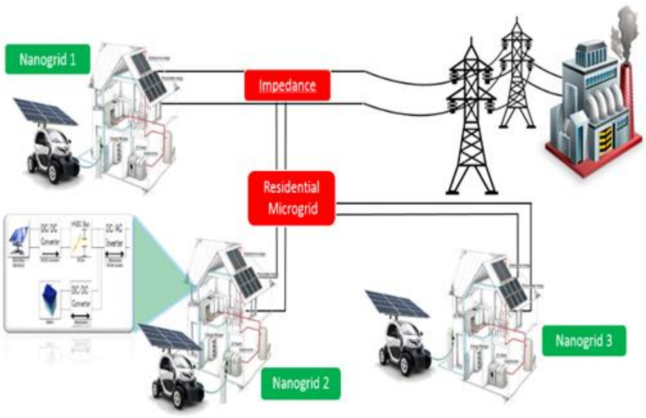

Figure 4: overview model a multiple nanogrids interconnected via AC bus

A. Tracking of maximum power point

The main objective of the MPPT controller (Maximum Power Point Tracking) is to achieve the maximum energy production of PV systems since the panels vary with environmental conditions as discussed in Figure 5 and Figure 6, the P & O algorithm is one of MPPT algorithms most commonly used has been selected in this work since is the simplest in terms of complexity [23], [24], [25].

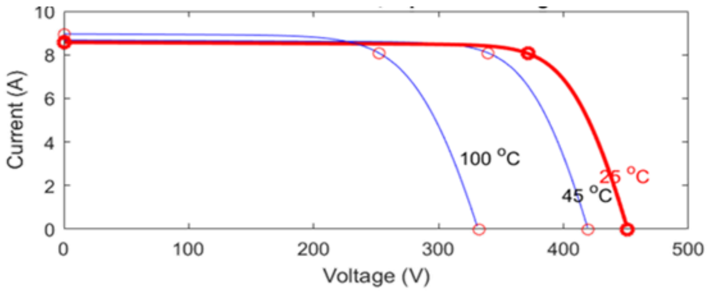

Figure 5: I-V characteristic

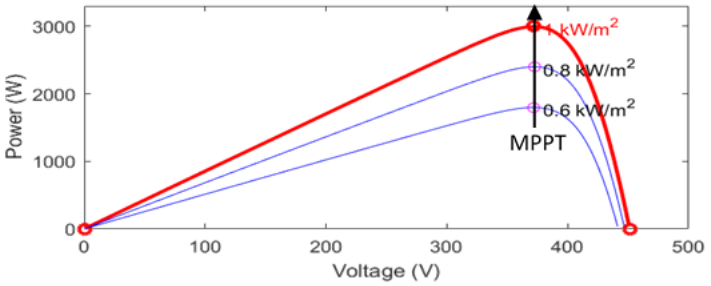

Figure 6: P-V characteristic

B. Grid connected operation

The DC / AC converter (the inverter) is the essential device for ensuring the interface of all DGs systems to AC buses (distribution networks, alternating loads). Otherwise, all DC power generated by each DG must use an inverter to convert the DC voltage to an AC voltage with the desired amplitude and frequency.

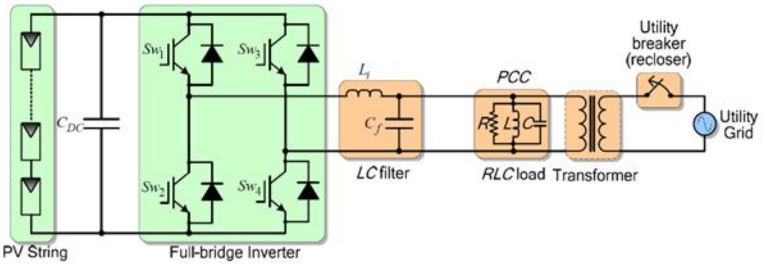

Figure 7: single-phase AC inverter

Figure 7 illustrates the electrical circuit of a single-phase inverter. This power electronics interface offers great flexibility and allows the DG to function as a semi-autonomous power system.

C. Grid-side inverter control

The aims of the control applied on the inverter is to export the power with the established voltage. The role of the phase current component is to control the power generated. The controller receiving data power demand from the prediction values, operates DG units is in a constant output power or a way of following charge [17].

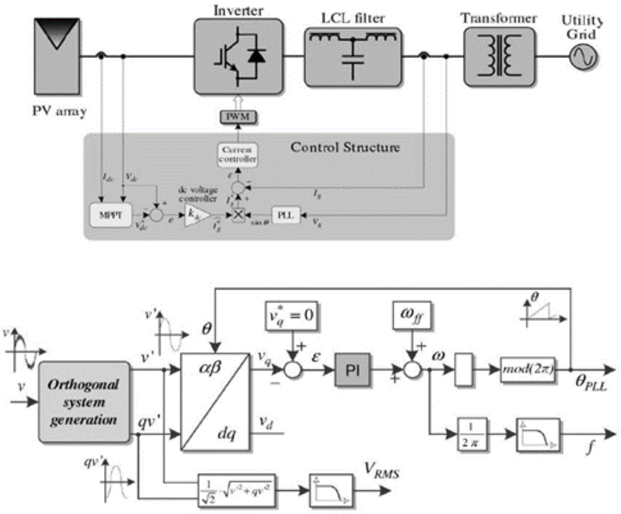

Figure 8: Grid-side inverter control

In Figure 8, the closed loop controller ensures that the output current follows the reference value with zero stable state error [18].

D. PI current control scheme

Figure 9 below shows the PI current controller with the grid voltage (vg), ig is the inverter output current which is used as feedback, i* is the inverter output current reference and v* is the inverter voltage reference.

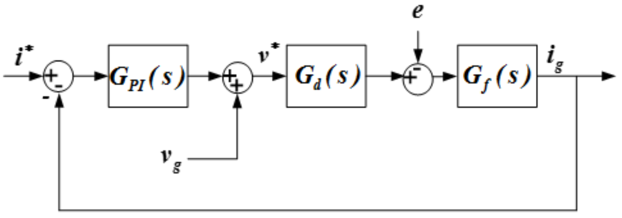

Figure 9: The current loop of PV inverter with PI controller

The PI controller GPI(s) is represented by:

$$G_{PI}(s) = K_P + \frac{K_I}{s} \quad (1)$$

When Gf represent the LCL filter and Gd represent the processing delay of the microcontroller.

E. PR current control scheme

The ideal resonant controller, which is given by (1) and in Figure 9, can be mathematically derived by transforming an ideal synchronous frame PI controller to the stationary frame and achieves infinite gain at the AC frequency of ω0 to force the steady-state voltage error to zero, no phase shift and gain at other frequencies. For Kp, it is tuned in the same way as for a PI controller.

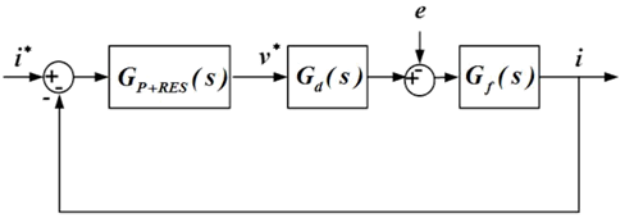

Figure10: The current loop of PV inverter with PR controller

The gain of PR controller is much reduced at other frequencies and it is no adequate to eliminate the harmonic influence caused by grid voltage. Therefore, an approximating ideal (non-ideal) PR controller, The resonant controller can be obtained via a frequency shift is given by (2), using a high-gain, low-pass filter is used to solve the problems mentioned above [9]-[10].

$$G_{P+RES}(s) = \frac{2K_i\omega_0 s}{s^2 + 2\omega_0 s + \omega^2} \qquad (2)$$

F. Basic concept of the Droop

Consider that among the important tasks in the microgrid, voltage / frequency stability and precise load sharing. These tasks can be better using droop control and all its derivatives (droop control based virtual impedance loop, adaptive droop control, and robust droop control) [19]. In addition, a higher value of droop gains improves the accuracy of power sharing, but increases the frequency / voltage deviation from their normal values, which results in a compromise [20].

When the inverter output impedance is highly inductive, the active and reactive power drawn on the bus can be expressed equations (3) and (4)

$$P = \left(\left(\frac{EV}{Z}\right)\cos(\varphi) - E^2/Z\right)\cos(\theta) + \left(\frac{EV}{Z}\right)\sin(\varphi)\sin(\theta) \quad (3)$$

$$Q = \left(\frac{EV}{Z}\cos(\varphi) - \frac{E^2}{Z}\right)\sin(\theta) - \frac{EV}{Z}\sin(\varphi)\cos(\theta) \quad (4)$$

Which V is the amplitude of the output voltage of the inverter, E is the amplitude of the voltage of the common bus is the phase of the voltage of the converter. Z and θ are respectively the amplitude and the phase of the output impedance.

For an inductance transmission line, θ =90° equation (3) and (4) can be written as:

$$P = \frac{EV}{Z}\sin(\varphi) \quad (5)$$

$$Q = \frac{EV}{Z}\cos(\varphi) - \frac{E^2}{Z} \quad (6)$$

If φ is small: $P = \frac{EV}{Z}\varphi$ (7)

$$Q = \frac{E}{Z}(V - E) \quad (8)$$

In the inductive wires of the AC microgrid, the conventional frequency droop control is expressed in equation (9) and (10) [21].

$$\delta = \delta_0^* - m(P - P^*) \quad (9)$$

$$V = V_0^* - n(Q - Q^*) \quad (10)$$

Where and are respectively the nominal frequency and voltage, and are the set points of the active and reactive powers, and are the coefficients of control droop active and reactive. The frequency and voltage control characteristics are illustrated in Figure 11.

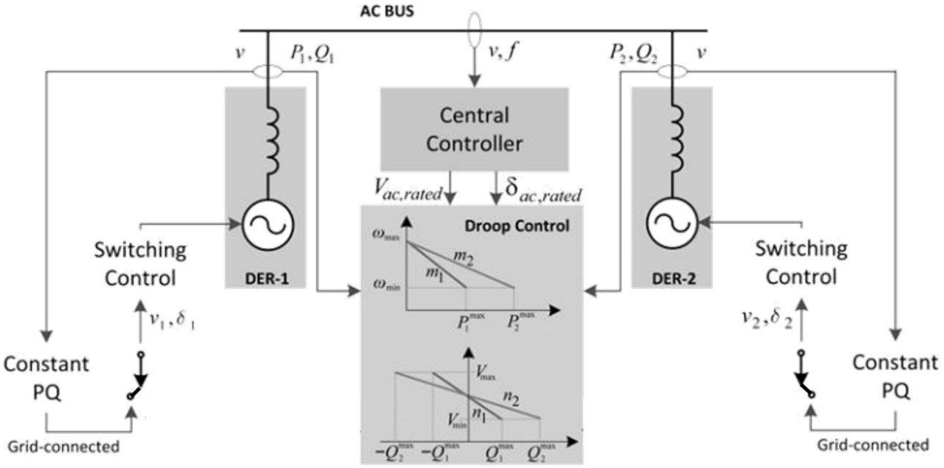

Figure 11: Control block diagram of the PVs in the AC nanogrid.

G. Nanogrid system

Our nanogrid can be defined by a set of elements such as:

- A power source that can be photovoltaic panels, wind turbines or a DG generator.
- A supply load that can be an AC and / or DC load.
- If it is possible to have a storage device (battery).
- A controller in each house is required for basic control of all internal elements.

Figure 12: model of nanogrid system

In this work, all nanogrids are simple consumers of energy. Thus, the nanogrid includes a power source defined by 3.5kw PV panels, an AC load with a variable load, an inverter allowing connecting the nanogrid to the grid and controlling all the internal elements with the possibility of guaranteeing system stability and frequency synchronization with the grid.

III. PROPESED DISTRIBUTED CONTROL METHOD

Our system can be defined by of nanogrids that are interconnected at AC bus as shown in Figure 13 each building is equipped with an alternating current nanogrid, energy sources (photovoltaic panel) and variable loads. These nanogrids are then interconnected on an AC power bus with neighbors to form a community-wide AC microgrid, as shown in Figure13.

The DC-AC converters are used interface between nanogrids: they allow to actively control the flow of energy and to disregard the design of internal nanogrid.

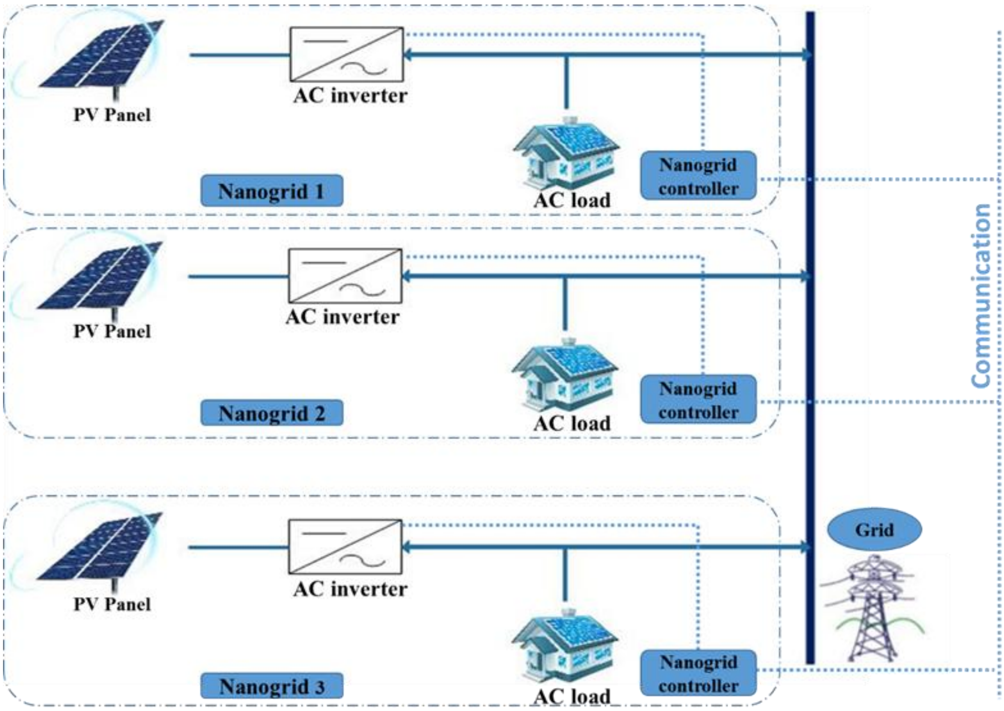

Figure 13: A cluster of multiple nanogrids interconnected AC microgrid.

For this, power sharing can be done within a community to help balance demand response requirements and consequently increase self-sufficiency, without requiring the grid but always being connected to the grid for the when needed. The Microgrid AC simulation system consists of three sources of distributed energy with the same power value of the photovoltaic panels installed in each building but with variable AC loads. The control logic is based on the request and the response of each nanogrid, the algorithm process all data (load, PV power) and calculate the need or excess energy and subsequently seek a requirement that and try to recover their energy need, when all the nanogrids satisfying the rest will be injected on the grid, as shown in Figure 14.

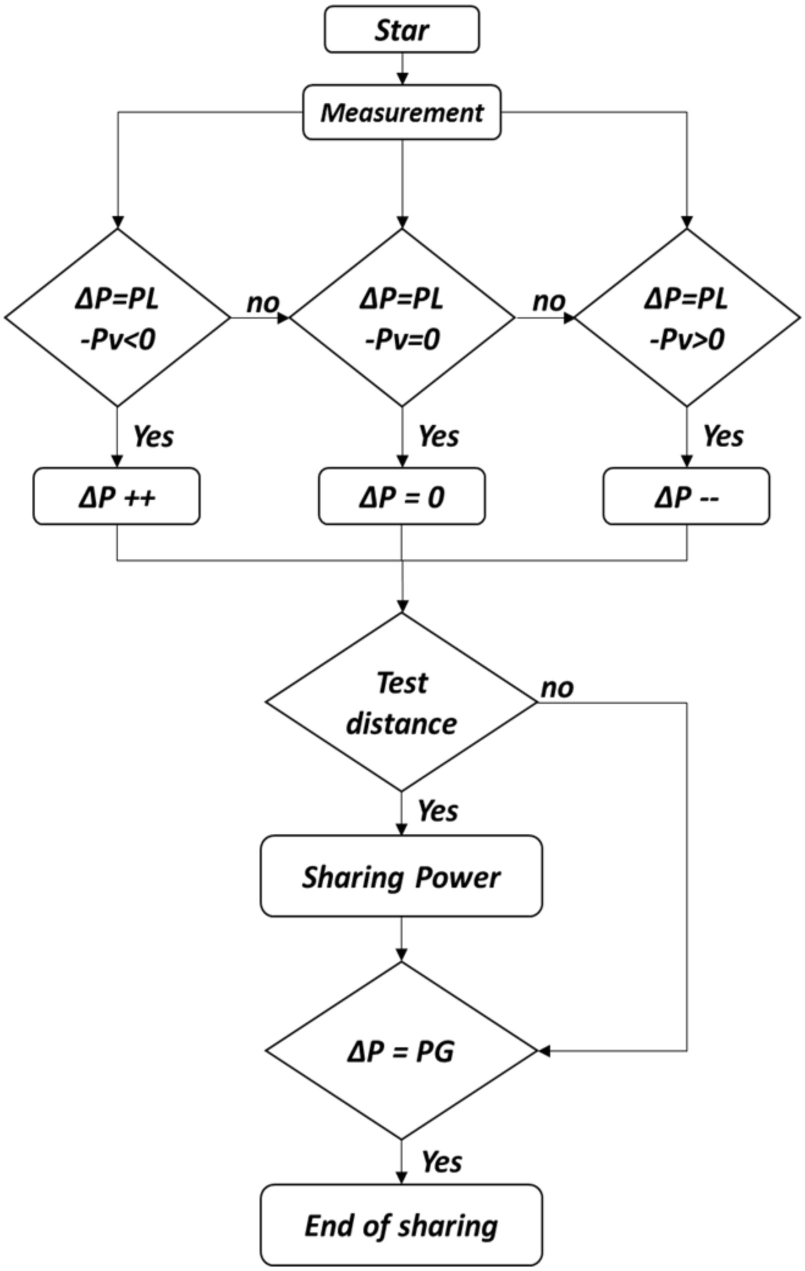

Figure 14: Flow Chart of load sharing.

Where P_v and P_L are respectively the power of photovoltaic panels and the power load. There are scenarios in the trading strategy that is used to decide the demand or inject of energy. After having tests at the level of each building based on the difference between the powers produced by the photovoltaic panels and the load. In another level, another test will be scheduled for those who have requested and those who have excess energy. Thereafter, the exchange will be made between nanogrids until energetic self-sufficient. In case and after exchange they remain in need, the grid recover this need.

IV. SIMULATION RESULTS

The proposed control strategy is constructed through Matlab / Simulink to verify the feasibility of desired performance. Table 1 gives the power system and the proposed controller parameters.

Table 1: PVsystemparameterspower

PV power	14 panels = 3,5 kw Pv1 = 3.5kw; Pv2 = 3.5kw Pv3 = 3.5kw
converter inductor	Lb = 1,8 mh
PV capacitor	Cpv = 3000 µf
LCL-filter	Linv = 2 mH, Lg = 4 mH, Cf = 4.7 µF
DC-link capacitor	Cdc = 1100 µf
switching frequency	Boost converter: fb = 16 khz, inverter: finv = 2khz
DC- link voltage	Vdc = 450 v
Grid voltage	Vgrid = 230 v
Grid frequency	ω0 = 2*π*50 rad/s
Parameter PI	Ki=12 , Kp=200
Parameter PR	Ki=0.3 , Kp=80

To check for proper energy management in this system, the simulation model shown in Figure 4 is constructed using the Matlab / Simulink software, and the system is configured as shown in Table 1. It is assumed that the model constant lighting in all nanogrids is adopted for the PV due to similar weather conditions in the same city.

Table 2: Configuration of demand load

demand(kw)/ time(s)	0-1.5	1.5-2.5	2.5-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Load 1	2	2.5	2	3	2	2.7	2	2	2	2
Load 2	2.5	4	2.5	3	2.5	3.3	2.5	2.5	2.5	2.5
Load 3	3.5	4	4	3.5	3.5	5.5	4.5	3.5	3.5	3.5

Simulation 1: The scenarios define the exchange strategy used to decide whether to request or accept a power agreement (decisions in gray boxes on the flow diagram in Figure 8). The scenario currently used is based on need as shown in Table 2. A request is sent when a building consumes more than the energy produced by PV.

With the control method proposed in this article, three PV units with a capacity of 3.5 kW are connected to the bus in parallel. The energy management strategy based on power sharing proposed in this study is used.

At the beginning, all the buildings are connected with the grid due to avoiding the risk of breakdown or the energy isolation of the city. The system begins to read the values of each building such as the power produced by the photovoltaic panels installed on the roof of the building and the load power and to differentiate between them to decide the building status (demand or excess).

At t = 1.5s the load profile of each building starts has changed as follows PL1 = 2.5kw, PL2 = 4kw and PL3 = 4kw, building n ° 1 shares the power since it has an excess of 1kw with those that need energy (building n ° 2 with 0.5kw and building n ° 3 with 0.5kw). This sharing is done using the algorithm illustrated in Figure 8. In this case, the city will achieve energy self-sufficiency without needing the grid.

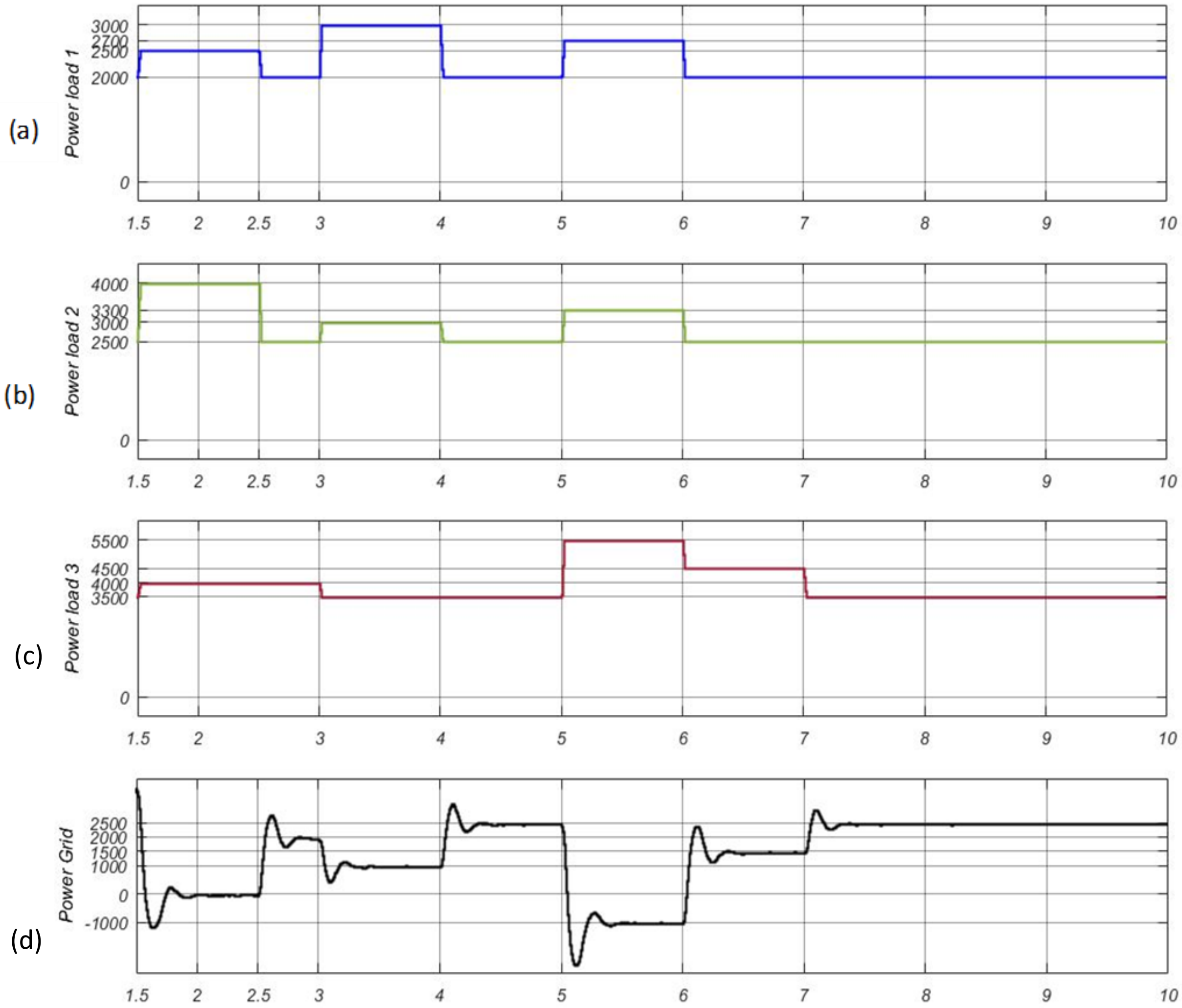

Figure 15: Simulation results of AC bus: a) AC load 1 active power, b) AC load 2 active power, c) AC load 3 active power, d) AC grid active power

Simulation 2: At t = 4s, the load profile of each building has changed as follows PL1 = 2kw, PL2 = 2.5kw and PL3 = 3.5kw, building n°3 has sufficient energy since the power produced by the panels will be consumed. The building n°1 and n°2 have an excess of energy respectively of 1.5kw and 1kw which consequently will be injected in the grid as indicated in the figure 15.

Simulation 3: At t = 5s, the building load profile has changed as a result PL1 = 2.7kW, 3.3kW = PL2 and PL3 = 5.5kw, Building n°1 has a 0.8kw of power surpluses and building n°2 a 0.2kw of surplus energy. The block n°3 is a need to 2kw which consequently will be covered by those that have excess production, but in this case the sharing of power between the buildings do not meet the need for it the rest (1 kw) will covered by the grid as shown in figure 15.

In order to have an intelligent management algorithm has a test on the distance and it will be done when power sharing between buildings decides to share power with those who are closest to minimize energy loss in the lines.

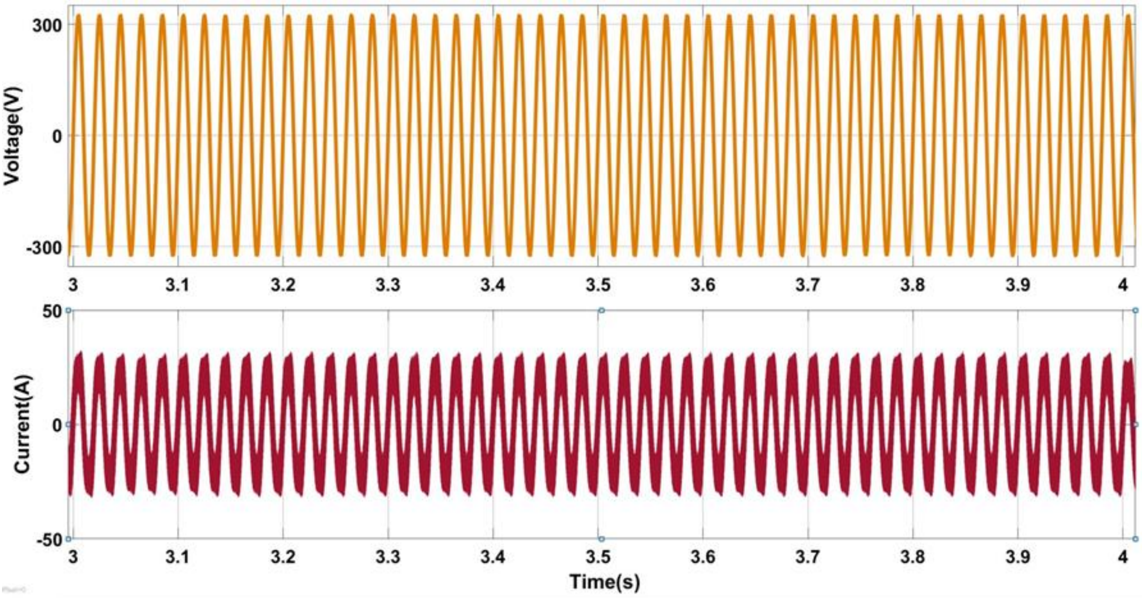

Figure 16: Current and voltage inverter.

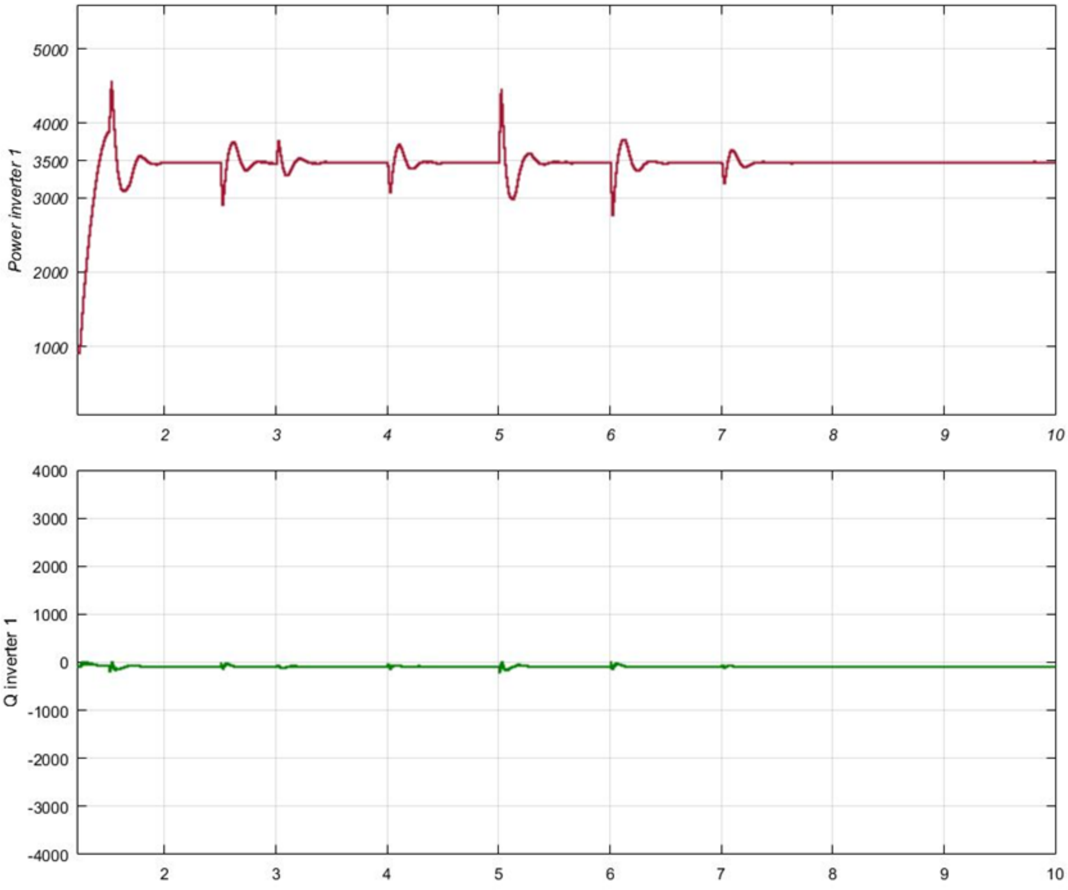

Figure17: Output power (active and reactive) of the PV generator.

V. CONCLUSION

The objective of this research is to provide a detailed and comprehensive review of various microgrid control levels, which is very important in the development of smart microgrids. This article analyzes a hybrid grid system that interconnects nanogrids to a micro network in which energy is exchanged via an automatic exchange algorithm. It explores such alternative network system that can develop in parallel to the existing network system but works independently and is connected with the grid when needed energy. This sharing of power increases the self-sufficient group of building using the control technique of subsidence to avoid gaps encountered. This study considers the same profile of photovoltaic capacity in all nanogrids with a variable load profile. Hoping that this method will be used in an applied experiment.

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