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Simulation and performance of Optimal Power Improved Energy and Optimized Electrical Architectures of Photovoltaic Systems

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Abstract- This paper presents a simulation and performance of optimal power improved energy and optimized electrical architectures of photovoltaic systems the concepts that must be understood to use Multi-Agent Systems for the control of distributed energy systems incorporating renewable energy sources. The objective of this paper is to show the way that photovoltaic converter topologies have made from centralized converter to distributed power system. In this paper, different photovoltaic converter topologies are analyzed, the purpose of Solution PV is to design and optimize architectures of the energy conversion chain, monitoring, and control strategies from the PV module to the utility-grid in order to increase the reliability of installations pointing out the advantages and drawbacks for each of them. Moreover, we will focus on the converter optimizer structures, analyzing their electrical structure solution that is present in the scientific literature. We finish with the studies of existing solutions to improve efficiencies and lifetime. We simulated and compared the different conversion configurations in order to find the best one in terms of efficiency and energy produced.

Keywords: Distributed power systems, MAS Multi-Agent Systems, Photovoltaic Generator, Converter optimizer, Inverter.

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1. INTRODUCTION

In order to handle inherent uncertainties of renewable sources, it is necessary to design controllers able to implement the interface between the grid and the renewable energy systems. The controller must be capable of intelligent and suitable responses to changing environments. In the next generation of grid connected renewable energy systems, the inverters will be the core enabling technologies for the growth of large-scale energy systems. These more intelligent inverters with advanced control features will improve the performance and controllability of future renewable energy systems. The inverter is the intelligent device of the energy conversion system. It has the capability of sensing and storing a wide variety of environmental conditions. By reacting to these changing conditions, the inverter will improve the system's health. Furthermore, the inverter can be used in a distributed control system by taking advantage of the implemented intelligent algorithms and the communication ability of the inverter. This feature will increase the penetration of renewable energy systems by facilitating their connection to the conventional electrical grid. The use of intelligent inverters will increase the reliability of renewable energy systems by improving the quality of the power transferred to the grid. Among the functionalities that inverters are capable of, we find: reactive power control, phase balancing, harmonic cancellation. In renewable energy distributed energy systems, the inverters enable renewable energy systems to ride through grid disturbances, operate in islanded or micro grid modes [1]. Solar energy could be one of the significant sources as an alternative energy for the future. In regard to endless importance of solar energy, it is worth saying that photovoltaic energy is a best prospective solution for energy crisis [2]. Due to environmental awareness, renewable energy penetration in power generation and distribution is continuously increasing. This causes many problems when the distributed renewable systems are connected to the main conventional grid. Many researches had been conducted on distributed energy systems. The scientific community addressed many issues including technical, environmental, and economic issues. They generally represent an important part of the size, weight, and cost of the equipment and can reduce its global lifetime [3]. The architecture of the power converter is important in a PV system. This structure determines the main characteristics of the photovoltaic installation, as the amount the PV modules need for the PV system and its type of connection. The effect of the partial shadowing or mismatch between PV modules in the energy production will also depends on the type of the architecture.

Nevertheless, the price and cost of the PV also depends on the choice of the architecture. In resume, the choice will involve a bigger or smaller energy production and efficiency as well as an importance difference in the cost. For this reason, it is important to know different types of architecture in order to choose the correct PV architecture for each PV installation [4]. Centralized control systems may be able to solve a given problem using powerful computational tools. However, as the complexity of the energy systems increases, computational and communications overheads become a significant problem. To get ride through these issues, decentralized control is an ideal solution, because data are locally processed and only the results are transferred, computation time and communications are considerably reduced.

This work studies the use of the multi-agent technology .For the control of distributed energy systems and power electronics interfaces. The multi-agent concept is well suited for the control of distributed energy resources to achieve higher reliability, higher power quality, and more efficient power generation and distribution.

2. MULTI-AGENT SYSTEMS (MAS)

Agent-based systems technology has generated lots of interest in recent years because of its promise as a new paradigm for conceptualizing, designing, and implementing power control systems. This is particularly attractive for power systems that operate in open and distributed environments. In order to explore the potential benefits of MAS to power generation and distribution systems, the concepts associated with multi-agent technology need to be described.

First, the concept of agent needs to be described. Second, some critical notions in MAS are presented below.

2.1 Definition of an Agent

The agent concept was defined first from computer engineering. The computer science researchers have proposed several definitions of what an agent is [5-6]. Agents are typically defined to have the following traits:

* Autonomy (they operate without human intervention).

* Cooperation (they interact with other agents).

* Reactivity (they perceive and react to their environment).

* Pro-activeness (they have goal-oriented behavior).

In this paper, the adopted definition of the agent paradigm is as proposed by Wooldridge [7]:"software (or hardware) entity that is situated in some environment and is able to autonomously react to changes in that environment".

2.2 Definition of a Multi-Agent System (MAS)

If a problem is particularly large or complex, then the best way it can be handled is to use a number of agents that are specialized at solving a specific problem aspect [8]. According to Wooldridge's definition, agents must have the ability to communicate with each other. A multi-agent system is a combination of several agents working in collaboration to achieve the overall assigned goal of the system.

3. MAS IN POWER SYSTEMS

Power system control is currently performed by a central SCADA (Supervisory Control and Data Acquisition System) system in combination with smaller local SCADA systems. The control methods based on SCADA technology are no longer efficient as power systems are increasing in complexity, requiring large amounts of data transfers and computations. However, there is actually a growing trend towards the application of MAS for the control of power systems. The justification of the use of MAS is their ability to be flexible, extensible and fault tolerant [9]. Mc Arthur stated that the MAS systems have been used in two ways. First, as a method to building flexible and extensible power systems. Second, as a modeling method. Furthermore, four main applications of MAS have been identified [9]:

* Monitoring and diagnostics.

* Protection.

* Modelling and simulation.

* Distributed control.

This paper focuses on distributed and autonomous of control systems needed for the control of distributed power systems.

4. DISTRIBUTED POWER SYSTEMS

Alternative energy production using distributed energy resources attracts growing interest due to their potential benefits to provide reliable, efficient, environmentally friendly, and sustainable energy from renewable sources. However, as the degree of penetration increases, the interconnection of distributed energy resources with the main grid involves many problems.

The main issues that

can affect the quality of supply include:

* Equipment and public safety

* Stability

* Synchronism

* Reactive power compensation

* Harmonic injection

* Central control

* Market organization

To address the different issues, the research community has conducted many research works. It is clear that the distributed nature of this energy production system requires a distributed and autonomous control system [1]. The next section will present a review of topologies used in grid-connected installations. They will later be compared and using the proposed evaluation criteria.

5. REVIEW OF GRID-CONNECTED PV SYSTEM TOPOLOGIES

Accompanying the expansion of grid-connected installations different arrangements of PV modules with their associated power converters have been developed to increase power production and reliability of the solar generators [10]. The following system topologies that have been identified in scientific literature will be presented beginning with the centralized layouts and ending with the distributed ones.

6. ARCHITECTURES GRID-TIED PHOTOVOLTAIC SYSTEMS

Historically, the first grid connected photovoltaic installations where built using the topology (figure. 1) [11]. This structure connects a large number of PV modules to the grid through only a high power inverter. In this type of installation, the photovoltaic modules are first connected in series building strings, in order to reach high voltage levels (normally 400V). The interest is to avoid a voltage amplification stage in the power inverter, and simplify the power conversion structure in this way. The strings are connected in parallel to increase the input current, and therefore the power. These installations could have from several kW to some MW peak of power. The architecture of the power converter is important in a PV system. This structure determines the main characteristics of the photovoltaic installation, as the amount the PV modules need for the PV system and its type of connection. The effect of the partial shadowing or mismatch between PV modules in the energy production will also depends on the type of the architecture. Nevertheless, the price and cost of the PV also depends on the choice of the architecture [4].

These structures are characterized by its high robustness and reliability and they have been widely used in spatial applications, to supply electricity to isolated villages or house and in big photovoltaic farms for electrical generation plants.

6.1 The centralized inverters

The biggest drawback of this type of topology resides in the MPPT centralization. As only one power-processing unit is charge to process all the PV modules, and therefore, there is a unique MPPT control, the mismatch losses between the PV modules and partial shadowing have a huge effect in the power system efficiency. Another drawback for this kind of installations is the halt of all the energy production in case of the breakdown of the power inverter, as all the PV power is passed though the alone inverter.

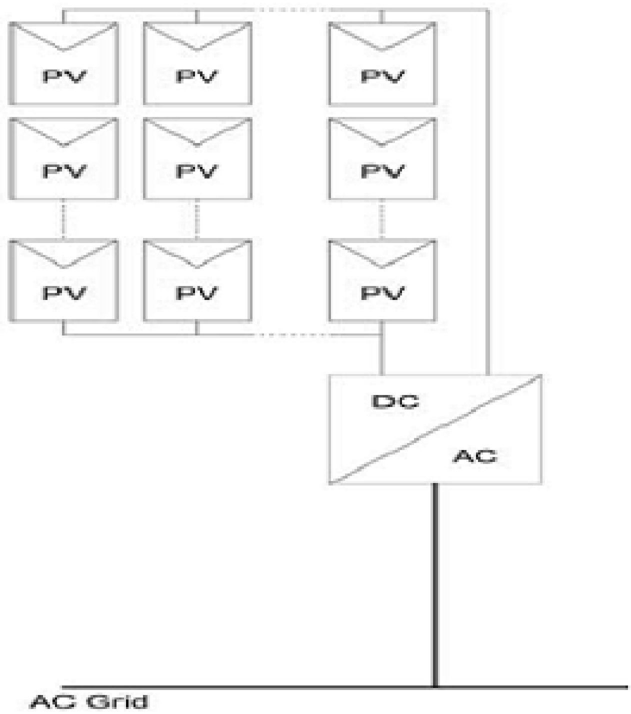

Figure 1 Photovoltaic system based in centralized architecture.

The centralized inverters are being considering the past of earth photovoltaic system applications. Although they are still used in big photovoltaic farms, other PV structures begin to be used in order to exploit the PV energy in more distributed way and harvest bigger efficiency. First, the string and multi-string topologies have took the place of centralized inverters, which divide the PV arrays into strings. Later, a bigger division is taking place, and the PV group is directly divided in individual PV modules connected to a unique power converter.

6.2 String level energy management solution

A string is a group of PV panels connected in series. In the multi-string [12] and string Architectures (figure. 2. a; and figure. 2.b), the PV array is divided into PV strings. In multi- String topology, each string is connected to a DC-DC converter. The outputs of the DC-DC converters are connected to the centralized grid-tied inverter. The difference for the string topology is that each string is directly connected to the grid by an inverter. In both topologies, each string benefits of the MPPT control and the maximum power point tracking is carried out in more distributed way than the centralized architecture. Thus, a partial shadowing in one of the string does not affect to the energy production of other strings and the PV power production is improved.

As each converter is connected to fewer panels than in centralized architecture, the initial investment can be smaller, being the user who determines the size of the installation depending in the number of installed inverters. So on, for particular and domestic users, the investment is easier. Nevertheless, the problem of the decrease of efficiency due to mismatch losses between PV panels is not really solved with these topologies, as a partial shadow in a PV panel follow affecting to all the PV string.

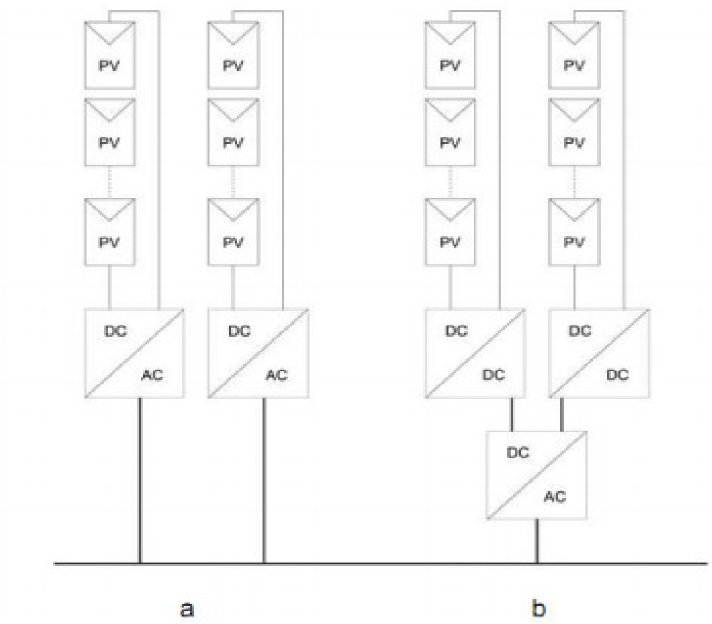

Figure 2 String level energy management photovoltaic architectures: a) string topology and b) multi-string topology.

7. MODULE LEVEL POWER MANAGEMENT (MLPM) PHOTOVOLTAIC SOLUTIONS

The latest PV system topologies tend towards the distribution of the power processing system. In order to increase the efficiency of PV systems, Module Level Power Management (MLPM) solutions are fast growing. It is expected to be almost the 40% of the residential PV Installations for 2014 [13].

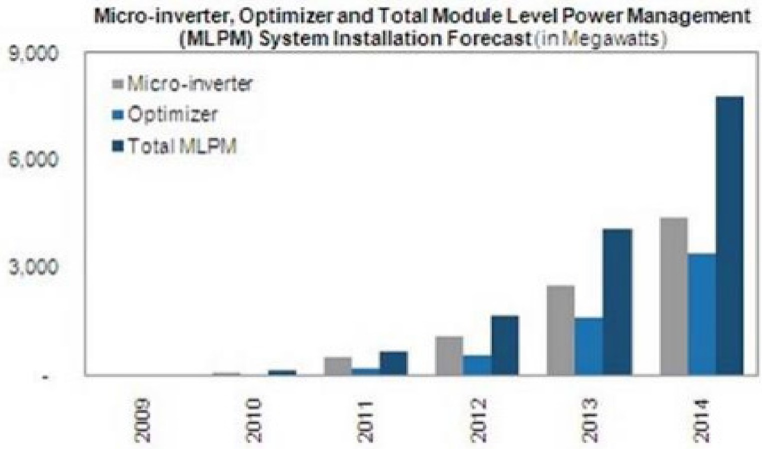

Figure 3 Micro-inverter, DC-optimizer and MLPM PV system installation forecast [14].

The MLPM systems consist on micro-inverters and DC power optimizers, which manages the energy of PV modules individually. The figure.3. Shows the micro inverter, optimizer and total MLPM system installation forecast for until 2014 [14]. Micro-inverters convert direct PV current (DC) from a single PV module to alternating current (AC), whereas optimizers use DC-to-DC converter technology to take full advantage of the power harvest from the PV systems.

MPPT algorithm of the proposed system is based on the direct adjustment of the duty cycle of DC/DC converter which is resulted from the sequential comparison of the output power of solar modules as well as the difference of output powers in two consecutive moments [20]. Micro-inverters consist on AC-DC power structures that manage the power of a unique PV module and integrating module dedicated MPPT control (figure.4.a). They are designed to be connected to an electrical network. Therefore, they include in their structure the voltage amplification, the MPPT control and the inversion and the adaptation to grid connection. They are also been known as AC module structures. This kind of structure presents many advantages. The most important is the distribution of the MPPT control in each PV panel, avoiding the problems due to the mismatching of them. In this way, the system can extract the maximum power of the PV panel. Moreover, these kinds of installations ask for a small initial investment, as we can install the PV modules one by one. As well as the facility of enlarging of the PV installation, due to the parallel operation capability in the AC side.

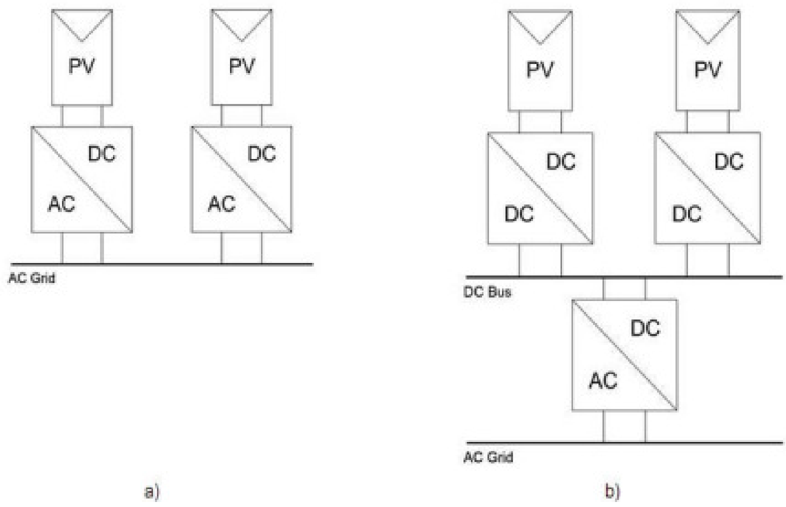

Figure 4 Distributed PV architectures: a) AC module and b) DC optimizer connected to DC bus and Grid-tied inverter

7.1 Control systems for inverters

Most distributed energy resources are not suitable for direct power transfer to the electrical grid due to the characteristics of the energy produced. Therefore, power electronic interfaces (inverter or converter) and their control systems are required for interfacing the distributed energy resources with the electric grid. The importance of the inverter is increased because its role has two important aspects. First, it extracts and manages the maximum power from the source. Second, it conditions the input power in order to deliver clean and compliant power to the grid. In this work, the MAS is intended to be used to build a flexible and extensible control system based on control units interconnected with inverters serving as power interfaces. Figure. 5 illustrates the concept of the control method to be used in this work.

In these partially autonomous systems, specific loads have a secured power supply provided by beforehand charging, using the PV array or the network grid, of the energy storage. However, the design of energy storage equipped grid-interactive installations must not permit the energy storage system feed the grid during discharge [15].

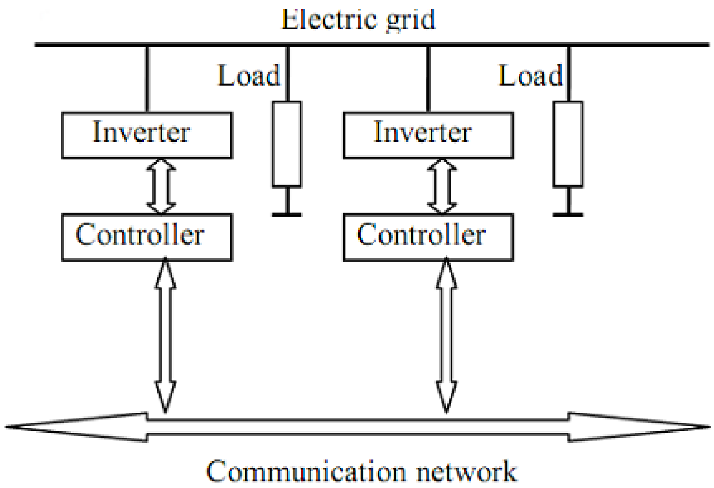

Figure 5 Schematic diagram of distributed control for distributed energy systems.

The electrical schemes of these installations are presented on Figure 6.

7.2 Degraded mode management

The evaluation of degraded mode management consists in determining how the topologies perform in case of faulty operation of the power electronics equipment. Indeed, electrical systems can operate in three distinct operation modes: correct operation, safe improper operation and dangerous improper operation. In the case of a PV system, the correct operation mode has been taken into account in the previous paragraph when studying the system that functions properly. However, field experience has shown that PV systems can reach between 20 and 41 failures per hundred systems with a 5% per year decrease of the failure rate as shown on Figure I.10. The least reliable component was the inverter accounting for 66% of the reported failures [16].

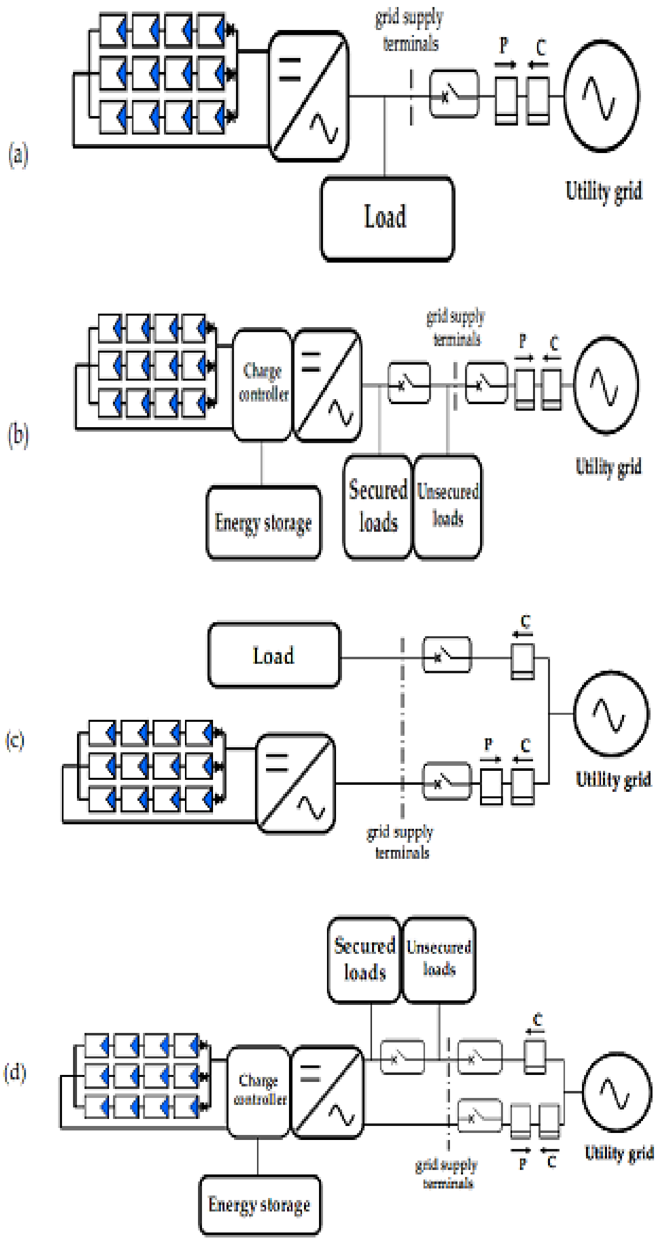

Figure 6 Electrical schemes of (a) grid-interactive, (b) secure grid-interactive (c) total grid-feeding, and (d) secure total grid- feeding PV systems [15].

A reliability evaluation of the topology can use indicators such as Mean operating Time between Failure (MTBF), Mean Time To Failure (MTTF), or Mean Up Time (MUT). In order to take into account the necessary time to repair a faulty inverter the Mean Time to Repair (MTTR) or Mean Down Time (MDT) may also be considered [17]. The capacity of a topology to rapidly detect the type of failure and its location, thanks to its associated monitoring system, is advantageous and should be considered while conducting a comparison of plant topologies.

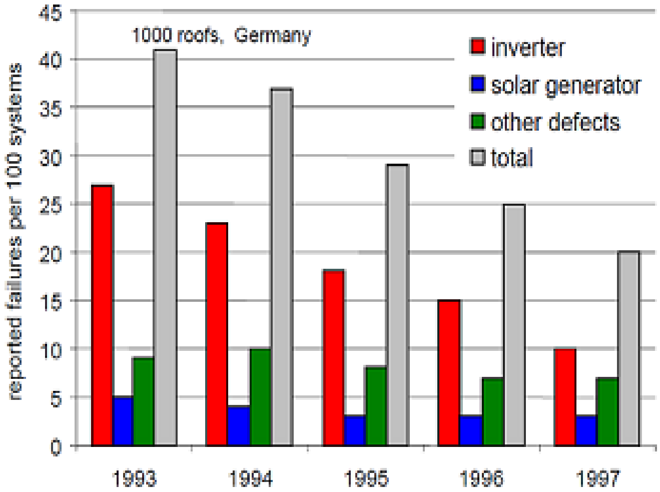

Figure 7 Failures by main component reported by owner under the German 1000 roofs program [16].

Finally, when the PV system operates in degraded mode it does not necessarily mean that no energy is fed to the grid. The configurations that can continue to produce energy while having lost certain system components have higher continuity of service levels. The continuity of service should be taken into account in an extensive evaluation.

7.3 Investment costs

A decisive element to consider when planning building a PV system is the investment cost. At present, the cost of a residential PV installation is principally driven by PV modules (55%), followed by installation materials (16%) and the power conversion units (13%) as shown on Figure 8. Since power conversion units are expensive, the quantity of converters in the plant will highly affect the initial investment costs of the complete system.

Nevertheless, the possible earnings, in the case of grid feed-in tariffs [18], made by supplementary energy produced with additional converters may reduce investment return rates.

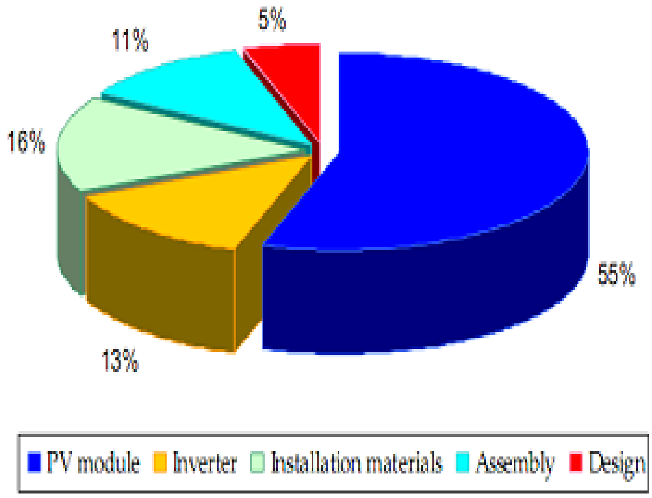

Figure 8 Distribution of PV system costs for residential applications [19]

The end of life cost of the entire system should also be included in this criterion. Topologies containing numerous components will not be advantaged in both nitial and recycling costs, yet conducting a specific case study per installation to minimize investment costs can ead to the determination of the optimal number of $converters to be used in the installation.

8. SIMULATION RESULTANTS AND DISCUSSION

The simulations were done using PSIM software for electrical circuits

8.1 Simulation of a central grid connected photovoltaic

Pin =1627 w , Pout = 1606 w, η = 0.98

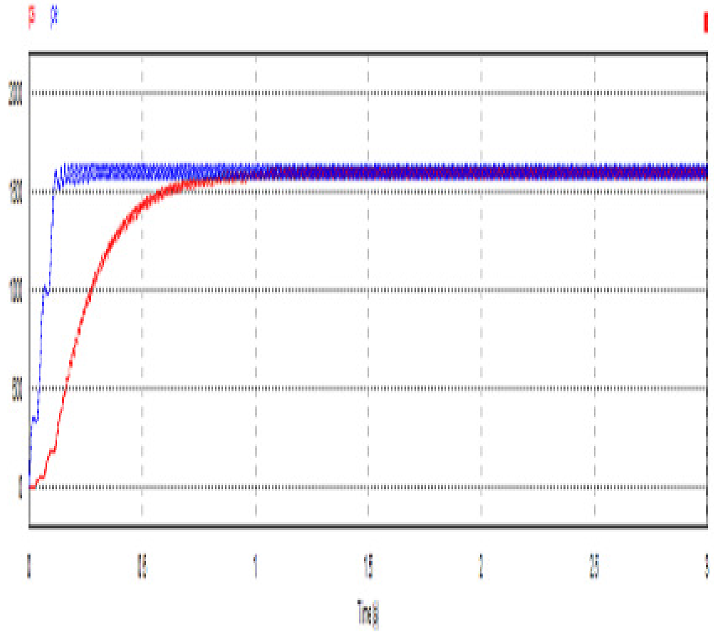

Figure 9 Simulation results of central grid connected photovoltaic.

8.2 Simulation of a string grid connected photovoltaic

1/ the grid connected are connected in series

Pin= 598 w, Pout = 516 w, η= 0.86

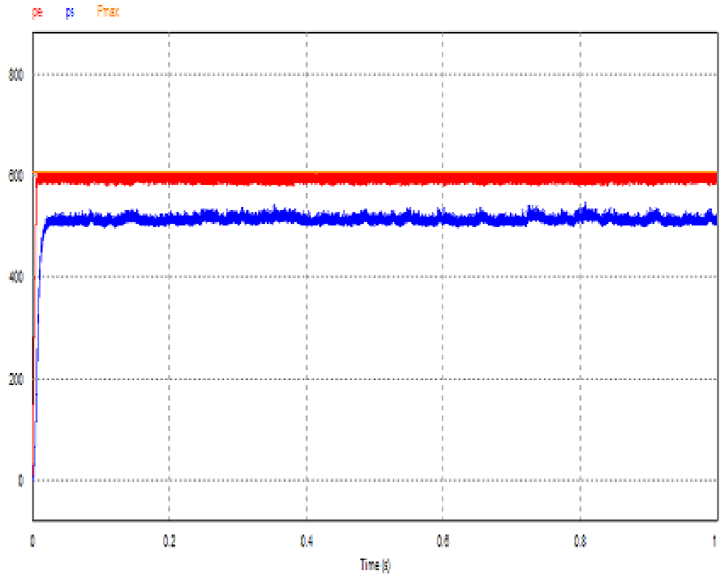

Figure 10 Simulation results of grid connected in series.

2 / The grid connected are connected in parallel

Pin = 592, Pout = 588 .32, η= 0.99

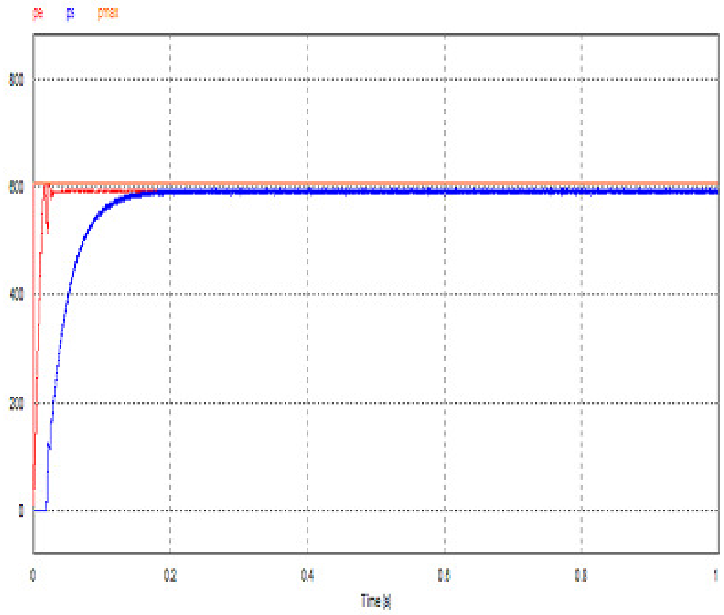

Figure 11 Simulation results of grid connected in parallel

It shows that the efficiency η increases rapidly with the power to reach a maximum yield of 85% -99 %.

η= 0.98 in central grid connected photovoltaic.

In string grid connected photovoltaic: η= 0.86 in series and η= 0.99 in parallel.

9. CONCLUSION

In this paper, we have studied in details and simulation the performance of optimal power improved energy and optimized electrical architectures of photovoltaic systems. The approach adopted in this paper was based on principles of multi-agent systems has been presented. They are intended to design a controller for the control of a power system where many distributed renewable energy sources are connected to the conventional grid by inverters. The design method of the MAS controller Grid-connected PV systems has seen a tremendous development this last decade.

This trend is expected to continue with lower growth rates. PV systems comprise three main electrical components to perform secure power production: PV modules, power converters, and protection apparatus. Grid-connected PV system layouts have been reviewed going from centralized topologies to distributed plant topologies. The centralized configurations have the advantage of remaining simple and low cost whereas distributed technologies offer better upgradeability, continuity of service and monitoring services, but currently remain more expensive, there is no overall optimal topology; the most adapted solution depends on the importance attributed to the evaluation criteria by PV system owner.

The performance of PV systems is essentially determined by its capacity to deliver the most energy during its lifespan. Power production increase can be achieved by reducing power losses that occur in the PV generator and power conversion units. It is important to investigate different types of architecture in order to choose the correct PV architecture.

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