GRADUAL PENETRATION OF PHOTOVOLTAICS INTO ISLAND GRIDS AND GRID MASTER CONTROL STARTEGIES

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ABSTRACT: The aim of this work is to clearly indicate a way to transform island grids powered by diesel generators into hybrid ones with the main power contribution coming from distributed PV inverters. The daily production and consumption cycles will be balanced with battery storage allowing further the evolution to a 100% renewable energy system. The development of modular components (hardware and software) needed for this purpose is required as well.
Throughout the evolution process of a typical island system, the Grid Master Control System (GMC) goal is to achieve relevant improvements in terms of power availability, frequency and voltage regulation, fuel and maintenance savings, air emission and noise reduction.
The work was partially supported by the European Commission, under the Research Directorate General, Non-Nuclear Energy Programme, contract JOR3-CT97-0158. The paper focuses on the objectives, implementation and the Grid Master Control System
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Keywords: Hybrid - 1: Grid-Connected - 2: Expert-System - 3

1. INTRODUCTION

The aim of the project is to clearly indicate a way to transform island grids powered by diesel generators into hybrid ones with the main power contribution coming from distributed PV inverters. The daily production and consumption cycles will be balanced with battery storage allowing further the evolution to a 100% renewable energy system. The development of modular components (hardware and software) needed for this purpose is required as well.
Throughout the evolution process of a typical island system, the Grid Master Control System (GMC) goal is to achieve relevant improvements in terms of power availability, frequency and voltage regulation, fuel and maintenance savings, air emission and noise reduction.
The GMC strategies have been defined in order to obtain the above mentioned improvements with the lowest impact over existing systems and to assure maximum easiness of the implementation. Distributed roof-top PV inverters will be dealt as autonomous devices, with no centralised control, equipped with local control logic that lead to a globally co-ordinated behaviour, maximising the solar energy production and the overall efficiency. Such a solution is preferred to standard centralised control to avoid the need of installing communication cables. Frequency and voltage regulation will be performed by the GMC through diesel power genset's voltage regulators and a Central Energy Buffer System's (CEBS, developed by A.N.I.T. for this project) with bi-directional power modulation capability. The power modulated PV inverters have been prepared by Total Energie. Different control strategies and operating modes have been defined in order to cope with system's evolution. GMC's tasks include configuration management, control strategies management and charging methods management.
Two solutions will be presented for the implementation to the GMC, one is based on the use of a fuzzy logic [1] and the second one on predictive control strategy [2]. The test runs will take place in a hybrid pilot plant at CRES. The supervision and automatic control of all the components installed will be performed by the central supervisory control unit (CSC), that sets the reference state of the power supply system and receives information on the actual state of each component. The exchange of information is performed by RS-485 cable, with a communication Fieldbus, serving as the medium to transfer information both ways. The information received in the central supervisory control station allows automatic operation.

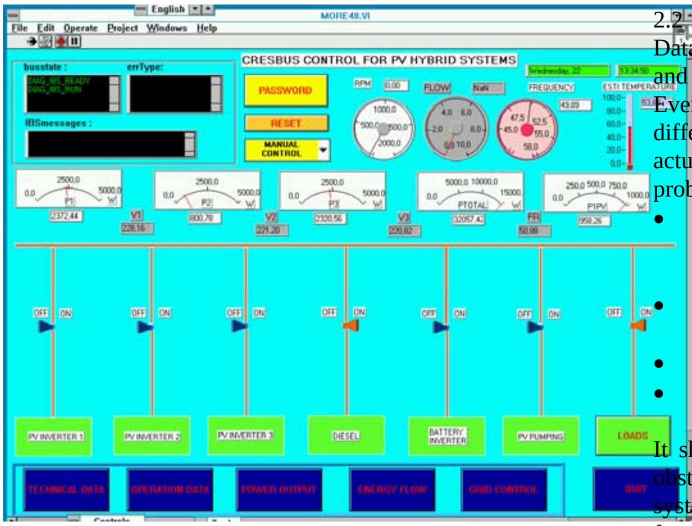

Figure 1 : CRESbus automatic control for PV Hybrid Systems

The visualisation and operational strategy of the PV hybrid system is achieved with the use of LABView, as presented in Figure 1.

The work advances a clean technology to be integrated in a wide variety of small utility grids, enhancing the quality and the reliability of the energy delivered to customers, contributing to energy savings, and furnishing employment opportunities both in industry and on islands where the systems will be implemented.

2. IMPLEMENTATION

2.1 Application area

The application area for the technology developed throughout the Project is in the multitude of small islands having the following characteristics:

- population up to a few thousand permanent residents; in these islands there is a significant increase in population during the tourist period. In some cases this is largely over 50% of the permanent residents;
- installed power capacity of diesel generators ranging from about 100 kW to up to about 10 MW. The yearly electric energy consumption may range from about 150 MWh to up to 40,000 GWh and its increase ranges from 5% to 8% per year;
- production cost of electricity ranging from about 12 cEuro/kW, for large size islands, to up to about 1 Euro/kW for the small ones.

Even though already the cost is competitive in some islands, photovoltaics are not introduced by utilities on a large scale due to the following main concerns:

- stability of the local utility grid with high PV penetration
- performances of PV systems with low grid power quality
- uncertainty regarding the real diesel fuel saving
- reliability of PV systems

2.2 Electricity costs and Power Quality in Islands

Data from Greek, Italian and French islands were collected and analysed for project purposes.

Even if some differences have been pointed out among the different utilities (energy costs, development policies, actual structure and renewable penetration), many common problems can be highlighted:

- electricity production cost is very high compared to interconnected electric systems, thus enabling PV systems to be competitive as fuel saving devices;
- large variations in grid frequency, up to 6% to 10%, are usual;
- large variations in grid voltage , up to 20%, are usual;
- frequent grid failures caused by grid weakness;

It should be noted that such a poor power quality is an obstacle to the diffusion of most commercial grid tied PV systems, since they usually require much more narrow frequency and voltage limits for continuous operation. This obstacle is overcome by the development of an appropriate grid tied tolerant inverter, suitable for the interface between PV systems and the island grid.

2.3 Problems related to high PV penetration

Major problems related to the high penetration of PV systems in island grids concerns grid stability and PV power excess.

As regards to grid stability, it has been noted that commercial inverters for grid tied PV systems require frequency and voltage limits that are very often exceeded in island grids. Such constraint violations are responsible for inverter disconnection from the grid, thus emphasising stability problems. In fact, if an overfrequency limit is exceeded due to a load reduction, as an example, this would cause the simultaneous disconnection of most of the PV systems. If PV power contribution is significant, such an event leads to sudden load excess that could evolve to a system blackout, or at least to greater frequency oscillations.

Another important issue concerns PV power excess. As previously mentioned, the population of the considered islands is variable during the year, and this implies a great variation of the load profile between winter and the tourist season. If the installed PV power is a considerable percentage of the peak load occurred throughout the year (in summer), let's say 30% to 40% or more, then it is expected that the PV power will exceed the load demand for several hours during the year. The conventional approach to solve this problem is to remotely control the PV inverters, with high costs and complexity increase. An alternative solution that does not require centralised control is presented in the paper.

2.4 PV inverter Maximum Power Point tracking

The algorithm of the Maximum Power Point tracking is as follow. The inverter supplies 100% power available from the solar array for the range of frequencies included between Fmin and Fmax. Should the grid frequency be higher than Fmax, because the load is low and we can not reduce anymore the power of the Diesel generator and the batteries are full, then the inverter will reduce gradually its output power to keep the grid frequency below Fmax. The inverter will supply again 100% of the energy available from the solar array once the frequency will drop below Fmax (this drop will result from a load increased in the grid). This algorithm has to give always the priority to the PV power production.

Table I: Transfer of the energy generated according to the grid frequency

GRID FREQUENCY	49 H_z	50 H_z	51 H_z
DIESEL GENSET POWER	100 %		20 %
PHOTOVOLTAIC INVERTER POWER	100 % available		0 %
	F min	F n	Fmax Fh

The different thresholds (Fmax, Fmin, Fh) can be configured with specific software.

2.5 Technical approach

The strategy for the gradual penetration of photovoltaics in island grids can be summarised into four phases (Figure 2):

Phase 1: the total PV contribution is significantly lower than the instantaneous load demand of supplied loads. Tolerant PV systems are required to allow for economic operation of PV.

Phase 2: PV contribution on the island approaches the instantaneous load demand in some periods of the year. The technical limitations to additional introduction of PV are overcome by appropriate control strategies involving distributed PV power modulation.

Phase 3: Economic losses associated to growing PV power wastes due to additional introduction of PV are overcome by a centralised energy buffer.

Phase 4: Further increase in PV penetration and energy buffer capacity allows for temporary switch off of diesel generators.

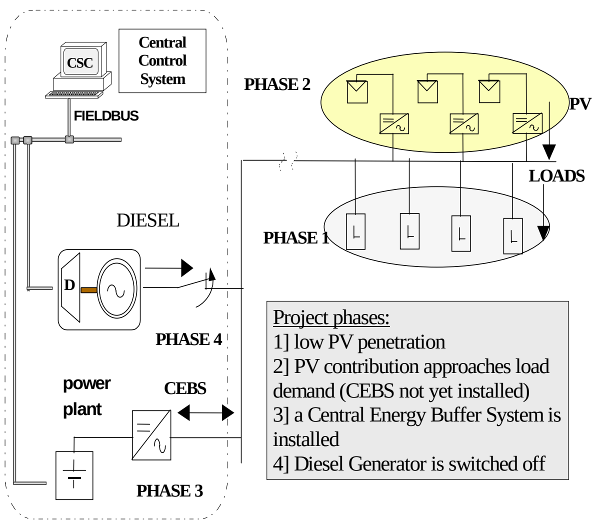

Figure 2: Block diagram of hybrid system.

A Grid Master Control unit (GMC) is required to manage diesel, energy buffers and PV generators. The Grid Master Control has to solve the following problems:

- frequency and voltage regulation;
- interaction between the centralised energy buffer, the diesel generators and distributed
- photovoltaics generating units;
- daily operating modes policy;
- alarms and emergency management;
- black-start procedure

The CEBS is able to perform voltage and frequency regulation functions on a passive grid, like any industrial UPS, but it also allows bi-directional power flow whenever the grid might become an active load. The CEBS should be considered as kind of unusual UPS with recovery capability. This particular feature will be crucial to the practical feasibility of phase IV of the project. In addiction, the CEBS will accept real and reactive power input signals from the GMC, while the Diesel Generator is running.

The paper is focused on the first two points in order to define grid voltage and frequency regulation policy and to define interfaces between the GMC and the various generating units.

3. GMC OBJECTIVES

The basic idea of the design is not to centralise the control of the distributed PV inverters in order to reduce costs and to increase system simplicity and reliability. Such a non-conventional solution requires some special control actions that are shortly described in the paper.

The Grid Master Control goal is to achieve the following improvements for the typical island systems:

3.1. Power Quality

- Power availability; the GMC is expected to bring considerable improvements in terms of stability of the local utility grid, reducing faults disturbances due to small isolated systems' intrinsic weakness
- Frequency regulation; to fully satisfy standards' requirements for frequency range in non-interconnected electrical systems, the grid frequency must be kept within rated frequency 2% over 95% of a week, and rated frequency 15% over 100% of a week. The target is to reach better results with a narrow frequency deviation.
- Voltage regulation; according to international standards, the system voltage, in normal operating conditions, must be kept within VR 10%, where VR is the system rated voltage.

3.2 Costs Savings

- Fuel savings; appropriated design of the GMC and its strategies should lead to diesel fuel savings
- Maintenance and machinery life cycles

- the GMC implementation will positively affect the rotating generating units' availability and will reduce the maintenance costs.

3.3 Environmental issues returns
- Air emission reduction;
- Noise reduction

A must of the project is to allow the transformation of existing conventional grids into hybrid grids to be gradual, in order to gain acceptance from local utility companies. Therefore, great importance is given to technical solutions, which guarantee easiness, adaptability and low impact over existing systems.

4. SYSTEM DESCRIPTION

When the large-scale penetration of PV systems is reached, in such a system the main actors are identified as follows:
- loads, to be considered for the absorbed power;
- tolerant grid tied PV inverters (PV), to be considered for their power injection;
- Diesel Generator(s) (DG), which are able to perform frequency and voltage regulation or power control,
- the Central Energy Buffer System (CEBS), which allows for a bi-directional power flow according to the control strategy implemented by the GMC

Some of these actors are present from the very first phase of the project, while some others will be added according to the system evolution described in the following paragraph. It has to be noted that while DG(s) and CEBS are located in the power plant, and therefore easily accessible from the control room, PV systems and loads are distributed along the island, and not subject to any remote control.
Two solutions will be implemented on the GMC through the Central Control System, one is based on the use of a fuzzy logic and the second on predictive control.
The specific skills of fuzzy controllers in dealing with uncertain information, of not clearly shaped constraints or limits and the ability to work on systems for whom mathematical models are not available or are difficult to be developed, handled or modified. A control approach based on adaptive scheme will be developed and tested at the pilot plant. The advantages of adaptive control in hybrid systems are the optimisation of fossil fuel consumption with respect to the load, maximizing the use of renewable energy sources.
The GMC, together with the various components developed for the project, have been installed in a hybrid pilot plant at CRES, in Greece. The tests will be performed in the following months.

5. CONCLUSION

The project indicates a way to transform island grids powered by diesel generators into hybrid ones with the main power contribution coming from distributed PV inverters and ultimately to establish 100% renewable energy electrified, isolated communities. The Grid Master Control System (GMC) goal is to achieve improvements in terms of power availability, frequency and voltage regulation, fuel and maintenance savings, air emission and noise reduction.

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