PV SYSTEM TECHNOLOGY DEVELOPMENT FOR THE GRADUAL PENETRATION OF PHOTOVOLTAICS INTO ISLAND GRIDS

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ABSTRACT

The aim of this project was 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 was realised 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 operations studies in the project were performed by ISET (Germany)

Distributed PV inverters (developed by Total Energie, France) are considered autonomous devices, equipped with an autonomous control logic that leads to a globally co-ordinated behaviour, which is able to maximise the solar energy production and the overall efficiency. Frequency and voltage regulation are performed by the GMC through diesel power gen-set's voltage and speed regulators and a Central Energy Buffer System's (CEBS, developed by A.N.I.T., Italy) with bi-directional power modulation capability.

Different control strategies and operating modes are defined to cope with the forecasted system evolution. GMC's tasks include configuration management, control strategies management and battery charging management.

The GMC, together with the various components developed for the project, were installed at a pilot plant at CRES (Greece) to be tested and validated.

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Photo 5 : A general view of the pilot plant. The PV modules are visible as well as the cabin where the CEBS and diesel generator are located. .... **Error! Bookmark not defined.**

1. OBJECTIVES

The project JOR3-CT97-0158 deals with the development of technologies that will allow for a large scale introduction of PV systems in existing island grids, currently powered by diesel generators. Technical issues concerning this transformation are addressed in the project.
The aim of this project was to clearly indicate a way to gradually transform a conventional island grid powered by diesel generators into a hybrid grid with the main power contribution coming from solar PV, and to develop for that purpose the required set of modular components able to operate under the very harsh and typically "weak grid" operating conditions in islands. To this aim, specific objectives of the project are:

- To design, develop and test a set of prototype modular components, allowing for the gradual penetration of distributed PV power systems (e.g. PV rooftops or similar) into conventionally powered stand-alone island grids
- To integrate and test all these new PV system components in a pilot plant at CRES, Greece
- To study and solve all major technical problems associated to the gradual transformation of conventional island utility grids to hybrid ones.

The developed systems are modular and expandable, while cost reduction through simplification is a very important factor. The strategy for the gradual penetration of photovoltaics in island grids can be summarised into four phases (Figure 1):

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.

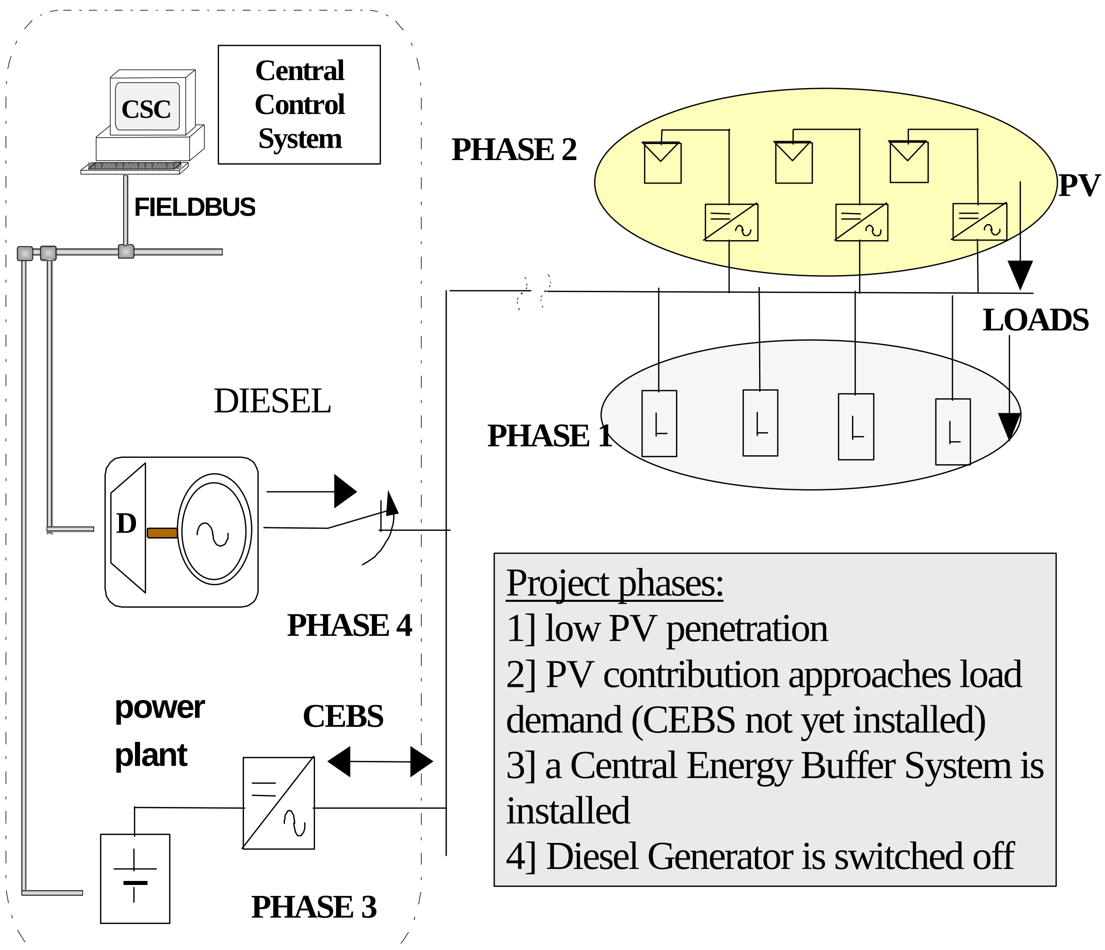

Figure 1: Block diagram of an island hybrid system.

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 project 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.

In cases, when the energy demand is lower than the energy production, and the diesel generators are already operating in their technical lower limit of energy production, the resulting increase of frequency in the grid will trip the decentralised PV inverters to a droop regulation mode, which will provoke a sharp decrease in power output of the PV inverters, thus no more operating in MPP (Maximum Power Point) mode.
The required power reduction function, in case an excess power condition arises in the grid, shall be ensured by adding to the control logic of each individual PV inverter a very simple droop control loop, which is activated when the grid frequency exceeds a certain (adjustable) threshold value (e.g. 51,0 Hz). The increase of the grid frequency provokes a sharp decrease in power output of the PV inverters no more operating in MPP (Maximum Power Point) mode. Vice versa, when grid frequency returns to normal conditions (e.g. 50,5 Hz adjustable) all PV inverters will return to normal operation in MPP mode. Therefore, the decentralised PV inverters will not be remote controlled, but instead remain completely autonomous and independent from any external control signal. This approach is expected to improve reliability of the overall grid performance.
Nevertheless, a communication link between decentralised PV inverters and the Grid Master control was provided for the pilot plant tests, serving the collection of operating data from PV inverters.
On the other hand, the CEBS (Central Energy Buffer System) and the diesel units need to exchange real-time information on instantaneous operating conditions and require therefore, an effective fieldbus communication means between each other and with the GMC (grid master control).
The supervisory control of the central power station was developed by CRES in LabVIEW environment.
All devices developed by the project follow, as it was agreed, comply with EN 50160 regulation enlarged as follows:

Frequency: 50Hz ±15%,
Voltage: 230/400 V +10% -20%

2. Technical Description

When the large scale penetration of PV systems is reached, the electric system of a typical island grid appears as it's schematically shown in Fig. 1. 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.

2.1 System evolution

The maximum PV penetration on an island grid is reached gradually, and four phases can be identified:

Ph. I: The PV penetration is low. The diesel generator is the only actor and PV's power contribution just reduces fuel costs.

Ph. II: Due to increasing PV penetration, PV's generated power approaches, and sometimes exceeds, the load demand. The CEBS is not yet installed. For most of the time, the diesel generator is the only actor or the main contributor. However, in some midday hours we have to deal with two power contributors needing some co-ordination action.

Ph. III: With further growing of PV contribution, to avoid economic losses due to PV's energy waste and to stabilise the system operation, the CEBS must be installed. This allows to absorb exceeding power from the grid and to return it when necessary. In this phase three different generation entities are present (distributed PVs, diesel generator and CEBS), and a GMC is necessary.

Ph. IV: With a further increase in PV and CEBS capacities, the CEBS is able to cover the entire load demand, allowing to temporarily switch off the diesel generator. Finally, it will be possible to run the system using only the CEBS and distributed PV's generators, while the DG should be used in extra-ordinary situations or high load seasons.

Table I summarises the various system's configurations to be handled throughout the system evolution.

Tab. I : Power System configurations

	DG	distr. PV contr.	CEBS Inverter/Rectifier		Conf. name (abbr.)	comments	GMC
Phase I	ON	low	X	X	CONVENTIONAL (**C**)		not required
Phase II	ON	high	X	X	DIESEL/PV (**DP**)	PV contr. approaches or exceeds instantaneous load demand. Actions are needed to avoid power excess	not required
Phase III	ON	high	ON	X	DIESEL/PV/CEBS Inverter mode (**DPBI**)	Frequency and voltage regulation are possible in various ways	required
	ON	high	X	ON	DIESEL/PV/CEBS Rectifier mode (**DPBR**)	Battery charging methods have to be considered	
Phase VI	OFF	high	ON	X	PV/CEBS Inverter mode (**PBI**)	Frequency and voltage regulation have to be considered	required
	OFF	high	X	ON	PV/CEBS Rectifier mode (**PBR**)	Frequency and voltage regulation have to be considered	

Notes to Table I:

- for each phase, only configurations different from those listed in previous phases are considered
- each phase includes all the system's configuration related to the previous phase, although not listed according to the previous statement

2.2 Grid Master Control Objectives

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

1. Power Quality;
   1.1. 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
   1.2. 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.
   1.3. Voltage regulation; according to international standards, the system voltage, in normal operating conditions, must be kept within $V_R \pm 10\%$, where V_R is the system rated voltage .

2. Costs Savings;
   2.1. Fuel savings; appropriated design of the GMC and its strategies should lead to diesel fuel savings
   2.2. Maintenance and machinery life cycle; the GMC implementation will positively affect the rotating generating units availability and will reduce the maintenance costs.
3. Environmental issues returns;

3.1. Air emission reduction;
3.2. 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

2.3 Distributed PV inverters control

Commercial PV inverters are designed to run in Maximum Power Point Tracking (MPPT) mode, using the grid frequency to synchronise the inverter, provided that grid voltage and frequency operating limits are respected. This feature, allows to maximise the PV system efficiency for any given solarisation condition and has no drawbacks as long as the PV inverter is tied to an interconnected grid. However, when the PV power contribution becomes an important part of the total generated power, a more complex control logic is needed. In fact, the gradual increase in PV systems installation leads to a situation (envisaged as the Project Phase 2) in which the PV power contribution needs to be modulated, i.e. reduced with respect to the MPPT value, in order to allow the diesel generator to remain within its operating limits. To solve this problem, a frequency droop is introduced in the inverter control logic to lower the power injected into the grid. When the frequency rises above a given threshold, the output power is reduced accordingly to the frequency error with a settable gain (droop). Such a logic doesn’t require any remote control action from the GMC, with the following advantages:

- power availability is not reduced by the presence of the communication network (required if a remote control has to be performed);
- distributed PV inverter are traditionally autonomous devices; changing such philosophy may have unexpected effects on the behaviour of a proven technology;
- the GMC machine can be downsized, since no communication task is required;
- eliminating the communication and remote control simplifies the software structure of the GMC, thus increasing its availability and maintainability;
- legal troubles arising from the different properties of inverter (users) and grid (utility) are avoided;
- the global efficiency of the system is maximised.

2.4 Central Energy Buffer System (CEBS)

The CEBS is made up of three main elements as shown in Fig. 2:

- a Two Way Inverter (TWI), allowing bi-directional power flow
- an Accumulator Battery (AB), providing the energy storage capability
- a CEBS Control System (CCS), driving the TWI according to the GMC strategies and monitoring the whole apparatus.

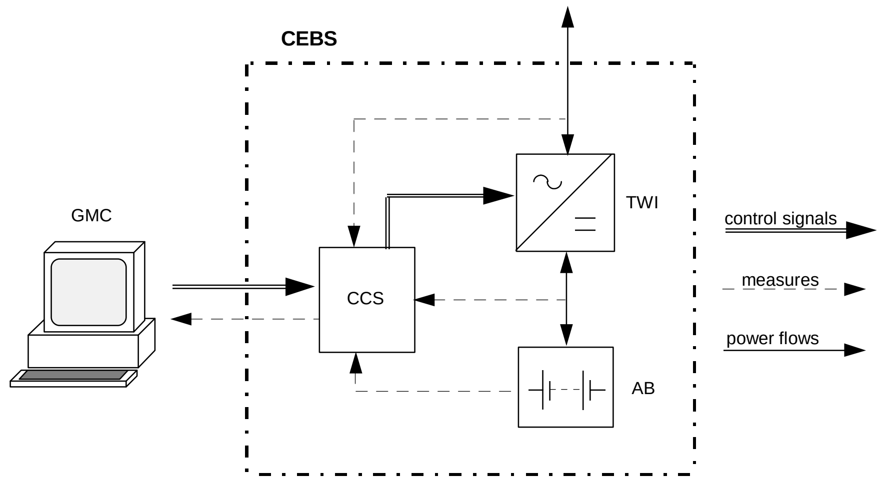

Fig. 2: CEBS elements

The CCS drives the TWI in two different operating modes: current mode or voltage mode.

In current mode the TWI injects real and reactive power into the grid, by controlling the rms value and the displacement factor of the current. The real and reactive power values are the input signals for the CCS and are provided by the GMC. In this operating mode, the CCS uses the grid frequency to synchronise the inverter.

In voltage mode the TWI controls the grid voltage on the connection node of the CEBS with the grid. Therefore, the power flow is determined by the grid real and reactive power demand. This is the typical operating mode for a UPS, that's why it's also referred to as "UPS mode" in this paper. It must be pointed out that in this operating mode the CEBS is able to generate power or to absorb power according to the grid requirements. This particular feature is crucial to the practical feasibility of phase IV of the project. When the voltage mode is selected, the GMC sets the voltage and frequency reference to the CCS.
It has to be noted that, due to power electronics technology adopted, the CEBS performances in terms of frequency and voltage control are higher than those of traditional power generating units. Such a characteristic is very useful in order to improve the power quality of the grid. The CEBS is located in the power plant, near the DG units, so their co-ordination is quite simple.

2.5 Conventional configuration (C)

In this configuration, the Diesel Generator is the main power contributor.
This is the only configuration possible as long as the PV penetration inside the electrical system is low, but it's also very common in phase II of the project, since PV contribution is solarisation dependent and the battery storage facilities is not yet available. Moreover, such configuration can be obtained even if the project is in more advanced phases, according to GMC policy or due to system's faults.
When the system is in C configuration, both frequency and voltage regulation are carried out by the DG as in any conventional island grid. This is accomplished by the existent DG regulators also when GMC system is installed and the C configuration is selected.

2.6 Diesel/PV configuration (DP)

This configuration is reached with the gradual penetration of PV inverters, when the PV power contribution approaches the instantaneous load demand (phase II).
In such a condition, it becomes impossible for DGs to manage grid master functions, unless the PV generated power is somehow regulated or lowered, since DGs cannot run below their minimum power rate (P_{dmin}). On the other hand, they cannot be switched off all together, because a system with only PV power contribution is unstable since no device performs frequency control.

The DP configuration is very important since it represents the very first technical obstacle for a large scale introduction of photovoltaics into island grids.

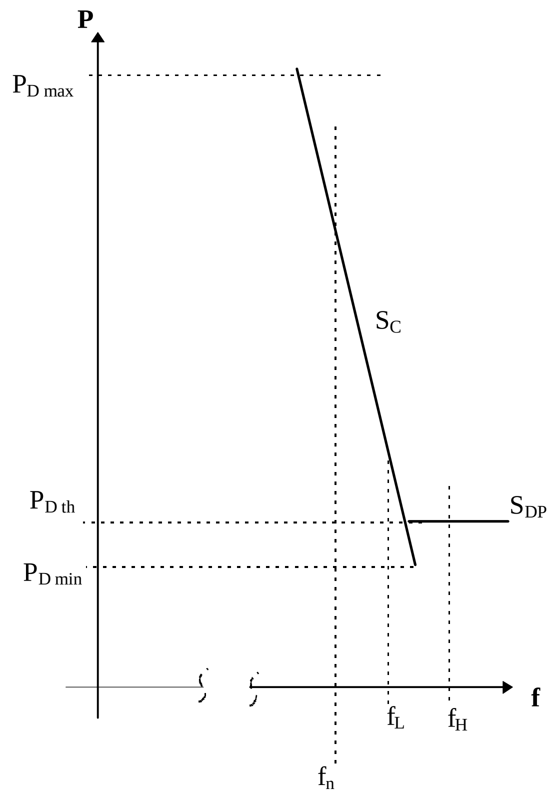

Fig. 3 : DG regulation characteristics

A major feature of the presented technical approach is that frequency and voltage regulation are carried out by the DG in almost the same way of configuration C, just introducing some minor modifications to the DG's speed regulator. This is achieved thanks to the autonomous control logic of the tolerant PV inverters developed for the project. The control strategy is based on the fact that decentralised inverters lower their generated power whenever the grid frequency exceeds a specified value (f_H) for a given time, and that they come back to MPPT mode when the frequency returns below a given value (f_L) for a defined time.

To assure that decentralised PVs lower the power supplied to the grid before the DG reaches its minimum real power limit (P_{DMIN}), a threshold level on the DG's throttle actuator is introduced, so that the following behaviour can be obtained:

- Until the PV power contribution is low with respect to the instantaneous load demand, DGs regulates the frequency as they usually do (S_C characteristic in Fig. 3).The system is running in its Conventional operating mode.
- As PV power contribution approaches instantaneous load demand, DG's speed regulator gradually closes the Diesel throttle until the introduced threshold is reached. DG's throttle is not closed anymore even if the frequency error remains. The system enters into DP mode and any further increase in PV power injections, or a load demand lowering, makes the DG accelerate, and the frequency rise (S_{DP} characteristic on Fig. 3)
- As frequency exceeds the value f_H, decentralised PV inverters leaves the MPPT mode and lower their power injection into the grid until the frequency is stabilised within acceptable values.

- If the PV power becomes lower or the load demand increases, the frequency goes below the value f_L, and the PV inverters switch back to MPPT mode; the system returns into its Conventional operating mode.

2.7 Diesel/PV/CEBS Inverter mode configuration (DPBI)

This configuration becomes possible with the introduction of the Central Energy Buffer System and the Grid Master Control system. The GMC does not control directly the PV inverters. Their effect is indirect through the grid power balance. In the power plant, both DG and CEBS have the capability to perform frequency and voltage regulation. A control strategy is implemented to co-ordinate their operation and to satisfy the grid demand (P_G and Q_G). The DPBI configuration and its control strategy is presented in Table II.
The major feature of the control strategy defined for the project are the following:

- The DG runs at constant power rate, receiving the reference power value P_{D*} from its interface with the GMC
- the real power is balanced by the GMC through the CEBS, controlled in current mode; the GMC measures the power P_G (t) requested from the grid and drives the CEBS to inject the power value P_I (t) = P_G (t) - P_{D*}
- Voltage regulation is carried out by the DG's voltage regulator
- The CEBS reactive power injection into the grid is proportional to its real power injection through a constant value, K, set from the GMC

Tab. II: DPBI control strategy

CEBS	$P_I(t) = P_G(t) - P_{D*}$	active power control - frequency regulation
(inverter mode)	$Q_I(t) = k\, P_I(t)$	fixed real/reactive power ratio
Diesel Generator	$P_D(t) = P_{D*}$	fixed power according to GMC system strategies
	$Q_D(t) = f(V)$	reactive power control - voltage regulation

This technical solution is expected to be very effective, in fact:

- CEBS ability to perform fast power regulation improves power quality in terms of frequency stability and power availability;
- fixed power operation of the DG improves its energy efficiency with fuel savings to be added to those due to PV contribution;
- running the DG at fixed power rate brings considerable benefits in terms of combustion's results emission and noise reduction;
- fixed power operation has positive effects on machines' life cycle and maintenance costs.

2.8 DIESEL/PV/CEBS Rectifier mode configuration (DPBR)

In DPBR configuration, the CEBS charges the batteries absorbing power from the grid, while the DG is running and decentralised PVs inject power into the grid.
DPBR configuration accepts both positive and negative values for P_G (and Q_G). As for DPBI configuration, distributed PV inverters are not involved in GMC activities. Their power contribution is considered in P_G and Q_G values.
The control strategy implemented when the system is in DPBR configuration is exactly the same implemented for DBPI configuration. The only difference is in the direction of the power flow in the CEBS. Thus, the same benefits are expected. The charging power fed to batteries (i.e. the charging current) is modulated from the CEBS according to GMC control signals. Tab. III summarises the DPBR configuration and its control strategy.

Tab. III: DPBR control strategies

CEBS	P_R (t) = - [P_G (t) - P_{D*}]	real power control - frequency regulation
(rectifier mode)	Q_R (t) = k P_R (t)	fixed real/reactive power ratio
Diesel Generator	P_D (t) = P_{D*}	imposed power according to GMC system strategies
	Q_D (t) = Q_D (V)	reactive power control - voltage regulation

2.9 PV/CEBS Inverter Mode and PV/CEBS Rectifier Mode configurations (PBI / PBR)

These configurations are reached from configuration DPBI/R when the DG is switched-off (phase IV). In such a configuration, the CEBS is the only device capable of grid master functions.
From the power plant point of view, the whole island grid is considered as a variable load, absorbing the real power P_G (t) and the reactive power Q_G (t). The grid is supplied through the inverter using the energy stored in batteries; this is the typical job of a UPS. This is true unless the total PV generated power is lower than the total load demand, and the system is in the PBI configuration.
When the PV generated power exceeds the total load demand, the power excess results in a power flow from the grid to the CEBS. This is possible only if the battery state of charge (SOC) allows such a power flow. Since the CEBS makes no difference about power flow direction, PBI and PBR configurations can be considered together as one.
Major features of this control strategy are the following:

- the GMC switches the CEBS to voltage mode when the DG is switched-off
- the CEBS' control system drives the TWI, imposing the voltage on the grid
- the voltage and frequency values are set by the GMC

Tab. IV and V, summarise the PBI and PBR control strategy.

Tab. IV : PBI control strategy

CEBS	P_I (f) = P_G (t)	real power balance voltage/frequency regulation
(Inverter mode)	Q_I (t) = Q_G (t)	reactive power balance

Tab. V : PBR control strategy

CEBS	P_R (f) = - P_G (t)	real power balance voltage/frequency regulation
(Inverter mode)	Q_R (t) = Q_G (t)	reactive power balance

When the PV power capability exceeds the total load demand, a PV power excess occurs. The exceeding power is used to charge the CEBS's batteries, provided that the batteries SOC is below its maximum acceptable value (to avoid batteries damage), and that the power excess is within the TWI rated power. Whenever one of these conditions is missing, the PV generated power must be reduced. This is achieved driving the CEBS to increase the grid frequency, so that distributed PV inverters reduce their power contribution. The frequency value is set by the GMC according to its knowledge of the system status.

2.10 Central Supervisory Control unit (CSC)

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.

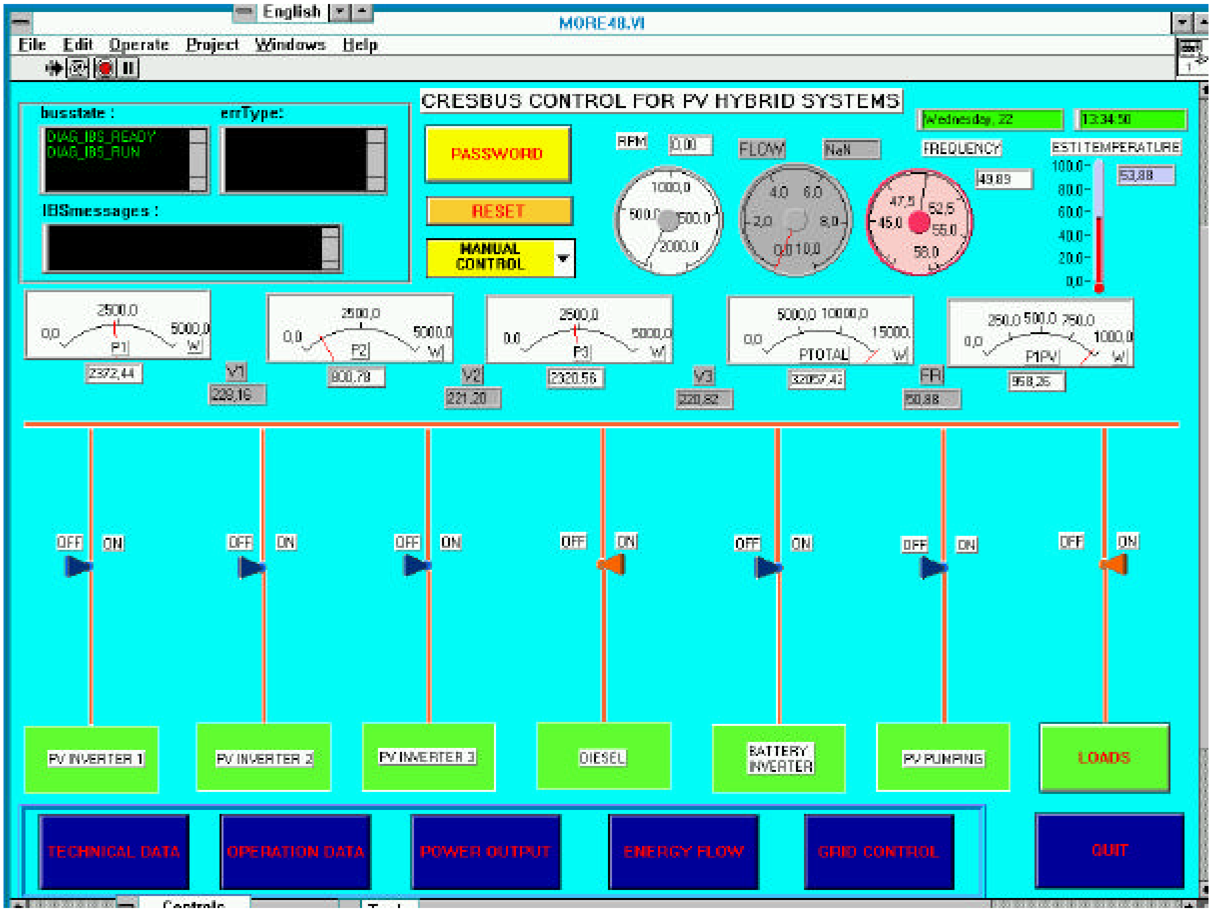

Figure 4 : CRESbus automatic control for PV Hybrid Systems

The visualisation and operational strategy of the PV hybrid system is achieved with the use of LABView, as presented in Figure 4.

3. Results and Conclusions

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.
The distributed PV inverters are not centrally controlled, in order to reduce costs and to increase system simplicity and reliability.

4. Exploitation Plans and anticipated benefits

Experiences gathered at European level (EC pilot plants, EC Working Groups on Batteries and PV systems, previous EC research projects executed by project partners) and the complementary expertise of four contributing partner organisations from three different EU member countries, namely Germany, Italy, Greece and France, have merged to set-up this research project. Following completion of the prototype development covered by this proposal, the industrial partners of the project, namely ANIT and TOTAL ENERGIE intend to proceed towards the industrialisation stage (not covered by this proposal) and to bring the envisaged components and systems to commercial maturity.

Once such commercial maturity of the product will be reached, ANIT intend to commercialise the developed technology as standardised and modular products aimed to satisfy the needs of rural electrification projects throughout the world, i.e. not only for island applications, but also for isolated village grid electrification projects in the developing world.
TOTAL ENERGIE, a world leader in the photovoltaic industry, directs its activities mainly in the field of rural electrification, professional applications (80% telecom) and water pumping. The strategy of the company is simple: to address the needs of existing and potential market.
Up to now, the number of photovoltaic systems connected to the grid by TOTAL ENERGIE remains low due to the lack of projects dealing with pv grid connection. But, over the last 2 years the number of projects dealing with this concept has increased and we strongly believe that this market has to be addressed generally in countries where the grid is not reliable and especially in French Indies. TOTAL is currently dealing with the local organisations in charge of the electrification and the reticulation of the grid and a strong economical interest has been observed by those key players. Today, TOTAL ENERGIE has in view 3 major projects in Guadeloupe, New Caledonia and French Polynesia where grid connected inverters will be used. It has to be noticed that TOTAL ENERGIE has launched a significant electrification program of 100 house in the context of a THERMIE project furthermore, several pilot projects are also implemented in the other area previously quoted.

ISET and CRES plan to use the results in publications and for dissemination though their information channels. The results will be available to each project partner as well as to different interested groups with the permission of all partners. Especially, the standards developed will be communicated to the industrial partners. According to the results of the project common working groups (European manufacturers) could be initiated in order to assure wide-spread acceptance of operational control.

4.1 Potential Direct and Indirect applications

As already mentioned practical applications for the technology in subject embrace basically:

- Power supplies for inhabited islands
- Remote village electrification in the developing world

The industrial fall-out expected from the project may be summarised in the following four items:

1. A tolerant inverter technology for small distributed PV systems (PV roof type) able to operate in parallel with weak grids, characterised by poor power quality (wide range of voltage and frequency fluctuations) so typical on islands and in any smaller stand-alone diesel grid always in compliance to typical safety requirements of utilities.
2. A power modulating control for distributed inverters allowing to reduce their power contribution instantaneously, and to provide thereby for a certain level of “dispatchability” of distributed PV power.
3. A central energy buffer system allowing to balance eventual differences between instantaneous power availability (from solar PV and from other sources) and demand from electricity consumers by absorbing and returning power from/to the island grid according to requirements.
4. A grid master control system providing the appropriate supervisory control of all different components, as such as diesel generators, distributed and central PV power systems, AC energy buffer systems etc., all connected to the grid.

ANIT and Total Energie as leading PV system companies in Italy and France are strongly interested in the development of commercial products and components to be offered for remote village electrification throughout the world. Accordingly, after completion of the prototype development, they both intend to proceed further by setting-up a testing and industrialisation stage for the prototypes to be developed during the project, and to bring these PV products to commercial maturity.

4.2 Market Segments to be Addressed by the Technology

The technology to be developed is intended to address the following two market segments :

1. Power supplies for inhabited islands already electrified by a stand-alone diesel powered grid system (without cable connection to the mainland)
2. Remote village electrification in the developing world, where a certain level of electrification by means of stand-alone diesel grids is already under way, and where the large distances to be covered make a cable connection to the national network little convenient.

Both these market segments present similar technical requirements (poor power quality and reliability, difficult fuel supplies, lacking technical logistics, poor maintenance etc.) as well as cost structure.

The investigation of the current situation on islands executed by project partners in Italy, Greece and French Polinesia encountered considerable difficulties in the collection of reliable electricity cost data from islands, since publicly available information refers, usually, only to the macro-scale (averages over all islands, or at regional levels including part of the mainland etc.), and at the micro-level, i.e. related to single islands, such information is not always available.

Nevertheless, the data collected regarding single islands, allow to draw some conclusions and to come up with a number of useful indications as follows :

- The per capita power consumption on islands tends to be unexpectedly high and especially in the case that a common electricity tariff is applied, the consumption becomes easily much higher than that in the mainland.
- Load management, particularly load leveling and AC energy buffering (storage) would be extremely useful and cost-effective to improve diesel exploitation in small island grids.
- Power quality and reliability behaves proportional to the island population size. On larger islands, with many inhabitants, it is generally acceptable, but on smaller island it is frequently extremely poor.
- PV technology presents much lower economy effect than diesel gen-sets. Consequently, the smaller the island community, the more convenient it is to adopt PV.

For southern Europe, the break-even case for island community size appears to be around 200-500 inhabitants, but it differs between countries as for different economics (utility structure, incentives, taxes, tariffs etc.). On smaller islands below this break-even size diesel power is very expensive (exceeding 0.5 ECU/kWh) and consequently PV power becomes a cost-effective alternative. In turn, on islands with more than 500 up to 2000 inhabitants, PV in some cases could still be considered, as indicated by the data in the Greek islands. For islands with population larger than 2000 inhabitants PV technology will usually present higher overall costs than diesel power (except in case that also externality costs are considered).

According to the above considerations, any isolated community (small village or other) presently electrified by diesel, whether it is effectively located on an island or simply at a distance from the nearest electric network, too far to allow for a cost-effective cable connection, represent potentially a market for the envisaged PV technology (especially if applied to remote village electrification in the developing world).

Unfortunately, the cost comparison based on overall diesel costs versus overall PV costs cannot be applied to PV systems operating in fuel-saver mode, i.e. in parallel to a normal diesel grid, since the economic benefits arising from the injection of PV power are limited to the cost of the saved diesel fuel, while the other diesel cost items (lifetime, depreciation, manpower, maintenance, replacements, spares, consumables etc.) are not affected and remain basically the same as without PV contribution. As a result, the apparently enormous market potential is in practice inhibited by the following well-known “entry” barriers :

- the required high initial investment for the PV technology and
- the already mentioned “either/or “ decision required to be made by local planners

For the above reasons, the present project aims to define ways how to avoid the otherwise required either/or decision, how to dilute required investments in time and how to gradually transform a conventional island grid powered by diesel generators into a hybrid grid.

4.3 Market Targets and Potential Users/Customers

Actually, the technical development requirements setup for this project have been defined in such a way as to satisfy the needs of the following **market target** :

Island communities with less than 2000 inhabitants electrified by :

- stand-alone diesel powered grids
- installed (diesel) capacity less than 5 MW

These island grids are also characterised by poor power quality which is improved with the applied technology.
Apart from PV system companies interested to sell and install PV systems (represented also by the project partners ANIT and TOTAL ENERGIE), the potential users for the technology to be developed by the project may be summarised under:

- utilities (both national and local)
- island municipalities
- economic development agencies operating in the developing world

Since the technical requirements to be met by the technology will in any case be set by utilities, at the present stage of developments, related investigations have been oriented to satisfy as much as possible their needs and requirements, and for same reason, the principle reference standards and specifications adopted for the project have been taken from the utility environment, namely the standard EN 50160 on “Power transmission and distribution systems”.
Technical personnel from utilities contacted for the purpose of collecting their opinion on the subject have expressed their interest in the project, as well as recognised that the project effectively faces crucial issues for the future integration and further penetration of PV energy (and renewables in general) into electricity network. Accordingly the approach presently adopted towards the project is characteristed by a kind of interested wait-and-see attitude.

5. Photograph, diagram or figure to illustrate potential applications of the project