Intelligent load control strategies utilising communication capabilities to improve the power quality of inverter based renewable island power systems

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ABSTRACT

It is often considered desirable to integrate renewable energy sources into diesel-powered island power systems, to reduce operating costs and provide other benefits. However, the combination of fluctuating generation from renewable resources, varying load profiles and relatively low system inertia can adversely affect system stability and efficiency. Load management provides a means of overcoming these problems. This paper describes work investigating the benefits of adding communications capability to Distributed Intelligent Load Controllers. Various communications techniques have been incorporated in the load controllers. A number of modified load controllers with communications capability will be tested on the PV hybrid diesel-battery system in the laboratory at CRES and on a similar system on Kythnos, to develop centralised control strategies for the management of distributed loads.

1. INTRODUCTION

Stand-alone power systems offer attractive power supply solutions in situations where the distance from a grid is too great for easy connection or the terrain over which cables must be laid is inhospitable. Conventional engine-driven stand-alone power systems use governors to control the input power and balance it with the system loading, to provide frequency control. Renewable energy systems such as solar-powered networks experience real-time variations both in input energy and in load demand. Load control is employed to maintain stability and achieve maximum penetration of the renewable resource - it also has the potential to provide improvements in system efficiency. Econnect and partners have developed a range of low cost, micro-controller-based load control products (Distributed Intelligent Load Controllers, or DILCs) which can be distributed around the stand-alone power system and operate autonomously to match the load to the available generation. These autonomous devices work very well in situations where the overall system supply loading can be determined using a locally-measured parameter such as frequency [1].

This paper builds on the work described in [2] and investigates the addition of communications to distributed load controllers in situations where supply loading cannot be determined locally within the system, or where a greater level of sophistication in control strategy is required. This can occur on inverter-dominated stand-alone power systems that do not have an artificial droop mode to allow system frequency to indicate supply loading. Communication allows more sophisticated control functionality to be added to the load control system, albeit at the expense of cost and complexity.

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Figure 1 shows a typical stand-alone power system with radio frequency (R.F.) communications.

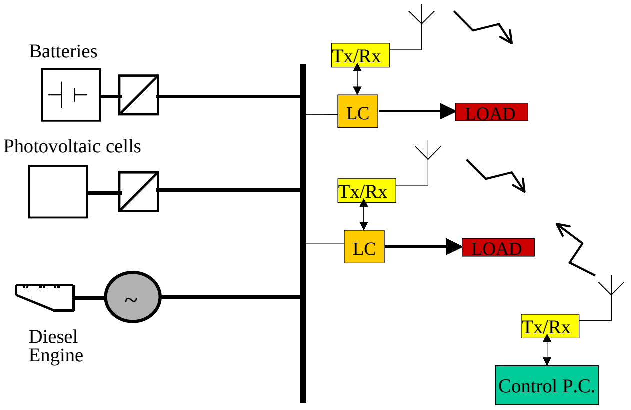

Figure 1. Typical stand-alone power system with R.F. communications.

This type of system relies both on a reliable communications technology and on a robust control strategy. This paper covers both these aspects, describing :

- the design and development of a number of communication technologies, developed as part of Econnect's contribution to the European DISPOWER project [3]
- plans for initial testing, to be carried out on the stand-alone power system in the laboratory at CRES, in Athens, which contains a stand-alone power system with photovoltaic cells, a diesel generator and batteries. This facility lends itself to the development of a communications-based load management strategy in a controlled environment.
- an inverter-based renewable power system on Kythnos, where load controller testing has begun, and which is a suitable site for field testing of suitable control strategies.

2. COMMUNICATIONS

2.1 Fundamental requirement for DILCs with communication capability

The use of autonomous distributed load controllers relies on the availability of a locally-measurable, global variable which indicates the level of loading on the generation. Voltage can sometimes be a useful parameter, but it can be complex to derive a simple control action from it as it is affected by a number of factors. Frequency is more straightforward to use, as it is a global parameter, and also relates directly to the balance between generated power and system loading in many types of power system. However in networks where frequency does not reflect system loading, typically inverter-based systems, distributed load control devices need some means of obtaining information to allow them to make switching decisions. In the absence of a local easily-measurable system variable, this can be provided by communications from a centralised controller.

Larger stand-alone networks which already operate a centralised control strategy to manage different types of generation and load may also need distributed load controllers to have a communications capability, in order to integrate them into the system control strategy.

2.2 Additional benefits

Once a need for a communications capability within the distributed load controllers has been established, other benefits can be identified. Communications can provide a greater level of sophistication in the overall load control solution. The following features could be implemented using communications coupled with an effective centralised control strategy:

- Remote reading of data (voltage, frequency, temperature, fault information, load status etc)
- Inclusion of dynamic tariff information
- Dynamic load controller configuration
- Modifying control strategies

- Integration with other control/SCADA systems
- Efficient loading of diesel generators
- Indication of the level of power availability
- Accommodation of loads with more complex operational requirements, e.g. desalination

2.3 Potential disadvantages

There are a number of potential disadvantages associated with communications. It increases the overall system cost and complexity. The resulting complexity may make the system less fault tolerant and more difficult to install and commission. The system has to be carefully designed to ensure that in the event of a communications failure, it fails gracefully and in a safe and robust manner. This involves a design choice as to the level of "intelligence" required at the load controller side.

2.4 Design considerations

2.4.1. Architecture

There are two general approaches to communication system architecture, "flat" and "hierarchical". The "flat" architecture is quite robust, as there is no single point of failure and it can provide dynamic rerouting if required, allowing data packets to travel by more than one route as shown Figure 2. The second approach is a hierarchical architecture. Network management is perhaps simpler and less network traffic may result. Each cluster controller is responsible for its associated cluster nodes and the cluster controllers form a network to pass data to a central controller as shown in Figure 3.

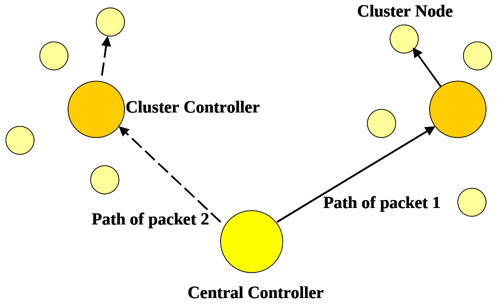

Figure 2 Flat Architecture

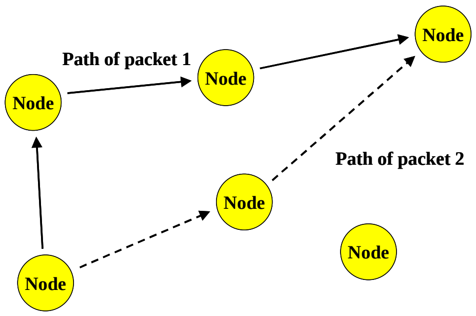

Figure 3. Hierarchical Architecture

A hierarchical approach was chosen which allows multiple systems to be integrated via a common control bus and lessens the processing requirements at the load controller micro-controllers.

2.4.2. Communications technologies

Radio frequency (R.F.) links, power line carrier (P.L.C.) links and TTL-based hardwired links have been designed, built and tested as part of the DISPOWER [3] project. The systems have been partitioned in such a way as to have much of the functionality implemented on low cost micro-controllers. This reduces the hardware costs of any commercial version. It is possible to optimise the communication system by integrating different technologies as shown in Figure 4. This shows the signal being transmitted to a dwelling via R.F. and being distributed within it using P.L.C.

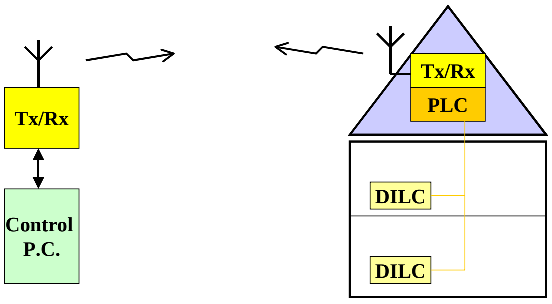

Figure 4. Integrated communication technologies.

2.5 R.F. links

Both uni-directional and bi-directional asynchronous R.F. links have been developed; using low power radio as the communication channel. A bi-directional link is more complicated to implement than a uni-directional link, and more expensive, but has the advantage of robust data transfer and the ability to send measurement data from a remote point to a central controller. Both systems use cyclic redundancy checks to check data integrity.

In the uni-directional system, the transmitter is located at a central point and transmits information to a number of remote receivers. Each receiver has a unique address as well as a group address and a broadcast address so the transmitter can send inform to an individual device, a subset of the total devices or all the devices at once. As the uni-directional system allows communication in one direction only it is impossible to verify that a data packet has been received correctly. Time diversity techniques are used with the data packet being transmitted a number of times to ensure that it has a high probability of being received without error. The system recognises three commands ON, OFF or AUTO which corresponded to switching the load controller on, off or placing it in autonomous mode. The transmitter, after verifying the command, compiles an appropriate data packet and then uses a “bit bang” technique to FSK (frequency shift key) the transmitter. The centre frequency of the transmitter is 433.90MHz.

The bi-directional link comprises a transceiver unit at a central control point and a transceiver unit associated with each load controller on the network. Information flows in both directions allowing data acknowledgement information, commands and measurement data to be transferred from the controllers to the central point. Figure 5 shows a block diagram of the bi-directional link. The bi-directional system has a simple character-oriented synchronous protocol to ensure that data is transmitted reliably. The bi-directional link conforms to the OSI 7 layer model [5]. Layers 1 and 2 are implemented on a micro-controller; the other layers are implemented on a P.C. and within the load controller.

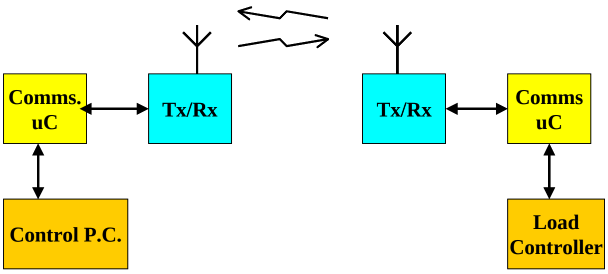

Figure 5 Bi-directional link block diagram

Both links are point to multipoint since the communication is between a central point and a number of outlying load controllers. The load controllers themselves do not communicate with each other either directly or indirectly. A variation of this scheme is point to point to multipoint.

Although in ideal conditions small amounts of R.F. energy can travel great distances, “real world” performance is somewhat different. A number of mechanisms prevent the range from approaching anywhere near the ideal, such as signal reflection, signal absorption and interference. The system has been tested and found to have a reliable range of over 500 metres and with careful siting of antennas up to 1km. Range can further be increased by adding repeater units to rebroadcast the data packet or by using a combination of higher output power and directional antennas.

2.6. Power Line Carrier

A prototype power line carrier system has been developed as described below:

<D.Rollinson to supply power line carrier description>

3. TEST PROGRAMME

3.1. Laboratory tests

CRES has a comprehensive test facility as described below:
The CRES Hybrid Power Plant laboratory has been constructed in the framework of EU projects, for the investigation of the impact of energy penetration from photovoltaic generators in small autonomous island grids. A schematic diagram of the facility is shown in Figure 6 CRES Hybrid Power Plant laboratory.

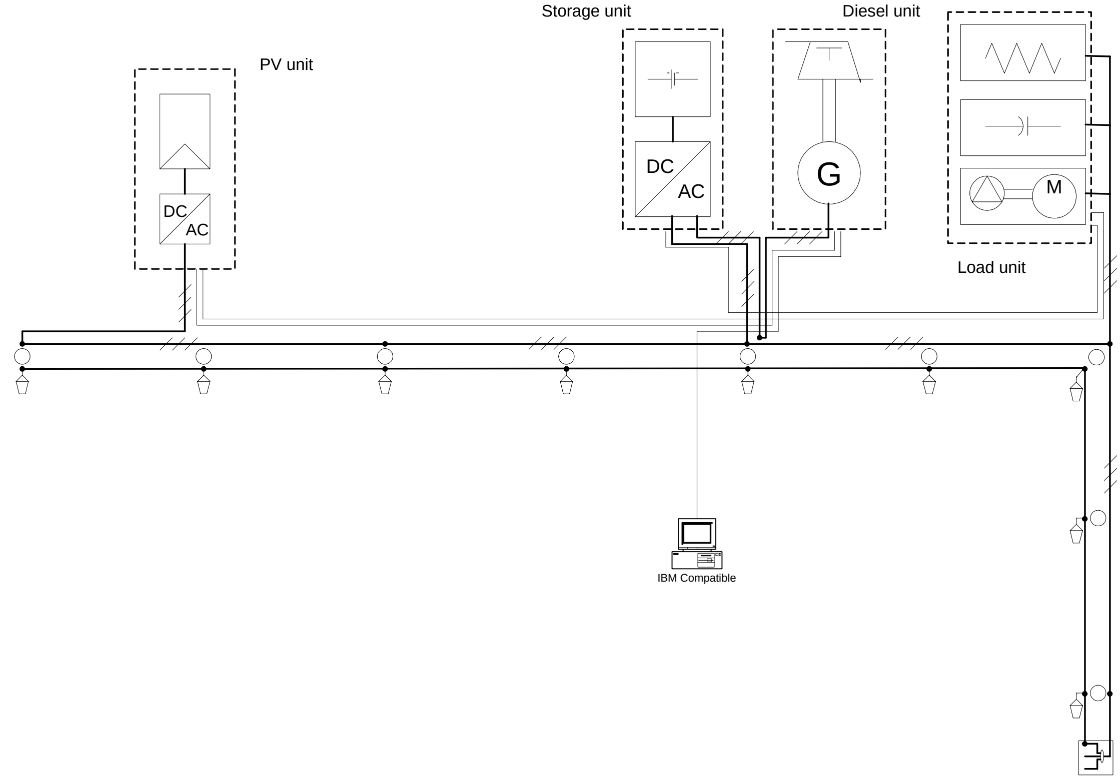

Figure 6 CRES Hybrid Power Plant laboratory.

The power units comprising the plant are:

- A 4.4 KWp PV unit connected to the grid through an inverter.
- A 40KWh battery storage unit connected to the grid through a power electronic converter.
- A 12.5KVA diesel-generator.
- A load unit.
- A desalination unit.

A supervisory control system, developed in the Labview 6.1 environment, offers the following capabilities:

- Grid monitoring, through the collection of measurements and information about the hybrid system components as well as meteorological information.
- Switching of the power components.
- Automatic operation of the hybrid power system according to a prescribed strategy.

The communication interface between the power system units and the supervisory control system is Interbus. Interbus is a serial bus system for transmitting data between control systems (e.g. programmable logic controllers, personal computers etc) and spatially distributed input/output units to which sensors and actuators are connected.

Econnect have supplied a number of DILCs to CRES which have been modified to allow integration with the communication network at the CRES lab. An interface has been added to allow commands to be sent and the status read back from each DILC on the network. These DILCs have been installed and tested, and the system is now ready for the testing programme.

The testing programme is designed to investigate the ability of DILC technology in conjunction with a centralised control strategy to:

- Maximise the use of P.V.
- Reduce the diesel generator usage.
- Run the diesel generator more efficiently.
- Provide a secure supply to the connected loads and prevent overloads occurring.
- Reduce the reliance on battery power.
- Provide best use of excess generation.
- Accommodate complex load management requirements, such as desalination loads

During the testing programme, control strategies will be developed and implemented on the main network control P.C. With the objectives in mind a test matrix has been devised. This incorporates various combinations of diesel, PV and batteries, and two main types of test, to investigate security of supply and system efficiency. The security of supply test overloads the system by approximately 10% whilst the efficiency tests load the system to 90% of maximum. Measurements will be made of voltage, frequency, real and reactive power flows, solar irradiance, state of battery charge and load controller status. All tests will be performed with and without load control for comparison purposes.

3.2. Field tests

As part of the DISPOWER project [3] the Centre for Renewable Energy Sources (CRES), Econnect , ISET and SMA have collaborated on the Greek Island of Kythnos to implement a simple load control system on a stand-alone photovoltaic battery-diesel power system. This system is being used as a test bed for the study of electrification in remote areas using photovoltaic technology [4].

The system on Gaidouromantra, Kythnos is a 3-phase mini grid with overhead power lines and a communication cable running in parallel, electrifying 12 houses in a small valley in Kythnos, an island in the cluster of Cyclades situated in the middle of the Aegean Sea. The grid and safety specifications for the house connections respect the technical solutions of the Public Power Corporation, which is the local electricity utility. The reason for such a decision was taken on the grounds that potentially the mini-grid may be connected at some point in time to the rest of the island grid. The settlement is situated about 4 kilometres away from the closest pole of the medium voltage line of the island.

There are two power systems supporting an AC grid, which have the ability to be connected in parallel. There is a PV-Battery-Diesel hybrid system and a PV-Battery system. Each system is composed of 6 kWp of Photovoltaics divided into smaller sub-systems and a battery bank of nominal capacity 53kWh for the PV-Battery system and 32kWh for the PV-Battery-genset system. The diesel genset is a 3-phase unit with a power output of 11kVA. In both systems three synchronised single phase battery inverters are interconnected to form the 3-phase AC system. One battery inverter is set as the master, providing the appropriate reference to the other two for frequency, voltage and the phase difference. Each battery inverter coupled to a phase has a maximum power output of 3.6kW and has the capability to operate in either isochronous or droop mode. The PV modules are integrated as canopies to various houses of the settlements. A system house of 20 m^2 was built in the middle of the settlement in order to house the battery inverters, the battery banks, the diesel genset and its tank, the computer equipment for monitoring and the communication hardware.

The system with the Diesel genset has two modes of operation, either the battery inverter or the diesel genset are the masters that form the grid. The preferred mode of operation is the one when the one battery inverter forms the grid. The genset is turned on only when the battery is low. The installation of the grid and the systems was performed in the framework of two European projects (PV-MODE, JOR3-CT98-0244 and MORE, JOR3CT98-0215).

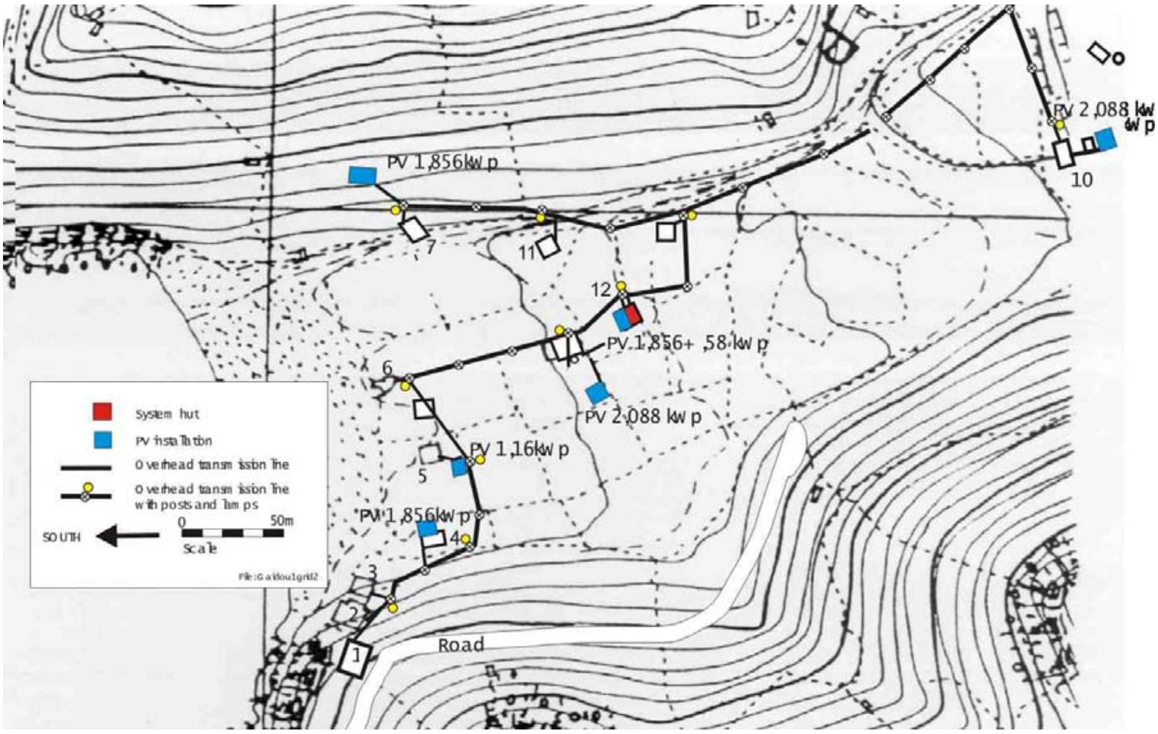

Figure 7 : The house numbers, size and location of the PV arrays at the settlement of Gaidouromantra in Kythnos.

Econnect have supplied and installed 12 distributed intelligent load controllers (DILCs) that are connected directly to the supply incomers of 12 dwellings. These DILCs operate autonomously and sense variations in supply frequency. As the inverters in the Kythnos system are operating in droop mode, the frequency will vary with inverter loading. The variations are analysed and then a switching decision is made, either to disconnect the dwelling if the system is overloaded, or to re-connect it if surplus power is available. The DILCs have been operating successfully for over 12 months.

Assuming the laboratory tests show that communications offer significant benefits, the system will be reviewed in the light of the test results and then implemented on the island of Kythnos for long term field trials. A number of centralised control strategies will be developed and refined. The configuration on Kythnos offers the ability to operate the inverters either in droop mode or isochronous mode, and its existing hardwired RS485 communications network means that the load controllers can be tested with and without centralised control. Tests will be carried out with various combinations of these options to investigate the system's functionality, reliability and performance, which will allow a cost-benefit analysis of adding communications to Distributed Intelligent Load Controllers to be performed.

4. CONCLUSIONS AND FURTHER WORK

- A technical and functional rationale for distributed load control with communications has been identified, with the main application being seen as inverter-based stand-alone renewable power systems, although equally applicable to other generation technologies such as wind and hydro.

- Two low power radio data links and a power line carrier data link have been developed. This allows individual load control solutions which require communication to be constructed in an efficient manner, taking into account the advantages of each communication medium.
- An extensive test laboratory to study the behaviour of photovoltaic power systems has been created at CRES. A number of Econnect's distributed intelligent load controllers with additional communications capability have been integrated into it.
- A testing plan has been devised to enable the investigation of the communications as part of a load control system. The testing programme is to be undertaken shortly at CRES. Analysing the results will show the benefit or otherwise of having communications associated with DILCs.
- Assuming the tests show that communications offer significant benefits, the system will be reviewed in the light of the test results and then implemented on the island of Kythnos for long term field trials. A number of centralised control strategies are to be developed and refined.

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