Review of methods for a Hybrid Energy System islanding efficient management

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Abstract. Nowadays, when a long time problem happens in the electric net (e.g., voltage falls), Hybrid Energy Systems (HES), those which combine wind turbine generators, solar panels, fuel cells, etc. can be disconnected of it to avoid damages. This kind of system can be used, for example, to support the electrical network for distant sites. The aim of the research described in this paper is to study the possibility that the HES, once it has been disconnected, could be able to provide energy to near loads creating a micro-grid (islanding scenario). Furthermore, the DC/AC inverters used by the HES must find a new voltage and frequency reference after disconnection in order not to perturb the generated electrical signal.

When in islanding, it is very important to know the characteristics of the loads to assign priorities to each one in order to connect or disconnect them depending on the available energy. The control of that feature is going to be performed by means of Demand Side Management (DSM), using wireless communications and analyzing different options.

Key words

Hybrid energy system, islanding, micro-grids, demand side management, wireless communications.

1. Introduction

The term "islanding" makes reference to the disconnection of a section of an electrical grid from the main net, despite the islanded part continues generating energy. In this paper, the islanding of a Hybrid Energy System is going to be studied not as a problem, but as an added value to the electrical network. It is important to know when the HES is in an islanding scenario, in order to activate all the necessary procedures. There are different mechanisms to detect islanding, aiming to avoid it, that can be useful for our purposes. Once the HES in islanding state, it can be considered and studied as a Micro-grid (MG). In this new situation, there are some tasks to execute, the most important one is to establish new voltage and frequency references for the inverters. Some techniques are presented in this paper.

Demand Side Management (DSM) is going to be applied to manage the islanded grid. DSM needs a telecommunication network to support the protocols that allow sending messages to control the components of the MG. There are different solutions developed in terms of network topology, modulations schemes, communication protocols, etc. Communications using the electrical line as physical support, named Power Line Communication (PLCom), are frequently used. The different techniques existing now are overviewed. However, one of the aims of this research is to use wireless communications to support DSM. Existing wireless technologies are presented, with its pros and cons to be used in our MG. Ad-Hoc networks are mentioned too as a good architecture to be used.

2. Islanding features

When a long term hitch occurs in the electrical net, such as power blackout or voltage falls, islanding of a HES can be necessary in order to protect the energy generators. However, intentioned islanding is also possible in order to force the HES to supply near loads.

In this section, it is described the set of problems associated with islanding, in terms of how to detect the disconnection with the electric net, the general characteristics of micro-grids and the different possibilities to obtain a new electrical reference for the DC/AC inverters.

A. Islanding Detection Techniques

When an accidental islanding occurs, it is important to detect it in order to carry out the necessary actions. There are different techniques developed to make this task, according to IEEE 1547, IEEE 929-2000 and UL 1741 anti-islanding test specifications [1], [2], [3].

Non Detection Zone (NDZ) is one of the concepts to take to account. [4] describes a method to determine the

islanding by measuring the variations in the RLC load voltage and frequency values. When these values are out of the nominal range fixed by the user through the use of two thresholds, it is possible to ensure that the HES is in islanding. It is necessary to pay attention because it is impossible to detect the islanding if the voltage and the frequency remain in the NDZ. So, it is very important to select the correct voltage and frequency threshold values: a little threshold reduces the NDZ but can detect false islanding situations; on the other hand, a bigger threshold is more exact to determine the islanding but has a bigger NDZ.

There are other techniques, such as the algorithm proposed by the Sandia National Laboratory, which is described in [5]. In this case, a positive feedback is used in order to determine the islanding: when the HES is grid connected, the loop has minimal effect on the voltage since the grid regulates the voltage, but, in islanding situation, with the feedback loop, the voltage becomes higher and higher causing an over-voltage that indicates a disconnection.

Although there are more techniques and algorithms, all of them are based on detection of voltage and frequency variations in the HES.

B. Micro-grids Architecture

Once the HES islanded, it can be considered as a MG, so at this point, it is important to review concepts and characteristics of them [6]. In Fig. 1. it is showed the architecture of a MG which uses a Micro-grid central controller (MGCC).
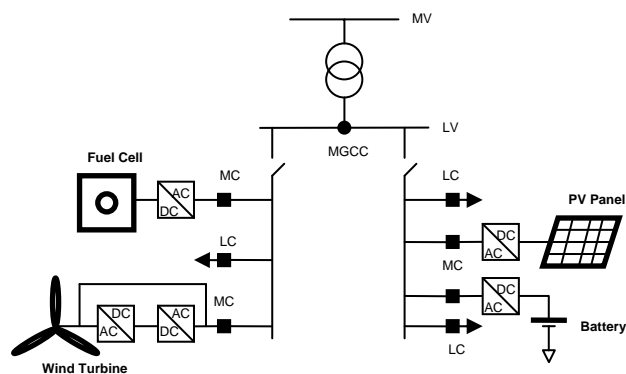

Fig. 1. Micro-grid with micro-grid central controller (MGCC) architecture.

In this case, the MGCC is the brain of the hierarchical system. It is connected to low voltage (LV) line, installed at the LV substation. The MGCC performs different functions such as economic managing and control functions. There is a second hierarchical control level, with load controllers (LC), which are connected with electrical loads, and micro-source controllers (MC), connected with electrical generators, batteries, etc. LC and MC exchange information with the MGCC to control all the operations. As it is shown, MGCC, LC and MC have intelligence in order to manage the MG, so a communication network to transmit messages between them must be used.

C. Micro-sources and Storage Devices

Micro-sources (MS) are electrical sources of low power, smaller than 100 kW. These sources are placed at customer sites, and consist in micro-turbines, wind generators, photovoltaic panels, and fuel cells, as it is usual in a HES. All power systems have storage provided by the generators inertia. When a new load is connected to the line, there is a variation in the system energy, but this energy balance is corrected by the mentioned inertia. In the case of MS working in an island mode, the inertia is not high enough, so a way to ensure the initial energy balance is required. Some MS, such as fuel cells and micro-turbines, have a large response time constants, needing storage devices which are able to provide the amount of power required to balance the system in situations such as disturbances or load changes. These devices acts as controllable AC voltage sources to avoid sudden changes in the system, but they have physical limitations and a finite capacity to store energy. The necessary MG storage can take several forms: batteries or super-capacitors on the DC bus for each MS, direct connection of AC storage devices or using traditional generation with inertia from the MS. A lead–acid battery is considered the most suitable for MG applications. They are capable of providing large currents for a very short interval of time.

D. Finding New Signal References for MG Inverters

Most of the technologies installed in MG are not prepared to be connected directly to the electrical network, because of the characteristics of the energy produced by them. When operating in grid connected mode, the MG sources are controlled as a constant power sources and they use as reference the grid voltage and frequency. Once in islanded scenario, the sources must be controlled in order to keep loads supplied by a constant voltage and frequency. To perform this flexibility, DC/AC or AC/DC/AC inverters must be used as interfaces between electrical network and MG. So, the control of these inverters is one of the main tasks in the MGCC.

E. Inverter Topologies

Normally, in LV distribution networks, there are four wires to be able to supply single-phase and three-phase loads.
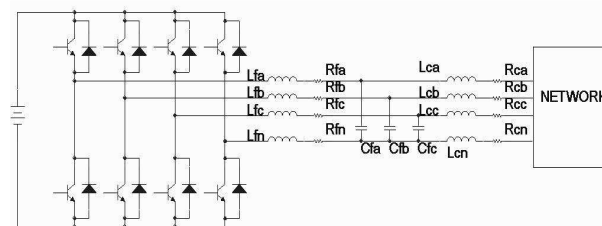

Fig. 2. Three-phase four-leg inverter with the mid-point of the fourth neutral leg connected to the neutral point.

Like this, it is possible to have a neutral connection to the four-wire system in three different architectures [7]: connection using a Delta/Wye grounded transformer; using split DC link capacitors with the mid-point of the DC link connected to the neutral point; or using a four-leg topology and connecting the mid-point of the fourth neutral leg to the neutral point.

The topology showed in Fig. 2. with the inverter controlled in stand-alone mode, is the most common used as interface between MG and the network. Sometimes, it is recommendable to connect several inverters in parallel creating a modular structure, in order to avoid the stand-alone inverters limitations (in terms of heat dissipation, reliability and costs) and making a MG more flexible to future demand increases. Fig. 3. shows a MG topology using two inverters connected in parallel. The electrical line resistors and inductances are included.
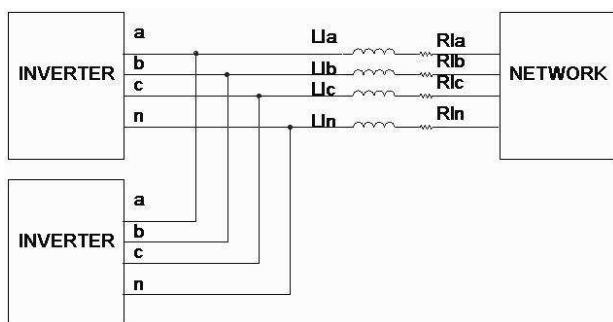

Fig. 3. MG with two inverters in parallel supplying a local network.

F. Control Strategies with MG Isolated

A MG can be considered as an inverter dominated network, because the frequency is controlled by means of the power electronic interfaces (in the inverters). In addition, the voltage must be also controlled to avoid oscillations, own and in the reactive power of the MG.

Usually, there are two basic kinds of control to operate an inverter [8]: PQ inverter control (the inverter provides supply for an active and reactive power set-point) and Voltage Source Inverter (VSI) control logic (the inverter feeds loads with predefined values for frequency and voltage). While the MG operates connected to the network (interconnected mode), all the inverters work in PQ mode. But, when a sudden disconnection of the network happens, the MG can not balance the generated energy and the load consumed energy, and it is also impossible to control the voltage. The only method that can be used to solve this problem is the VSI because it is able to operate in parallel with the electrical grid without injecting active or reactive power. So, in islanding, the output of the VSI is determined using the difference between load and generation in the MG.

In [9] two VSI control strategies to be employed when the MG passes to islanding are described: Single Master Operation and Multi Master Operation.

1) *Single Master Operation.* It is possible to use a VSI or a synchronous machine directly connected to the grid as a voltage reference once

the electrical network reference has been lost. In this situation, the Master inverter fixes the reference, which is followed by the rest of the MG. In Fig. 4. this operation scheme is described.
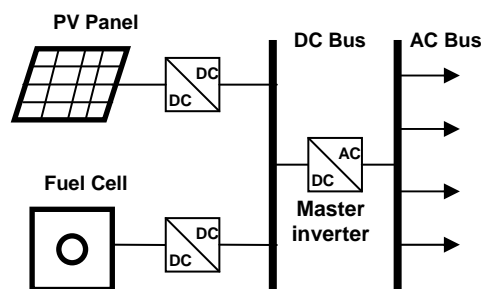

Fig. 4. Single Master Operation block diagram.

2) *Multi Master Operation.* In this situation, there are several VSI with defined characteristics in terms of voltage-reactive power and frequency-active power. Here the problem is to ensure that all the inverters have chosen the same reference. In order to do that, the MGCC gives this reference to all the inverters. Fig. 5. depicts this scenario.
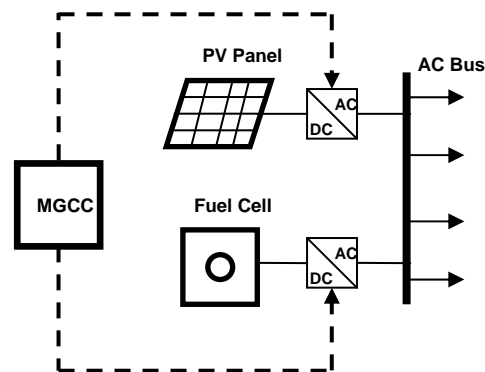

Fig. 5. Multi Master Operation block diagram.

Restoring the frequency to the values that it had before islanding is also important. For this, there are two secondary control strategies: Local Secondary Control and Centralized Secondary Control.

Local Secondary Control uses a local PI controller at each MS.

Centralized Secondary Control is mastered by the MGCC.

3. Demand Side Management (DSM)

The functionalities of DSM have changed in the last years because of the new technologies applied in the electrical networks and in communications. DSM has typical functions such as load control, SCRAM function (emergency shutting down of an electrical power generator) and energy metering. In terms of communications technology, load control and SCRAM function can be supported using one way communications, but in the case of energy metering, it is

necessary to employ two-way communications. Therefore, in the work described in this paper, two-way communications are going to be used in order to implement the DSM, to control connection and disconnection of the loads and to know at every moment the energy produced.

A. Communication Network Topologies

According with the MG topology described in section 2.B, it is possible to describe three basic communications topologies [10] according to the communication medium. In all of them, the Central Control Computer (CCC) is located in the MGCC, and the main nodes can be placed in the distribution substations.

1) *Configuration that uses the distribution network as communication medium (PLCom).* In Fig.6. is described this configuration. The volume of information transferred only depends on the CCC processing capacity. It is very simple to add new nodes in this topology.
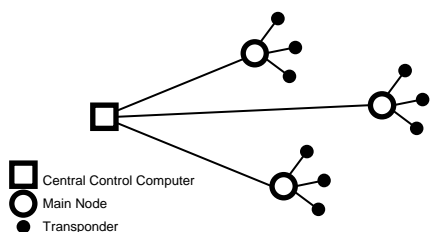

Fig. 6. Distribution network used as communication medium.

2) *Architecture for radiofrequency (RF) communications.* In this situation, (Fig. 7.) the main nodes communicate by RF technologies. Now, there are problems associated to wireless communications, such as the interferences between contiguous radio-electric paths, which must be taken in account.
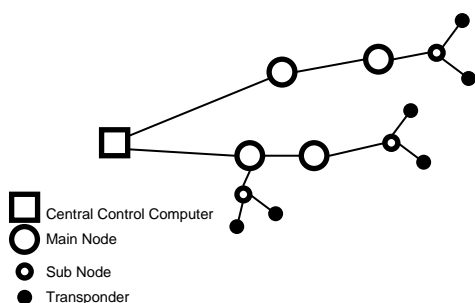

Fig. 7. Architecture for RF communications.

3) *Wide area network (WAN) with nodes linked using RF.* In each node, there is a local area network (LAN) that connects several transponders. The necessary routing protocols are more sophisticated and the transmission time is higher and not assured, as it is habitual in a

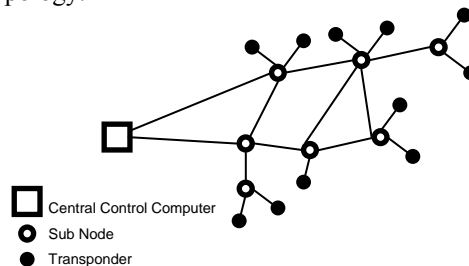WAN scenario. Fig. 8. shows an example of this topology.

Fig. 8. Network using WAN.

B. PLCom Implementation

Power Line Communications (PLCom) makes use of the existing electric network for communication purposes. The problem is that the electrical network has not been designed to transmit any kind of communication data, so it does not comply with the minimum requirements demanded in terms of some parameters, such as noise or channel characteristics. Among all of them, the most important is the electrical noise, which can be classified into three types: impulsive (often correlated with 50/60 Hz, due to switching power supplies), narrowband (long term with bandwidth under 100 Hz, mainly caused by radiofrequency interferences) and background (broad band and long term). So, all the communication protocols utilized in PLCom must be immune to this noises, specially, narrowband noise.

In medium voltage lines (MV) is used the Orthogonal Frequency Division Multiplex (OFDM) modulation [11]. OFDM combines a very good bandwidth allocation with a high data rate. Error correction code working at the same time with OFDM, avoids efficiently narrowband interferers, impulsive noise and frequency selective attenuation. In Fig. 9. the spectrum of OFDM is shown, where it is possible to see all the carriers, naming OFDM as Multi-Carrier Modulation too.
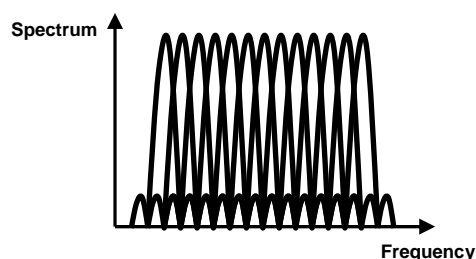

Fig. 9. OFDM spectrum.

Spread Spectrum-Fast Frequency Hopping (SS-FFH) modulation is used in LV [11]. This scheme encodes one bit or one symbol (several bytes) with sinusoidal carriers limited in time, called chips. The frequency of the carriers is chosen in order to make orthogonal chip waveforms, avoiding interferences between them. This is the usual technique in all the spread spectrum modulations. Other variation is the Direct-Sequence Spread-Spectrum (DSSS), used in wireless communications because of its resistance to multipath fading and narrowband noise.

One of the latest codification scheme proposed for PLCom is Ergodic Chaotic Parameter Modulation (ECPM) [12], which is very robust to multipath interferences and the receiver is quite simple.

C. Communication Protocols Susceptible to Be Used in DSM

All the tasks performed by DSM, such as load control, are going to be performed by means of communications protocols, so it is possible to define protocol architectures for them. By the moment, physical features of the signals have been described (e. g. modulations), but not logical ones.

If a LAN exists, it is possible to use protocols like IEEE 802.3 (Ethernet). Transmission Control Protocol – Internet Protocol (TCP/IP) can be used if a WAN exists. It will be also necessary to manage the communications network, and for this purpose, Simple Network Management Protocol – Internet Protocol (SNMP/IP) can be employed [13].

D. Wireless Communications Protocols

In the last years, wireless communications technologies have experimented a great development and expansion. Among all of them, there are some that are interesting because of its availability and their network infrastructure, which is widely extended in most of the countries. In this section, there are a list of wireless technologies, and a discussion of their convenience to be used in our application.

Trunking systems. Private Mobile Radio (PMR) systems use technologies based on trunking systems. The most important of them is Terrestrial Trunked Radio (TETRA), standard defined by the European Telecommunication Standard Institute (ETSI) to unify all the trunking technologies. This kind of systems is oriented to enable communications in some specialized professions, such as police or fireman. The data bit-rate is not very high, and it is necessary to create a complex network.

GSM. The main advantage of this technology is its great expansion, aided by the mobile telephony. That allows having an enormous communications network with practically uninterruptible coverage. Of course, the main limitation is the low bit-rate to transmit data information (9600 bps).

GPRS. It has the same advantages of GSM, because employs the same network infrastructure, but the data communications bit-rate is higher (40 kbps in transmission and 20 kbps in reception).

UMTS. This technology improves the GSM and GPRS limitations in terms of bit-rate, reaching 2 Mbps, but it is not very extended in many countries.

HSDPA. The High Speed Downlink Packet Access (HSDPA) technology consists in a UMTS optimization. It employs a downlink shared channel that improves notably the maximum information transfer capability, reaching bit-rates of 14 Mbps.

At this point, it is necessary to say that with GSM/GPRS/UMTS/HSDPA uses a telephone number at each node as addressing system, which is not very useful for our application.

Wi-Fi. This is a set of standards for wireless networks based in the IEEE 802.11 specifications. It is used mainly in wireless local area networks (WLAN). The most important advantage is the mobility and the high speed provided. On the other hand, there are some disadvantages, such as problems with the interferences and with the network security (although this problem has been resolved with WPA2, a protocol to make more secure the network access).

WiMAX. With this technology (IEEE 802.16 MAN), it is possible to reach distances of 50 km with a good quality of service (QoS). It is important to mention the improvements of this protocol in multi-path interference, delay and robustness.

In load control DSM, there are not a huge amount of data to transmit, only the request of the MGCC to the LCs and MCs, and their responses. Also, the commands envied by the MGCC to order load connection or disconnection. So, Wi-Fi and WiMAX technologies provide much more transmission capability than the required.

Bluetooth. This is the common name of the industrial specification IEEE 802.15.1. Its features are: intercommunication between different devices (mobile phones, portable PC, PDA, etc.), communication channel of 720 kbps, a range 10 m or 100 m with repeaters, and transmission full-duplex. The main limitation of Bluetooth is its little range distance, and the limited number of nodes that can compound the network, 8 in this case (1 master and 7 slaves).

ZigBee. This is a group of high level communication protocols based in the IEEE 802.15.4 standard. It is very similar to Bluetooth, but there are some differences between them. The ZigBee network can have more than 64000 nodes, lower electrical consumption than Bluetooth, and lower bit-rate, of 250 kbps. Again, this bit-rate is not a problem, as it has been mentioned above, because of the lower data traffic in DSM load control. Other advantage of ZigBee is that many microcontrollers provide specific modules which implement this protocol, being very easy to create and configure nodes in the network.

Another possibility is to create an Ad-Hoc network to perform the communications. This kind of network has not a defined support infrastructure, the transmission is multi-hop and the data mast be routed by intermediate nodes. Fig. 10. depicts one example of Ad-Hoc network, where the nodes (circles) are connected without having any defined network structure. If the nodes are mobiles, the network's topology changes at every time.
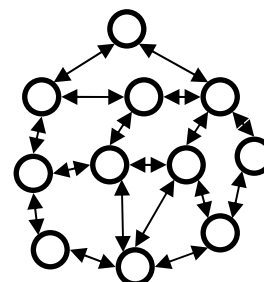

Fig. 10. Ad-Hoc network.

There are several advantages in Ad-Hoc nets, such as easy installation (it is not necessary a previous infrastructure), failure tolerance (stations which fail or disconnected can be avoided passing by other route), or the possibility to support mobility. Of course, ad-hoc networks have several problematic characteristics that should be solved, such as: communication between two distant points needs many intermediate nodes or the bandwidth diminution when the number of nodes increases, because all of them use the same channel.

4. Conclusion

This paper has presented the precedents in islanding and DSM. The HES in islanding scenario is like a MG, so the characteristics and all the problematic associated have been discussed: topology, finding references for the inverters, etc. About DSM, and the different wireless technologies mentioned, ZigBee seems to be the best solution for our application because its bit rate, number of nodes, distance covered and availability in many microcontrollers. Ad-Hoc net topology is proposed as a good network infrastructure, because is not necessary to have a defined structure and allows using mobile equipments.

Appendix: list of acronyms

CCC: Central Control Computer.
DSM: Demand Side Management.
DSSS: Direct-Sequence Spread-Spectrum.
ECPM: Ergodic Chaotic Parameter Modulation.
ETSI: European Telecommunication Standard Institute.
GPRS: General Packet Radio Service.
GSM: Global System for Mobile communications.
HES: Hybrid Energy System.
HSDPA: High Speed Downlink Packet Access.
LAN: Local Area Network.
LC: Load Controller.
LV: Low Voltage.
MAN: Metropolitan Area Network.
MC: Micro-Source Controllers.
MG: Micro-Grid.
MGCC: Micro-Grid Central Controller.
MS: Micro-Source.
MV: Medium Voltage.
NDZ: Non Detection Zone.
OFDM: Orthogonal Frequency Division Multiplex.
PLCom: Power Line Communication.
PMR: Private Mobile Radio.
QoS: Quality of Service.
RF: Radiofrequency.
SNMP/IP: Simple Network Management Protocol – Internet Protocol.
SS-FFH: Spread Spectrum-Fast Frequency Hopping.
TCP/IP: Transmission Control Protocol – Internet Protocol.
TETRA: Terrestrial Trunked Radio.
UMTS: Universal Mobile Telecommunications System.
VSI: Voltage Source Inverter.
WAN: Wide Area Network.
Wi-Fi: Wireless Fidelity.

WiMAX: Worldwide Interoperability Microwave Access.
WLAN: Wireless Local Area Network.
WPA2: Wi-Fi Protected Access 2.

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