A Microgrid with EMS based on a Standard Data Network. Analysis and Evaluation

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***Abstract*— In order to achieve optimal operation conditions in a microgrid with Energy Management System (EMS), a communication system is needed. It is important to consider in depth different characteristics of communication systems regarding issues like determinism, time constrains, cost effectiveness etc. This paper reviews different type of network protocols which can be used in order to fulfill the different communication needs for protection, management and automation in a microgrid. We also present simulations about the behavior of different networks protocols, showing whether some of the above conditions are met or not.**

***Resumen*— Para conseguir las condiciones óptimas de operación de una Microgrid con Sistema de Gestión de Energía (EMS), es imprescindible un sistema de comunicaciones, del cual es importante considerar en profundidad cuestiones como determinismo, restricciones temporales, relación costo beneficio, etc. Este trabajo revisa distintos tipos de protocolos de redes que pueden ser utilizados para satisfacer las necesidades de una microgrid, en cuanto a protecciones, automatización, administración, etc. También se presentan simulaciones del comportamiento de distintos protocolos en cuanto al cumplimiento de condiciones requeridas.**

I – INTRODUCTION

In the last few years much effort has been done trying to integrate different types of distributed generation, mainly using clean and renewable energy resources, to distribution utilities. Although the concept has been recently evolving, if we consider a set of low voltage Distributed Energy Resources (DERs) such as photovoltaic (PV), wind turbines (WTG), hydrogen fuel cells, diesel/gas (D/G), etc. generators. Also storage devices like flywheels, flow batteries, super capacitors, etc. Different type of loads like residential, commercial and industrial loads, which con be considered as non-controllable and pumping systems and cold storage considered as controllable loads, etc. Besides, this set can either work connected to a main distribution system or in islanding mode, then we are in presence of a microgrid. In order to have a safe, efficient and reliable behavior for this scenario, an Energy Management System (EMS) is needed. This can be done in different ways with different control and protection architectures and strategies. Independently of the architecture and strategies, a suitable communication network is a must.

Due to the existence of a wide variety of communication technologies, protocols, medias, algorithms, etc. together with the absence of a well proven standard for microgrids, a careful study must be done in order to choose the right communication system for a given application.

In this paper we present a generic microgrid (Fig.1) composed of distributed generation with a wind turbine, a photovoltaic cell and a diesel/gas generator. The storage system includes a flywheel and a flow battery and the loads are a pumping system as a controllable load and some housing and commercial as non-controllable loads. This microgrid can work either connected to a main distribution facility or in islanded mode.

For this set, using TrueTime [1] which is a Matlab/Simulink-based simulator for real-time control systems, that facilitates co-simulation of controller task execution in real-time kernels, network transmissions, and continuous plant dynamic, a comparison about the behavior of different wired communication networks will be made. The same microgrid deployment will be used in all cases, for a coherent comparison.

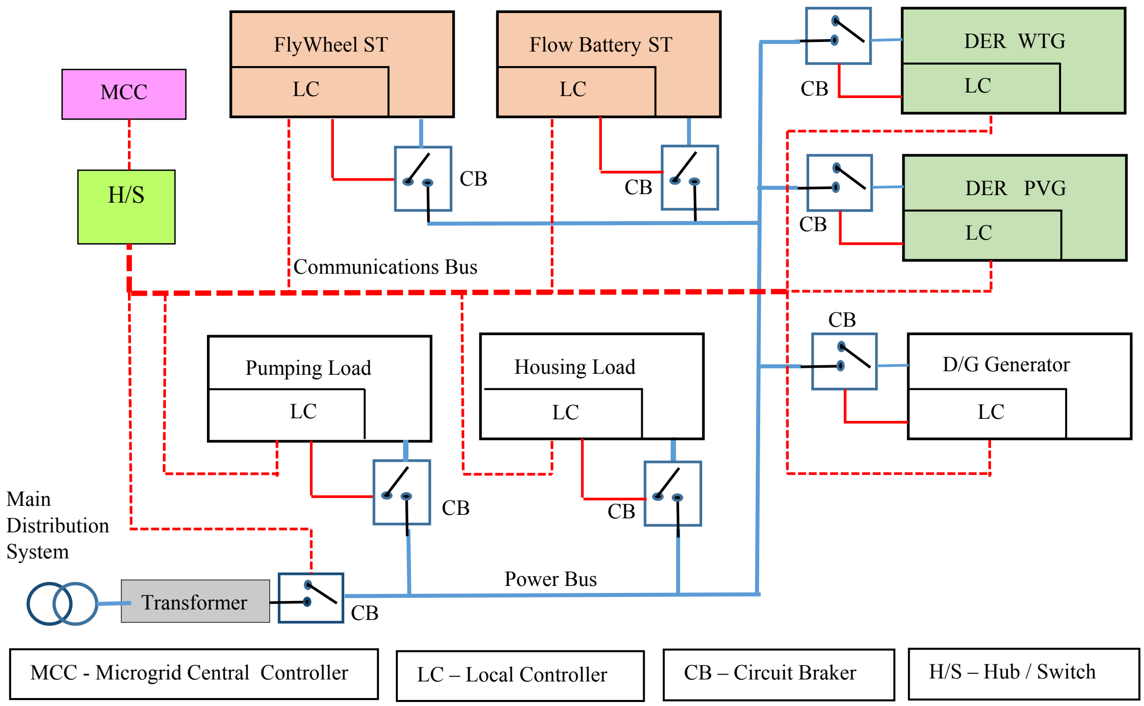

Fig. 1

The rest of the paper is organized as follows: In II we show the characteristics of the microgrid. In III some important protection issues are considered. In IV, a discussion about the communication environment is presented. In V Simulation Results are studied.

II – MICROGRID CHARACTERISTICS

Our microgrid can work, either with a weak connection to a main distribution system (MDS) or in islanded mode. Then, the idea is to provide enough energy with the DERs, in order to feed the total load of the microgrid. If the MDS is present, it provides the voltage and frequency reference but delivers the lowest possible energy and the D/G generator may be shut down. In islanded mode, the D/G generator imposes the voltage and frequency reference. The weak connection compels to be careful with voltage fluctuations on the microgrid power bus, while connected to the MDS.

The energy storage modules can be combined to resolve different type of problems, such as fast disturbances produced by WTG or the total absence of energy from the WTG and PVG.

Two types of loads are proposed, one controllable and one not. Although the housing and commercial loads are not controllable, some kind of intelligent device is needed to be able to communicate with the MCC and eventually operate the circuit breaker to protect the load and/or to maintain the load-generation balance.

Respecting the microgrid setting, it is considered to be in a relatively small area, 3 to 5 km^2. All modules are connected to a low voltage bus.

The proposed microgrid has a combined control system; part centralized for supervising, monitoring, protections and main distribution facility connection and distributed control for local devices. As it was said, every generation, storage and load modules have local control and those controllers may communicate between them when needed and to the Microgrid Central Controller through the communication bus.

In order to consider the best suited communication media, or at least good enough to achieve simplicity, reliability, scalability, etc., we can think on installing along with the low power bus, either aerial or underground, a multicore optical fibre cable. Nowadays, the cost of the fibre is going down and the deployment costs are absorbed by the power bus installation. [2], [3], [4].

III – PROTECTION ISSUES

Existing MDS were designed usually considering radial topology of passive networks with current flowing in just one way. On the other hand, a microgrid, independently on the amount of present DERs, loads and storage devices, can be seen as a module that behaves either as a net load or as a net power generator, state that may change frequently, those are the reasons for which new protection strategies must be considered.

Four types of faults can occur, which are the combination of whether the microgrid is connected to the MDS or in islanded mode and if the fault occurs inside or outside of the microgrid. Obviously an external fault while the microgrid is in islanded mode will not be considered. [5]

In both modes, the microgrid should be protected to ensure safe operation. In island mode, the power electronic source devices usually limit the fault currents to the maximum values allowed by the semiconductors, the same occurs for an external fault in connected mode. While in the same mode a fault produced inside de microgrid can generate much higher fault current values due to the contribution of the MDS.

Needless is to say that for microgrids, new protection strategies must be consider and those strategies will be based in the possibility to measure instant values of voltage, current, current flow direction, etc. and to be able to dynamically change different parameters in modern numerical/digital relays including tripping conditions, the setting of fault current levels, etc. [6].

IV – COMMUNICATIONS ENVIROMENT

Let us now review what type of messages, between who are they delivered and which kind of time restrictions do they have for all modules connected through the communication bus of the microgrid.

As it was said, all devices connected to de power bus have local control so the internal data transfers needed for such control do not aggregate traffic load in the communications bus. The information which travels over the communications bus is between the central controller and local controllers and occasionally between local controllers themselves. These types of messages considering monitoring and control issues do not usually have severe time restrictions. On the other hand, there exists communications concerning protection issues where one or more local controllers must suddenly actuate over relays, circuit breakers, or when the central controller needs specific data in order to maintain load and generation balance for the microgrid correct functioning. In such cases the communications time intervals involved drastically decrease.

Although the standard IEC 61850 [7] was thought for communications for substation automation, due to its penetration in the electric power systems industry, current studies are on-going to expand it for other systems. In fact, IEC have developed the IEC 61850-7-420 extension for DER systems and more recently IEC 61850-90-7 providing more object models which may be mapped to MMS, TCP/UDP/IP, DNP3, ModBus, and other protocols. [8].

The IEC 61850 proposes basically five different types of messages (Fig. 2). The measured values of current, voltage, etc. at the power bus, called Sampled Values (SV), the Generic Object Oriented Substation Event (GOOSE) and Generic Substation Event (GSSE) for tripping information, etc. are the most time critical messages since they should be completed in at least 4 ms. Every other type of messages have lower time requirements to be completed.

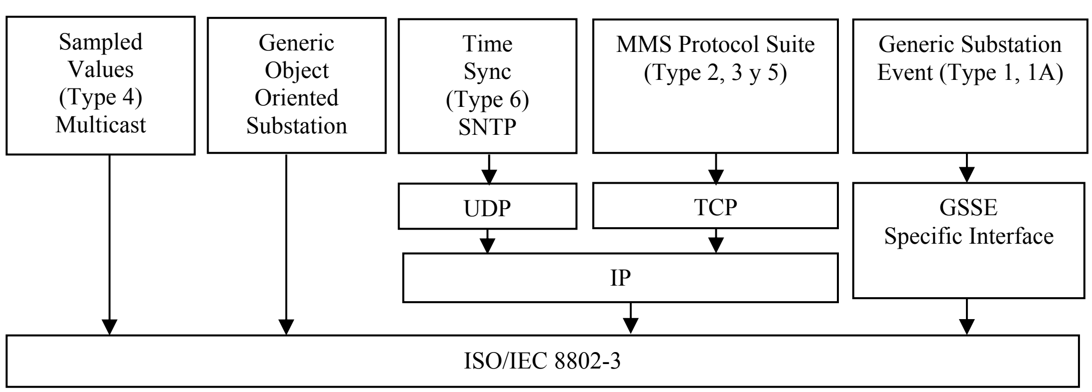

Fig. 2

V – SIMULATIONS RESULTS

For the following simulations we will consider the eight nodes shown in Fig. 1, being node 1 the MCC, nodes 2, 3 and 4 the local generators controllers, 5 and 6 the energy storage controllers, node 7 the pumping system controller and node 8 the communication controller for the housing load.

In Fig. 3, a very simplified scheme of the simulated communication network, with only two nodes out of the eight is shown.

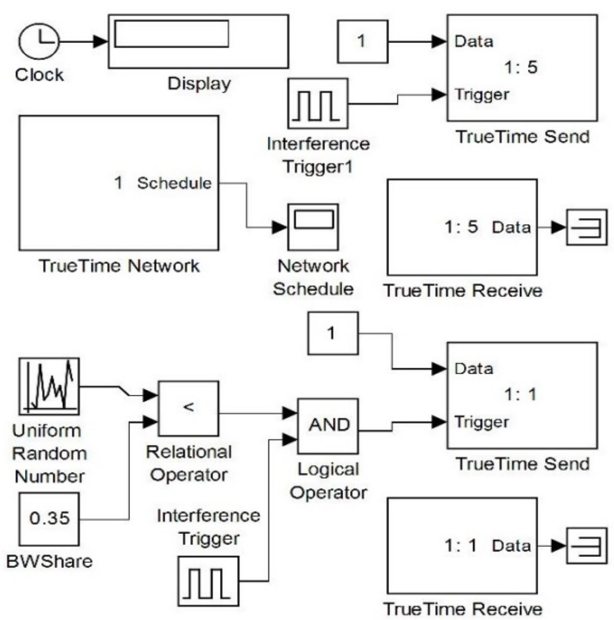

Fig. 3

The used protocol and some parameters such as quantity of nodes, data rate, minimum frame size, etc., are selected through the TrueTime network block. With the True Time Send block, node number, transmitter and receiver ID, data length, priority, etc. can be programmed. The block or combination of blocks connected to the trigger input of the TrueTime Send, allows to simulate different scenarios concerning the sometime fixed and sometime random accesses of the nodes to the communications bus.
For all the simulated cases, node 1, the Microgrid Central Controller (MCC), will try to access de communication bus much more often than the other nodes due to its own specific tasks.

A- Ethernet

Since the three types of time critical messages considered in the IEC 61850 Standard, are directly mapped over ISO/IEC- 8802-3, a plain simple 10 Mbit/s Ethernet LAN is considered as starting point for our simulation. The eight nodes are connected to a hub.

Fig. 4 shows the simulation results. The graphics represent the input of each node to the network activity. All nodes attempt to send messages randomly depending on their own needs. The meanings of the three levels in the graphics are: low level for node idle, it has nothing to send. Medium level, when the node wants to transmit but either the network is busy or a collision is being resolved. High level, the node is transmitting.
The results of the simulation shows that in a 4 ms period, the MCC (node 1) is able to send a dozen or so messages, while three other nodes can send one or two messages and the last four nodes are not able to transmit (not shown for the sake of simplicity). This was expected considering the transmission speed and the contentious characteristics of Ethernet.

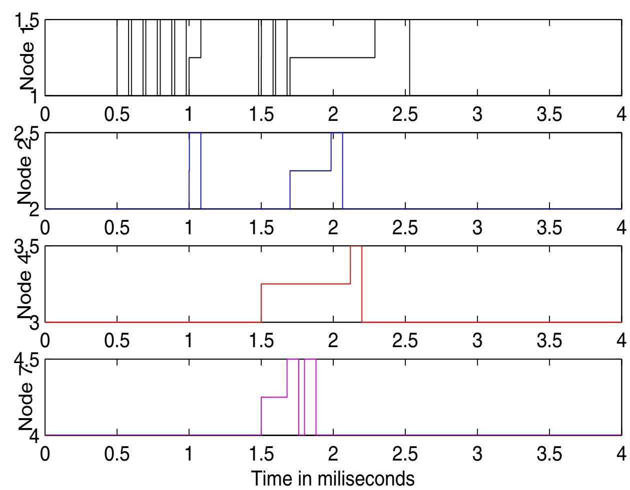

Fig. 4

Increasing the transmission speed to 100Mbps, although there is an improvement since all 8 nodes are able to transmit at least once, we cannot assure that all needed messages will reach destiny in the appropriate time.

B- CAN Protocol

Controller Area Network (CAN) is an extensive used protocol, especially in the automotive industry but also in many others fields. Although is not very common in microgrids, there is some work ongoing in different applications. [9], [10].
The Media Access Control used by CAN, is a combination of Carrier Sense Multiple Access with Collision Avoidance through Bitwise Arbitration (CSMA/CA-BA), combined with a Producer/Consumer scheme. This means that we can establish the priorities for the different nodes to access the communication bus, by varying the quantity of dominant bits at the beginning of the CAN frame. It is reasonable to think that in our microgrid set up, the MCC will be the node with highest priority.
Fig. 5 shows the results of a simulation for our microgrid, running at 1Mbps as established in the CAN protocol. As it

can be seen, node 4 is able to transmit one message and after that, node 1 (MCC) takes possession of the bus and none of the other nodes are able to transmit (again only four of the eight nodes are shown in the graphic).

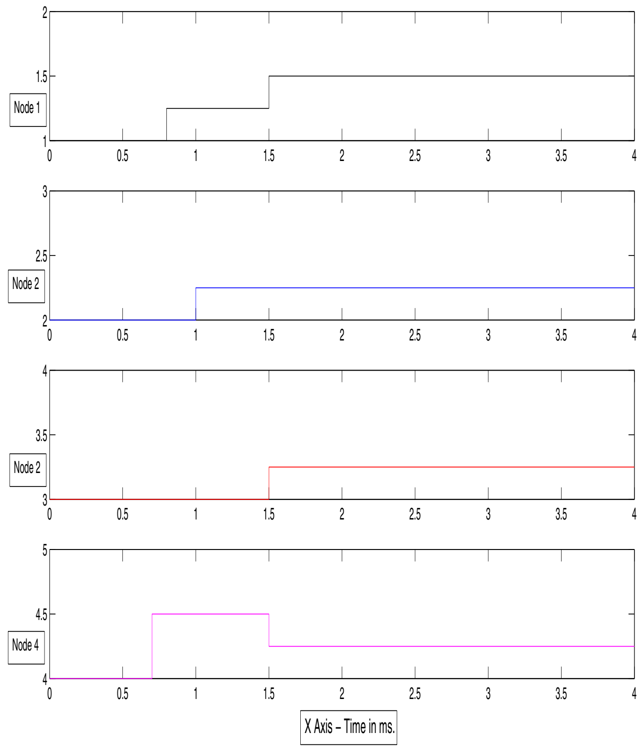

Fig. 5

C- Master/Slave

Another possibility is to try a master/slave protocol. Modbus is probably the oldest and a very widely used protocol of this type in different applications including power utilities. A close setting to simulate Modbus with TrueTime, would be using a TDMA model with static schedule scheme, where node 1 (the MCC) is the master and the other seven nodes are the slaves. The MCC will access the communication bus alternatively between nodes, addressing the corresponding slave. In this case some important things must be considered. Being Modbus an application level protocol it can be mapped directly over Ethernet or through TCP, UDP/IP and finally Ethernet. In both cases, the lower level protocols have their own headers which will add overhead to the final frame. Then, the length of the slot time should be enough to transmit the complete message, depending on the transmission speed.
Considering roughly 256 bytes for a Modbus message, 24 bytes for the TCP header, 20 bytes for the IP header and 26 bytes for Ethernet header and CRC, and that the hardware is capable to drive the bus at 100 Mbps, then the slot time should be around of 30 µs. Applying some security margins to overcome any possible delays, for the TrueTime simulation, the length of each master or slave message will be considered of 40 µs together with a 5 µs interframe gap. In such conditions, the master (MCC) will address each specific node every 630 µs, which means that all nodes will be able to transmit six times in a 4 ms period. This is considering that the master access the slaves in a continuous uniform periodic cycle. Fig. 6 shows the results, again for the MCC considered the master and three slaves, to make the graphic simple.

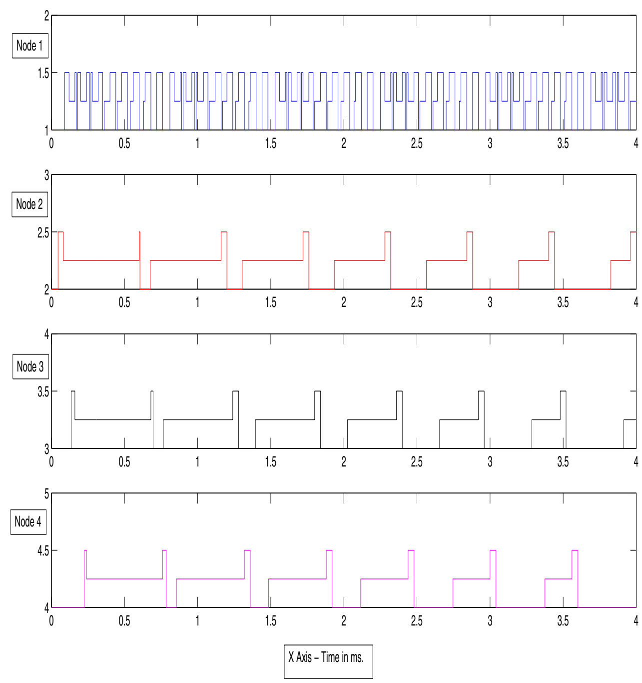

Fig. 6

D- Switched Ethernet

Let us change the hub used in the first simulation for a switch, in this case a medium quality rugged switch running at 100Mbps with a 256 Kbytes of buffer size and a switching capacity of 3.2 Gbps is used.
The simulation settings through the True Time Send block, allows to select the switch buffer type as either common or symmetric , the last, meaning that each port has its own buffer with one eighth of buffer memory, instead of just one buffer common for all nodes. Also, the switch behaviour under overflow conditions could be either of dropping or retransmitting the frame. Truth is that none of the above settings influence much in the simulation results, this is due to that the selected switch buffer size together with the switching capacity are large enough to generate a good performance.
We consider again the MCC (Node 1) with the highest activity in the communication network and the other nodes were considered with fewer needs for accessing the communications bus.

Fig. 7 shows the activity of just four nodes, but all eight nodes are able to transmit many times in a four millisecond period.

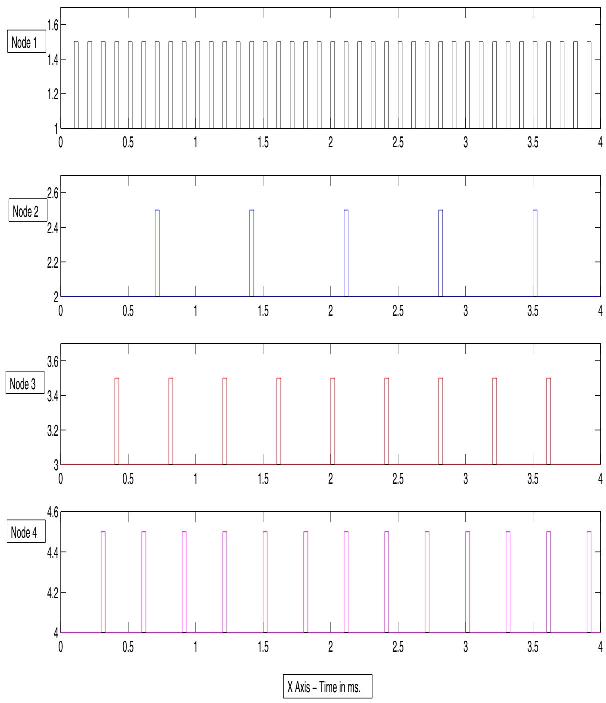

Fig. 7

VI - CONCLUSIONS

Although many issues had been addressed in this paper that for sure needs a much deeper treatment, the above considerations together with some simple simulations allow us to present some conclusions.

First, the use of a communication network in microgrids is imperative. Since the network must be useful for three main tasks in a microgrid: monitoring, control and protections, a careful study must be done in order to select the most appropriate type of network.

True Time Simulator was a very useful tool to corroborate the behaviour of different network protocols. The simulations showed that more than one protocol fulfils the restrictions and needs of the microgrid, then, other factors should be considered like simplicity, cost effectiveness, etc.

It would be wise to select just one protocol capable of fulfil all tasks. Try it to be a known and spread used standard. The hardware should be simple and of well-proven technology. Foresee scalability, since in a Microgrid, the change or addition of any DERs, loads or storage modules is a true possibility. Consider also that it may be necessary the use of some kind of redundancy.

Finally, spending some time and founds in a careful selection of the available choices in communication networks and protocols, will redound in considerable benefits.

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