The Ethernet POWERLINK Protocol for Smart Grids Elements Integration

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***Abstract-* In the paper it is presented control system of distributed energy resources (DER) based on Ethernet POWERLINK Protocol. Authors develop a common method for communicating with The Inverter-Based Microgrid System. This paper presents the optimal storage sharing control method of grid connected generation system. This system consists of photovoltaic panels (PV), windmill with induction generator (WG), supercapacitors (SC), AGM battery, controllable load, power converters and electric power system. These components can be connected to make a micro-grid system controlled by Energy Management System based on DSP, ARM 9 processors and FPGA hardware. In a case study, it is analyzed how Ethernet POWERLINK Protocol can be used to build a communication channels between converters, load and management system. Simulation results are presented to demonstrate reliability of proposed control systems. The whole control scheme and communication protocol are implemented on a DSP and FPGA.**

***Keywords* — storage control, distributed energy resources, Ethernet POWERLINK, energy management system**

I. INTRODUCTION

Continued improvement in the cost and efficiency of PV, mCHP, supercapacitor and AGM Battery technology hints at a future in which utilities will need to accommodate high levels of variable distributed generation (DG) on their transmission and distribution systems [1,2]. The communication connectedness of these diverse, often small-scale devices will be an essential factor in enabling their widespread integration . In fact, the development of a common language for communicating with distributed inverter-based systems, such as solar photovoltaic's (PV), wind power (WP), mikro Combined Head and Power (mCHP) and energy storage, has the potential to improve the monitoring, controll and management capabilities (EMS) and more competently exploit DG's aggregate benefits [3]. These distributed resources, connected via an electronic power converter (inverter), can offer new opportunities for faster power control and compensation of local voltage variations. Communication will enhance grid benefit by enabling the collaboration of many small resources with the larger public power supply. Unfortunately, capturing these benefits today is impeded by the lack of common functions and a common language to manage inverter-based systems [5,6]. The upshot: utilities will be better able to support higher grid penetration levels and to derive greater value from distributed assets such as grid-tied photovoltaic and energy storage. This paper describes efforts currently underway to identify the basic inverter/charger capabilities and develop a standardized communication protocol to enable distributed grid support. Distributed power generation of microgrid includes Wind Power Generation, Photovoltaic Power Generation, Fuel Cell Power Generation and various energy storage systems [6]. The present research, using an object-oriented methodology and methods for CIM (Common Information Model) based on IEC61970 and IEC61850 [5]. For the communications between the Custom Energy Management System (EMS) and the inverter, the following communications technologies could be used at different layers:

- Transport layers: Ethernet
- Application protocols: POWERLINK,
- Object models: IEC 61850

In most, if not all, cases, distribution automation represents one of the least latency-tolerant smart grid applications, with requirements for less than 1 second of latency for alarms and alert communications and 10 milliseconds for messaging between peer-to-peer nodes for control. The maximum latency for certain more latency-tolerant applications will not exceed two seconds. Bandwidth requirements will be in the range of 9.6 kbps – 1500 kbps, and the required level of reliability will be 99 percent to 99.9999 percent. As these functions are not only required when there is electricity available, than backup power is required in EMS - Tab. I.

TABLE I
SMART GRID FUNCTIONALITIES AND COMMUNICATIONS NEEDS

Application	Parameters			
	Bandwidth [kbps/node]	Latency	Reliability	Backup Power
Application Program Interface	10-100	1s -15 s	99,9%	Not necessary
Demand Response	14-100 kbps/node/ device	500 ms - 3 s	99,99%	Not necessary
Wide Area Situation Awareness	600-1500	10 ms - 200 ms	99,999-99,9999%	24 h supply
Distribution Energy Resources and Storage	9,6- 1000	10 ms - 15 s	99,99%	1 h supply
Distribution Grid Managment	9,6 - 100	100 ms - 2 s	99,99-99,999%	24 - 72 h supply

II. System Topology

Micro-grid systems with storage and generation systems can have various structures. The main components of these systems are grid, gas engine generator, converter, inverter, load, photovoltaic system, wind generator and storage with supercapacitor and valve-regulated lead-acid battery. Absorbed glass mat (AGM) is a class of VRLA battery in which the electrolyte is held on the glass mat separator by way of capillary action. All of these components can be connected to each other through grid bus, DC-line and AC-line as in Fig 1. In this topology the load is directly connected to the grid so as to supply the power from grid to load without any power conversion. The generator is connected to the DC-line through one inverter so that the power from the gas engine to load is converted two times.

Utilities can interact with PV/Storage systems using different architectures. The following diagram illustrates the use of a Customer EMS (Energy Management System) to help manage PV, Network, Windmill inverters responses to the broadcast utility request, with the idea that this Customer EMS will possibly be managing multiple DER inverters, customer appliances, other types of distributed generators and storage devices. For instance, if the utility broadcasts a specific request for DER inverter actions, then these can be passed directly or indirectly (through explicit commands) to inverters. If the utility broadcasts Demand Response signals or more generic volt/var requests, then the Customer EMS could use other devices in addition to inverters to meet these requests. With this approach, the Customer EMS could manage responses locally to meet the requests with the most effective mix of devices.

From a communications perspective, the utility broadcast to the customer site, between the utility and the "Customer EMS", could use different technologies at different layers, for example Ethernet Powerlink.

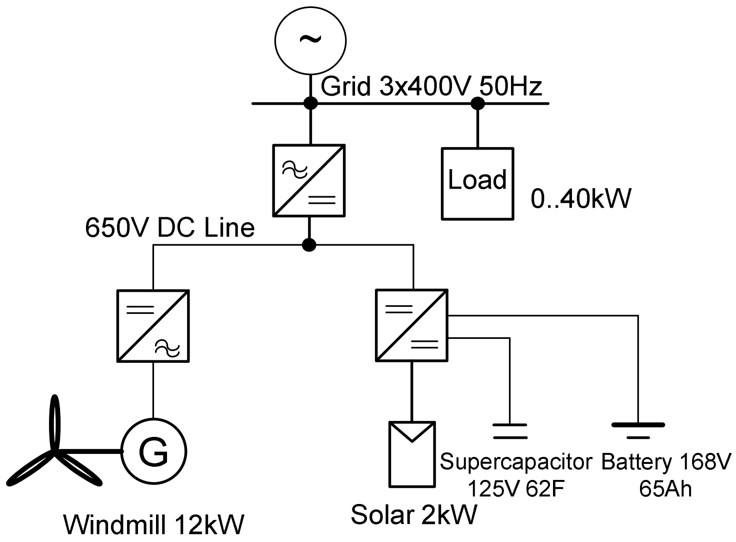

Fig. 1. Hybrid DC linked microgrid.

III. Ethernet POWERLINK Protocol

Networks that are used in industry must meet certain requirements. The most important include reliability, low price, time determinism and the appropriate speed of data transmission. Trends of recent years shows the growing popularity of protocols based on Ethernet technology. The most important are Ethernet POWERLINK, Ethernet/IP, Modbus/TCP, Profinet, EtherCAT and SERCOS III.

EthernetPOWERLINK is a protocol that uses the IEEE 802.3 standard and mechanisms occurring in CANopen. In 2003 was established independent association (The Ethernet POWERLINK Standardization Group - EPSG) [4], which ensures the development of the standard. The major advantages of the protocol is short, determined communication cycle time (down to 200 µs) with ultra-low jitter (down to 1µs). Tab. 2. consist the minimum cycle time for Ethernet POWERLINK protocol, depending on the used hardware platform [4,10].

TABLE II
POWERLINK Minimal Cycle Time [4,10]

Operating system	Min. cycle time	Possible applications
Linux (+RTPREEMPT)	400 µs	I/O, Motion, Safety
Windows XP	5 ms	I/O, Safety
Windows CE	2 ms	I/O, Safety
Embedded system	200 µs	I/O, Motion, Safety

What distinguishes EthernetPOWERLINK compared to other protocols is its accessibility. There is available a free stack of protocol, which is called openPOWERLINK. The latest available version is openPOWERLINK_V1.7 [8]. It contains sample programs that can run on X86 computers (under Windows or Linux), Atmel AT91RM9200 microcontroller or FGPA.

There is a free software available to make configuration of all network easier (openCONFIGURATOR). It is based on configuration files (xdd/xdc), that should be provided from manufacturer. It creates cdc file that is stored in MN memory and is used to configure all devices in the network.

There are two types of devices in EthernetPOWERLINK: Managing Node (MN) and Control Node (CN). MN is responsible for managing the network, while the CN act as a slave. The communication cycle consists of three phases: isochronous phase (critical data transferred via PDO), asynchronous phase (configuration data transferred via SDO) and the idle phase (waiting for the next cycle) [9].

IV. Simulation Results

The diagram of simulated system is presented in Fig. 2. Its parameters are presented in Tab. III. Tab. IV describe the variables from simulation transients. System consists of a wind turbine (12KW), photovoltaic panels (2kW), batteries (168V, 65Ah) and supercapacitors (125V 62.5F). The stability of DC- and AC-bus voltage is very important.

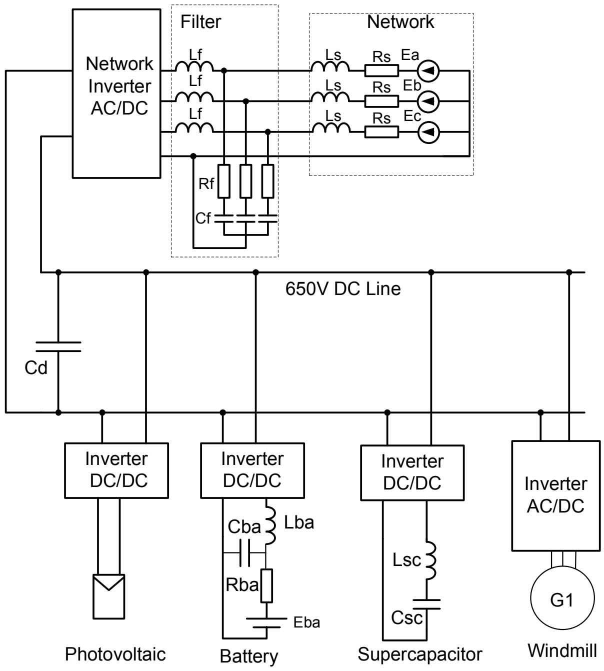

Fig. 2. Diagram of simulated system.

TABLE III
SYSTEM PARAMETERS

System Quantities	Values
Grid frequency	50 Hz
Lf	5 mH
Cf	30 μF
Rf	1 Ω
Ls	1 mH
Rs	0.2 Ω
Cd	1 mF
Rba	0.084 Ω
Eba	168 V
Lsc	5 mH
Csc	62.5 F
Cba	50 μF
Lba	5 mH

TABLE IV
NAME OF VARIABLES

Variable	Description
Pg	Power generated in windmill
Ppv	Power generated in photovoltaic cells
Pbat	Power supplied from batteries
Pgen	Total power supplied to the DC line Pgen=Pg+Ppv+Pbat
P	Power fed back into the power system
Urms	Phase voltage (RMS) at the output of the network converter
Ud	DC line voltage

When microgrid is connected to the utility grid, the magnitude of DC-bus voltage is regulated in standard solution by the network inverter (Fig. 3.) . And the magnitude and frequency of ACbus voltage are the same with the grid. However when the microgrid works in island operation, DC-bus voltage must be regulated by microsouces and storages. And the magnitude and frequency of AC bus are controlled by Network Inverter. If the storage discharges deeply in island operation, and the microsources also can't supply enough power to all the loads, energy management system will cut off the other loads except sensitive loads. If the battery charges deeply, and the microsources supply more power than loads' need, the wind turbine and photovoltaic will be controlled to supply load-needed power instead of Max Power Point Tracking (MPPT).

In this paper there are two simulations presented. The first one (Fig. 3) presents the situation in which the network inverter is used to control DC voltage and the second one (Fig. 4) presents the behavior of system when inverter from supercapacitor is used to control voltage in DC line. In both cases transients of generated power reflect the situation of a sudden gust of wind and reduced solar radiation by a moving cloud. Furthermore a rapid change of power supplied to the DC line was simulated by launching recharging of batteries. Those rapid changes in power supplied to the DC line was chosen to present potential threat to the grid.

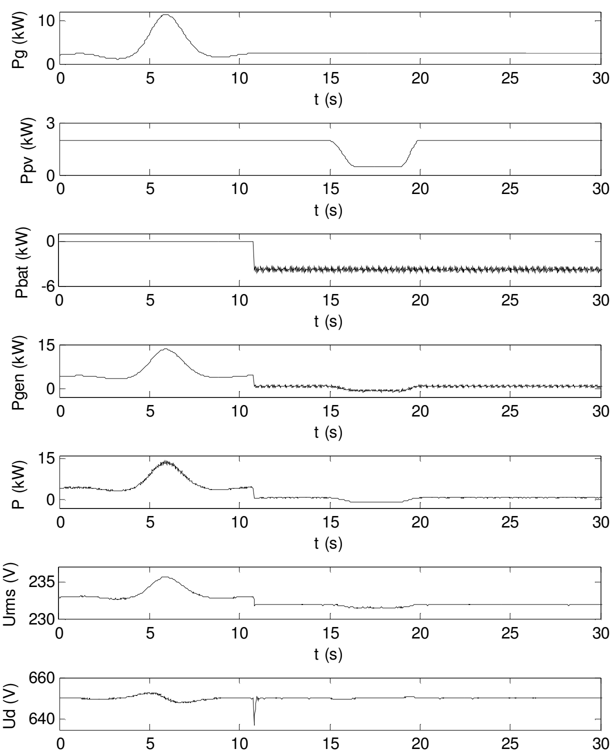

Fig. 3. Waveforms of the power generated from renewable energy sources. Ud controlled by network inverter.

In Fig. 3 is shown situation, in which the network inverter is used to control DC line voltage. Supercapacitor is disconnected from the system. Rapid changes in power supplied into DC line cause rapid changes in P, Urms and Ud.

That may cause unwanted behaviour of power system in the vicinity of the connection of renewable energy sources to the grid (eg. lights flickering).

Those rapid changes in waveforms were reduced by adding energy storage and changing the principle of control the DC line voltage. In that situation the voltage controller in network inverter was disabled and there was added DC line voltage controller in supercapacitor inverter. As a result, there was a need to change the method of generating the reference value for real power controller in network inverter (Fig. 5.). For that purpose Pgen value is calculated, which is the total power fed into the DC line and after transforming it is send as a reference value to the real power controller in network inverter. Reference power is calculated according to equation:

$$\mathrm{Pref} = \frac{k}{(T_1 s + 1)(T_2 s + 1)} \mathrm{Pgen} \qquad (1)$$

where: k – proportional gain, T1, T2 – time constant, Pgen – power fed into the DC line, Pref – reference value for power controller

Fig. 4. presents the waveforms for that situation. Rapid changes in Pgen does not cause rapid changes in reference value for power controller. When the Pgen is greater than Pref the difference power is fed to the supercapacitor. In opposite situation, when Pgen is lower than Pref, the difference power is fed from the supercapacitor. The gain k power fed back into the power system were eliminated rapid changes in Urms no longer occur.

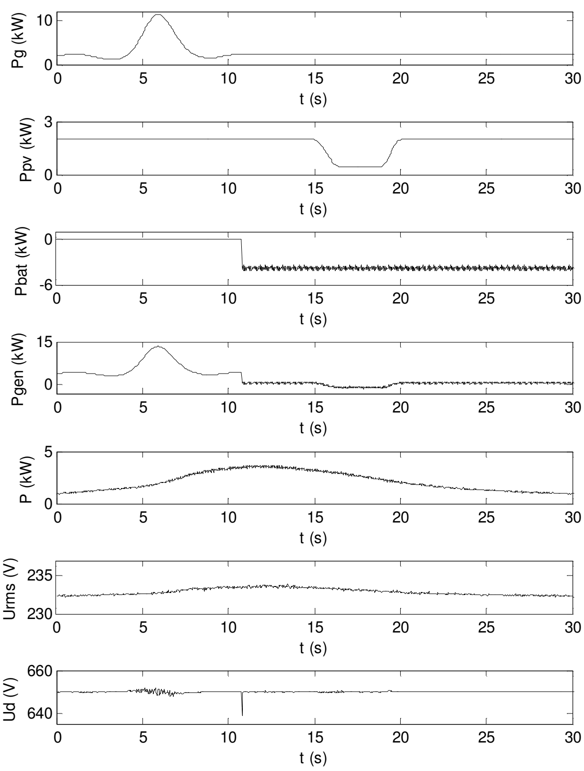

Fig. 4. Waveforms of the power generated from renewable energy sources. Ud controlled by inverter with supercapacitor.

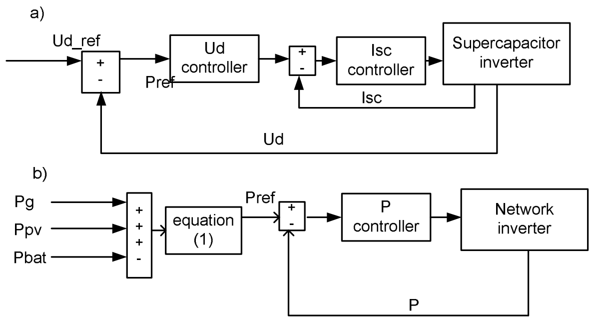

Fig. 5. Control system of Ud (a) and P (b)

V. Conclusions

The proposed improvement of control system provides a reduction in adverse effects caused by sudden changes in the power generated from renewable energy sources. The addition of energy storage and modification of the control loop reduces the fluctuation in power fed back to the grid. As a result fluctuation in voltage are also reduced. Proposed changes force the need for using fast and reliable communications, that will provide technical mean to exchange information between inverters in exact time. The authors point to the Ethernet POWERLINK as a protocol that can ensure the appropriate cycle time (down to 200 us). In addition that protocol is available for free as a openPOWERLINK. Using of Ethernet technology allows to increase the distance between the devices in the network, which can often occur in a situation of distributed energy resources.

References

[1] R. Asseter, A. Khil, C. Arnay, et al, "White Paper on Integration of Distributed Energy Resource-The CERTS Microgrid Conception," LBNL-50829, Oct. 2003.

[2] DING Ming, WANG Min, "Distributed generation technology," Electric Power Automation Equipment, vol. 24,no. 7, pp. 31-36, July 2004..

[3] B. M. Buchholz, Z. A. Styczynski, "New Tasks Create New Solutions for Communication in Distribution Systems," Power Engineering Society General Meeting, 2006. Montreal, Que 2006.

[4] Ethernet Powerlink communication profile specification version EPSG_DS_301_V-1-1-0_01 *www.ethernet-powerlink.org Ethernet Powerlink Standardisation Group*, 2008.

[5] B. Seal, "Standard Language Protocols for Photovoltaics and Storage Grid Integration," Electric Power Research Institute.*www.epri.com*, May 2010.

[6] F. Katiraei, R. Iravani, N. Hatziargyriou,et al, "Microgrids management," IEEE Power and Energy Magazine, vol. 6, no. 3, pp. 54 –65, May-June 2008.

[7] IEC 62350. Communication systems for distributed energy resources. IEC 57/750/CD

[8] openPOWERLINK: Ethernet POWERLINK Protocol Stack Software Manual Edition August 2010

[9] J. A. Maestro, P. Reviriego: Energy Efficiency in Industrial Ethernet: The Case of Powerlink *IEEE Transactions On Industrial Electronics, Vol. 57, No. 8, August 2010*

[10] Josef Baumgartner, S. Schoenegger "POWERLINK and Real-Time Linux: A Perfect Match for Highest Performance in Real Applications Realtime" Linux Workshop, Nairobi, Kenya October 2010