International Journal of Engineering & Technology, 7 (2.6) (2018) 171-175

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research Paper

Concept of Power Line Communication solution for Mesh DC Micro grid based on CAN protocol

Tran Thanh Kha [1]*, Yahoui Hamed [1], Genon-Catalot Denis [2], Siauve Nicolas [1], Fourty Nicolas [2]

[1]Ampere Laboratory, Claude Bernard University Lyon 1, Lyon, France
[2]LCIS Laboratory, Grenoble Institute of Technology, Valence, France
**Corresponding Author Email: thanh-kha.tran@univ-lyon1.fr*

Abstract

Recently, technologies related to smart grids have attracted more attention due to increasing the demand for renewable energy. One of the most important foundations of smart grids is commonly communications between energies services demands and responses. Almost all the operations on the grids are based on the communications, such as supervision, protection, and isolation. These operations request different requirements for data transmission. The communication technology needs to have high reliability, low latency, and a minimum throughput to guarantee interaction between elements. To limit wires, power line communication (PLC) is a natural choice to deliver bi-directional data transmission between network components to enable smart controller and management of the grid. This paper proposes a PLC solution as a data transmission method for the mesh type DC microgrid. This solution is designed to take advantage of a robust protocol of automotive network - Control Area Network (CAN). The presented architecture is thus intended to propose a PLC system compatible with CAN-bus to provide a safety protocol for DC microgrid with cost effective approach.

Keywords: *PLC, protocol, CAN, safety, Mesh DC microgrid, smart grid.*

1. Introduction

1.1. Mesh DC micro grid description

The mesh DC microgrid have been rarely investigated until now. These grids raise some problems to be investigated such as voltage control, power flow control and stability control. The basic mesh DC microgrid is shown in Fig. 1. It has a link to AC grid, storage system (battery), renewable resource (solar panel) and load (LED).

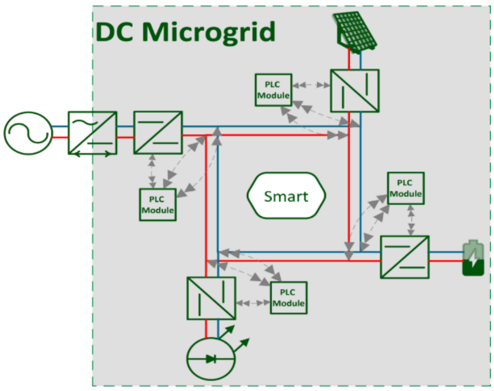

Fig. 1: A mesh DC micro grid

1.2. Communication requirements

As mention above, requirements for data transmission vary depending on the application. In TABLE I, the data transmission requirements of a few main smart grid functionalities are shown.

Table 1: Communication requirements

Functionality / Requirement	Meter reading	Supervision	Fault detection	Grid protection
Throughput	Medium priority	Low priority	High priority	Low priority
Latency	Low priority	Low priority	Medium priority	High priority
Jitter	Low priority	Low priority	High priority	High priority
Reliability	Medium priority	Medium priority	High priority	High priority

To guarantee minimum latency for safety, a strong protocol to exchange between modules and supervision is required. The supervisor must have updated status of each module to have the power exchange over the DC smart Grid. Therefore, to ensure functional safety, the communication method using in the system needs to have high reliability, low jitter, low latency and have an acceptable throughput.

1.3. Power line communication for Mesh DC grid

One of the main advantages of using PLC networks is the ability to re-use the existing electrical wired infrastructure to carry data signals [1]. The Smart Grid remains one of the most suitable applications of PLC and consequently this area has attracted considerable attention from industry. The PLC faces several technical

Table 2: Narrowband PLC and Broadband PLC

	NB-PLC	BB-PLC
Standards	IEEE 1901.2, ITU-T G.9902 G.hnem, ITU-T G.9903 G3-PLC, ITU-T G.9904 PRIME	ITU-T G.9963, IEEE P1901, HPAV
Data rate	1 – 10 kbps for low data rate PHYs 10 – 500 kbps for high data rate PHYs	1 – 10 Mbps (up to 200 Mbps on very short distance)
Frequency	Up to 500 kHz	Over 2MHz
Modulation	FSK, S-FSK, BPSK, SS, OFDM	OFDM
Distance	150 km	1.5 km
Network	NAN, FAN, WAN, large scale	HAN, BAN, IAN, small scale AMI

Table 3: Narrowband's standards

Standard	Technology	Band Occupied	Data Rate Range	Complexity
G1	SFSK	60 – 76 kHz	1.2 – 2.4 kbps	Low
PRIME	OFDM	42 – 90 kHz	21 – 128 kbps	Medium
ERDF G3	OFDM	35 – 90 kHz	5.6 – 45 kbps	Medium
P1901.2/ G3 FCC	OFDM	35 – 450 kHz	34 – 234 kbps	High

challenges due to the unexpected propagation characteristics of transmission and distribution lines as the power line was not designed to transmit high-frequency signal [2]. Some distortion factors are there in power line as attenuation, multipath, and noise [3].

There are two major PLC technologies operate in different bandwidths [4] that are narrowband PLC (NB-PLC) and broadband PLC (BB-PLC). Usually, narrowband PLC (NB-PLC) refers to low bandwidth communication, utilizing the frequency band below 500 kHz and providing data rates from few bps to 10 kbps and up to 500 kbps precisely that operate at 500 kHz. The other PLC infrastructure, BB-PLC operates at significantly higher bandwidth up to 200 Mbps and also higher frequency bands from 2 MHz to 30 MHz [2]. The parameters of NB-PLC and BB-PLC is shown in TABLE II.

Based on the discussion in [5], NB-PLC is fundamentally more appealing than BB-PLC in smart grid applications. TABLE III gives an overview of NB-PLC technologies. For now, we only focus on NB-PLC.

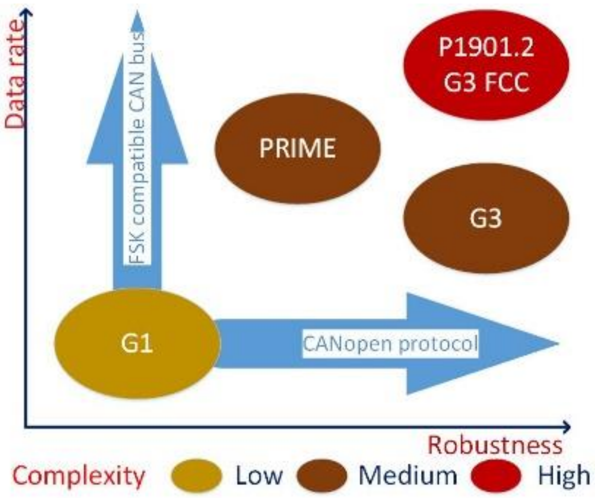

Fig. 2: A PLC solution on CAN protocol

As seen in TABLE II, NB-PLC uses some different modulation schemes, such as single-carrier modulation, multi-carrier modulation, and spread-spectrum (SS) modulation. Narrowband PLC mostly uses single-carrier modulation, while broadband PLC is based on multi-carrier modulation. In single-carrier modulations, like Amplitude-Shift Keying (ASK), Frequency-Shift Keying (FSK) and Phase-Shift Keying (PSK), an analog carrier signal is modulated by a discrete signal. Data is transmitted by changing a characteristic (the amplitude, the frequency or the phase) of a carrier signal. This kind of modulation uses a number of distinct signals to represent digital data. The advantages of single-carrier PLC technologies are low complexity, low power, and low cost. The main limitation of single-carrier PLC systems is their sensitivity to narrowband noise (FSK) and phase distortion (PSK). However, the robustness can be increased efficiently by error detection and correction mechanisms combined with message repetition. Recently, multi-carrier modulation schemes have been applied in NB-PLC. Orthogonal Frequency-Division Multiplexing (OFDM) is the most popular multi-carrier modulation techniques. These solutions address mainly the smart grid market. OFDM is implemented in solutions of industrial alliances like G3-PLC and PRIME. In this technique, data is split and transmit on a large number of closely spaced orthogonal sub-carrier signals. Each sub-carrier is modulated with a conventional modulation scheme, such as BPSK, QPSK or QAM. Hence, multi-carrier modulation is robust against narrowband noise and multi-path propagation. Multi-carrier systems allow also high data rates by transmitting different parts of the data on many different sub-carriers. OFDM is able to adapt to channel conditions, sub-carriers can be selected to avoid transmitting at frequencies where the signal-to-noise ratio (SNR) is too low. However, these features increase complexity, meaning higher cost and power consumption. Moreover, because of the large bandwidth, the data rate is considerably limited by the restrictions in frequency bands. NB-PLC systems use also spread-spectrum (SS) modulations like Direct-sequence spread spectrum (DSSS), Differential Code Shift Keying (DCSK). In this technique, the original narrowband information is spread over a relatively wide band of frequencies. The band spread is achieved by means of a higher data rate bit sequence. In this way, SS modulation allows overcoming narrowband noise. However, SS modulation has low spectral efficiency because of the redundancy in data transmission. Therefore, there are few implementations of this technique in PLC systems [9]. As seen in TABLE III, because of low data rate and robustness, G1 standard with Spread-Frequency Shift Keying (S-FSK) technology is replaced by G3 standard with orthogonal frequency-division multiplexing (OFDM) technology. G3. However, this technology still has high jitter and delay that cannot be accepted in grid safety applications. The other standards (PRIME and P1901.2) are not suitable for our system. PRIME has higher data rate but lower robustness than G3 and it is designed for Tree topology, not for Mesh [11]. P1901.2 is too complex to deploy in the system. Thus, strong safety solution is proposed to allow implementing safety in the system with cost-effective approach, as shown in Fig. 2.

1.4. Power line communication based on CAN

The PLC does not intend to compete with the existing CAN networks [6]. The proposal is designed to take advantage of the existing CAN protocol which is widely used in the automotive industry. Another PLC system using CAN protocol is proposed in [7], this solution uses one carrier signal which is shared by all the modems. Each modem will sense this common signal and modulates it by shifting the bus impedance. However, the bus length is a limitation of this solution. They need to keep the bus length small compared to the wavelength of the carrier signal. This system can achieve 92.7 Kbit. s-1 for a 3-meter bus. Yamar also designed its PLC devices as an alternative physical layer, using CAN protocols as an interface with microcontrollers providing a convenient solution to customers. DCAN500 is proposed by Yamar with an

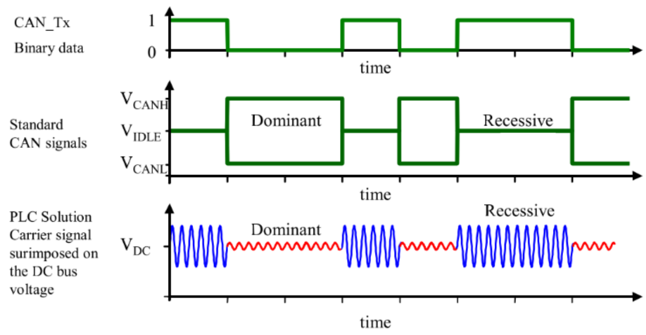

Fig. 3: The comparison between the standard CAN signal and the ASK modulation signal [8]

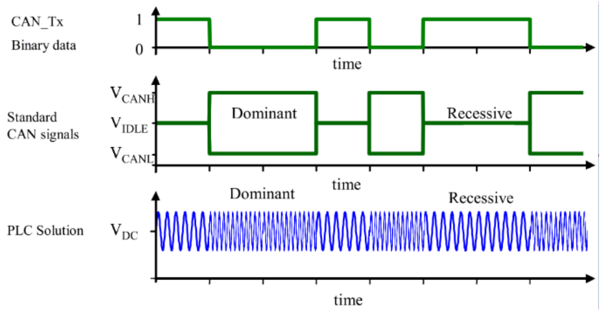

Fig. 4: Comparison between the standard CAN and the modulation of PLC

evaluation based on FPGA board to implement CAN bus over PLC. FPGA will be shrunk in an ASIC next month [6].

In these solutions, they use Binary Amplitude Shift Keying (BASK) or On-Off Keying (OOK) to obtain 100% Carrier-sense multiple access (CSMA). However, because of many limitations, the useful data rate is only up to 100 Kbit. s-1 [6]. Fig. 3 shows a comparison between the signals on a standard CAN HIGH/CAN LOW and ASK modulation of the PLC signal which is used in above solution. The ability to differentiate recessive and dominant levels are achieved by using two different amplitudes.

The CAN-based PLC solutions use mainly binary single-carrier modulation because of the possibility of adapting dominant and recessive pair in CAN bus. For the above-mentioned solutions, they use BASK. Because ASK is based on amplitude, it increases power consumption, it is only possible for short-range communications. Another single-carrier modulation is PSK. This technique has to face up with phase distortion. Unlike those, FSK is robust against variation in attenuation through channel [4]. In our solution, we propose an original Frequency-shift keying (FSK) compatible CAN-bus modem to replace the differential pair with a PLC medium to provide an interface to the DC bus without modifying the CAN protocol. This modem is used to obtain the dominant and recessive level as same as in CAN protocol.

The remainder of this article is organized as follows. In Section II, we describe the PLC solution for Mesh DC microgrid. In Section III, we show our first experimental results. We conclude the article with some final remarks and future direction in Section IV.

2. PLC solution for mesh DC micro grid

Fig. 4 shows a comparison between the communication signals generated on a standard CAN HIGH/CAN LOW and FSK modulation of the PLC signal. The higher Shift level stands for the dominant level and the lower Shift level stands for the recessive level. Modems can also impose a dominant state to achieve priority. The proposed solution is shown in Fig. 5. Each node transmits the data through a modem and a line adapter. A gateway supports IP interface to develop a supervision. Each node also has self-protection system that helps them quickly react when there are incidents on the grid before receiving the signal from another node.

2.1. Priority decision

The system uses Carrier-sense multiple access with collision avoidance (CSMA/CA) as in a normal CAN. The arbitration is based on the message ID. If two messages begin transmitting simultaneously, the one with the lowest message ID (more initial zeroes) will have higher priority, so the node is more likely to win the control of the bus and the other with higher message ID will back off and retry when the bus is available [9]. This is accomplished by monitoring the bus during transmission; since the higher frequency is dominant on the bus, if a node transmits a logic 1 in message ID but reads a higher frequency, the conclusion is that another node is transmitting with a higher priority. Fig. 6 [8] shows the arbitration logic between two nodes.

2.2. Node definition

The system reuses the addressing scheme of CANopen protocol [10]. CANopen is based on the central concept of an Object Dictionary (OD). The OD is basically a table which is the interface between the application and communication within each device as shown in Fig. 7. Every function, variable and data type must be described in the OD. Thus, it is possible to access all important data, parameters, and functions of a device using a logical addressing system. The OD defines a standard addressing scheme where each object has a 16-bit index and 8-bit sub-index. The index is the OD index of the data to be accessed like Boolean, Unsigned32, etc. An 8-bit sub-index is used in structured data types to denote a field inside a structure or array.

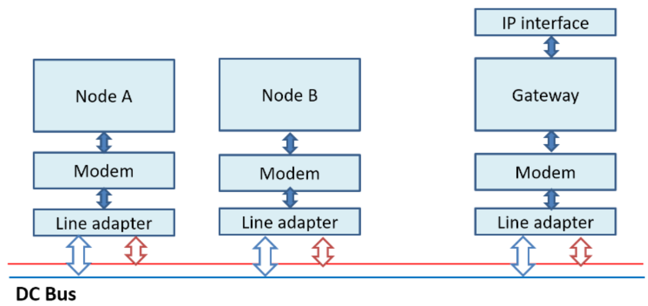

Fig. 5: A PLC solution on DC bus

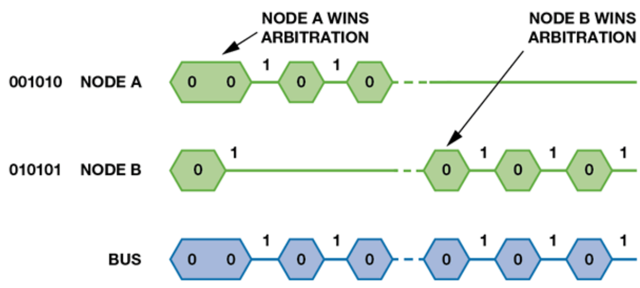

Fig. 6: The arbitration logic between two nodes [9]

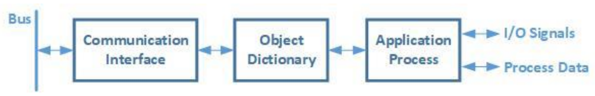

Fig. 7: The arbitration logic between two nodes [9]

Table 4: Node definition

N° register	Characteristic
Node 1	Gateway
Node 2	Solar panel
Node 3	Battery
Node 4	Solar panel + Battery
Node 5	Load
Node 6	Solar panel + Load
Node 7	Battery + Load
Node 8	Solar panel + Battery + Load

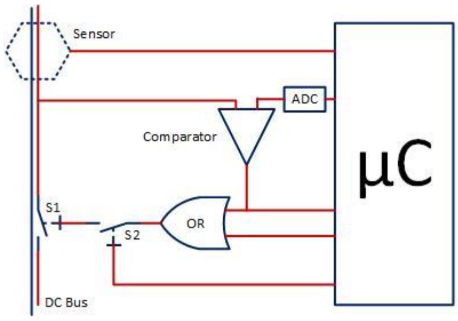

Fig. 8: Local self-protection system

2.3. Distributed control

The system uses the Blocktable – a public database table to records nodes' information. When a new node joins the grid, it will introduce its characteristic, as shown in TABLE IV. After that, this new information is broadcast to this network. The network nodes can validate new node, give it a new address that does not exist in the Blocktable, add it to their copy of the database, and then broadcast this database addition to other nodes and new node. Because the Blocktable is a distributed database, each network node stores its own copy of the Blocktable and has the information of other nodes without the need of a master node to achieve the distributed control in the system.

2.4. System safety strategy

To ensure the functional safety of the grid, the communication system is integrated 2 layers of safety. The first one – hardware safety layer is the local self-protection system as shown in Fig. 8 and the second one – software safety layer is the 4-safety level by using 2 most significant bits in message ID field as shown in TABLE V.

2.4.1. Hardware safety layer

The self-protection system of each node can react itself or perform an action when receiving information from others. This system has two switches, S2 is controlled by microcontroller allowing the node to isolate or connect to the grid and S1 will automatically react when a problem happens by directly sensing the line or slower through sensor and microcontroller. S1 can also react when receiving a signal from others through the microcontroller. The operation of this system is shown in Fig. 9.

Table 5: Safety 4 level

Binary	Level	State	Action
00	1	Normal	No
01	2	Signaling	Demand others
10	3	Local alert	Self react and inform others
11	4	System alert	Shut down

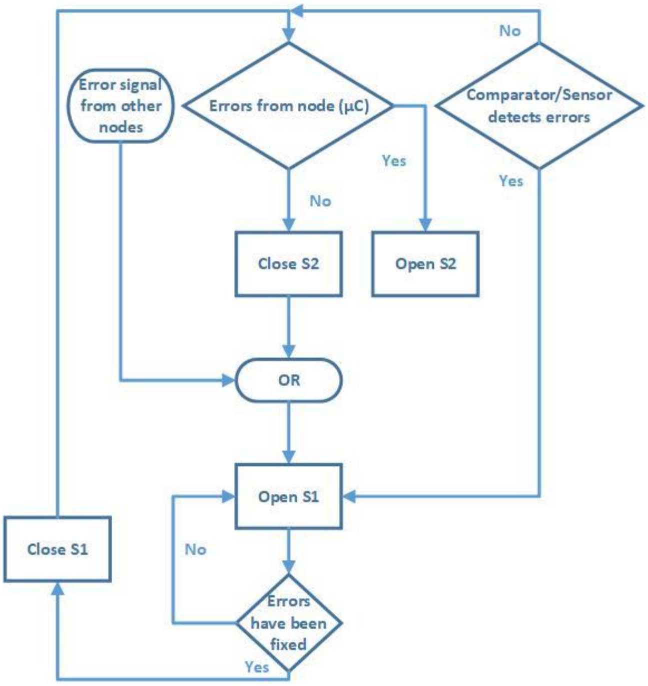

Fig. 9: Operation of the self-protection system

2.4.2. Software safety layer

We come back to the 4-safety level. In first safety level, the system is in the normal state. The priority is decided by CSMA/CA method. In this state, the communication system is used for meter reading purpose as described in TABLE V. The second level is reserved for signal state that means one node wants to demand another node to make an operation, such as "all batteries are full, solar panel changes to idle mode" or "the energy is running out in the grid, inverter connects to AC grid". The third level is used for the local reaction when the problem is only in one node and does not have or have a small effect on others. The local reaction system will cut the node out of the grid and inform others as shown in Fig. 9. The highest-level stands for emergency. The incident will affect the whole system. The local self-protection system will intermediately open the grid where the problem occurred then disconnect the node and inform others. If the problem cannot be isolated, all the system will shut down. The FSK compatible DC bus is very helpful in this case. When one line is still busy with the current message, the node can be able to use the other line to transmit an emergency message to inform the whole system.

3. First experimental results

To validate these concepts, the first test setup is shown in Fig. 10. We use Raspberry Pi for Gateway node and two other nodes are controlled by Tiva C Series TM4C123G LaunchPad from Texas Instrument. The system runs CANopen protocol stack from port GmbH. The CANopen Device Monitor (CDM) [11] is used to monitor the nodes, as shown in Fig. 11. Fig. 12 shows a message sent between node 1 and gateway node. Because the necessary components have not been available yet, we built the first experimental setup on CAN bus.

In next step, the practical data transmission tests will be performed by using DCAN500 from Yamar in next month when it will be available in an ASIC form. Now, we are working with a third-party electronics company to design and build this FSK compatible CAN-bus interface hardware. Finally, yet importantly, the final CAN interface hardware with alternative FSK modulation for robust transmission that is proposed will be tested to compare and verify our solution.

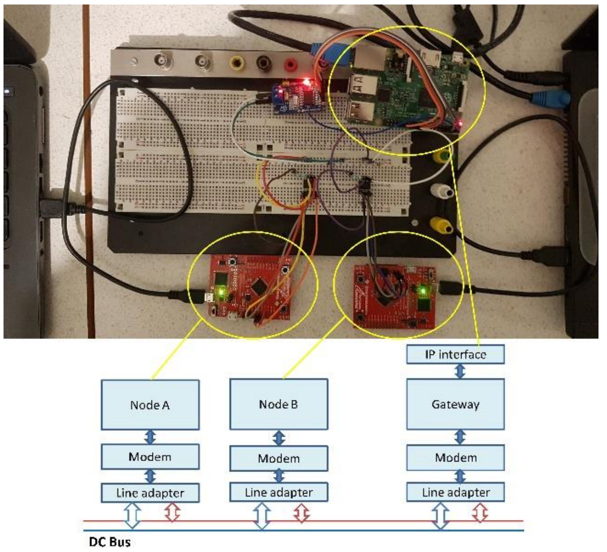

Fig. 10: The first test setup

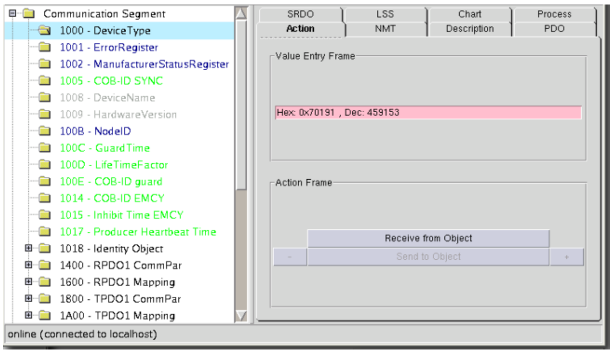

Fig. 11: The CANopen Device monitor (CDM)

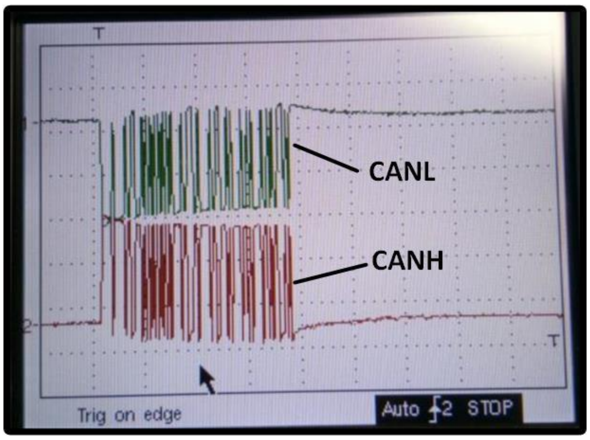

Fig. 12: A message sent between node 1 and gateway node

4. Conclusion

Through this paper, we would like to increase use of renewable energy but over a DC Smart Grid. Due to the time constraint data exchange, the essential parameter is required for the communication is low latency. In this paper, we introduced a solution based over CAN bus embedded in a PLC solution for DC microgrid. We compare several CAN bus interfaces for DC Smart Grid. Finally, we propose an original FSK interface for physical layer interface with low latency for the loop time-critical applications. The solution will support CAN open safety but with the high-speed interaction between the nodes and ensure the safe functionalities of the whole system. In the future, we will implement application stack based on CAN and serial solution for powerline to compare their performance.

Acknowledgement

This contribution is a part of C3µ project funded by ANR - National Research Agency. The project is dedicated to Mesh DC Smart Grid. This project investigates the possibility of using a DC Smart Grid architecture for distributing electrical power energy in the building (islanding from AC Grid). The proposed architecture will ensure the energy transfers effectively between different electrical resources. Moreover, this architecture allows easily deploy renewable systems. Two French laboratories, Ampere (UMR CNRS 5005), Lyon, France and LCIS (EA 3747), Valence, France, merge their competency to engage in this project [12].

References

[1] C. Cano, A. Pittolo, D. Malone, L. Lampe, A. M. Tonello, and A. G. Dabak, “State of the Art in Power Line Communications: From the Applications to the Medium,” IEEE J. Sel. Areas Commun., vol. 34, no. 7, pp. 1935–1952, Jul. 2016.

[2] Y. Kabalci, “A survey on smart metering and smart grid communication,” Renew. Sustain. Energy Rev., vol. 57, pp. 302–318, 2016.

[3] A. Mannan, D. K. Saxena, and M. Banday, “A Study on Power Line Communication,” IEEE Trans. Consum. Electron., vol. 4, no. 7, pp. 7–10, 2014.

[4] B. Baraboi and Ariane Controls Inc, “Narrowband Powerline Communication - Applications and Challenges — Part I,” EDN Network, 2013. .

[5] A. M. Tonello and A. Pittolo, “Considerations on Narrowband and Broadband Power Line Communication for Smart Grids,” pp. 13–18, 2015.

[6] F. Benzi, T. Facchinetti, and D. Caprini, “Powerline communication protocols Review, evaluation and tests for automotive applications Francesco,” Pavia, 2008.

[7] J. Jousse, N. Ginot, C. Batard, and E. Lemaire, “Power Line Communication Management of Battery Energy Storage in a Small-Scale Autonomous Photovoltaic System,” IEEE Trans. Smart Grid, vol. 8, no. 5, pp. 2129–2137.

[8] B. C. Watterson, “Configure Controller Area Network (CAN) Bit Timing to Optimize Performance,” no. September, pp. 1–3, 2014.

[9] S. Corrigan and I. Interface, “Introduction to the Controller Area Network (CAN),” Texas Instruments, no. August 2002, pp. 1–17, 2016.

[10] CAN in Automation (CiA) e. V., “CANopen application layer and communication profile,” 2011.

[11] C. Device and M. Version, “CANopen Device Monitor User Manual,” 2013.

[12] Ampere Laboratory and LCIS Laboratory, “C 3 µ - Appel à projets générique 2015 - défi 2 Components , Control and Communication for Microgrids DC,” 2015.