Energy Meter for Charging Stand in Smart Buildings

Z.Slanina, T.Docekal
VSB-TU Ostrava, 17. Listpadu 15, 70833, Ostrava-Poruba, Czech Republic.
Zdenek.slanina@vsb.cz

***Abstract*—This paper describes the design of smart energy meter and its = implementation, focusing on its firmware, which is based on real time operating system FreeRTOS. The main areas to use this energy meter are charging stations (stands) for electric vehicle (follows as EV) charging support and possible embedding into current smart building technology. This paper also presents the results of a research of commercial devices available in Czech Republic for energy measuring for buildings as well as the analysis of energy meter for specific purposes. For example, the description of the module includes the required measurement of voltage, electric current and frequency of power network. After integration into smart buildings (home automation, parking houses). there are pros and cons of such solutions mentioned.**

***Index Terms*—Nergy Meter; Electric Car; Smart Metering; FreeRTOS; Pseudo Parallelism.**

I. Introduction

Nowadays, there are still primarily internal combustion engines used in passenger transport vehicles. Especially in big cities, this is the main problem of heavy traffic due to over the limit level of toxic exhaust fumes. A good alternative is to offer alternative technologies as the electric or hydrogen powered vehicle. This article is mainly oriented to the application of electric vehicles to address this bad situation. The truth is that it brings many problems associated with the wrong idea of their use, their manufacturing and maintenance and especially development of the infrastructure for their use which lags behind the mainstream for decades. Leaving aside the possibility of replacing the batteries pack when they are depleted, the only way to recharge energy is using electricity at home or public grid. The second option means the need to measure the amount of electric energy in case of commercial use and also the need to regulate the charging current to prevent overloading of electric network [1-3].

At the Department of Cybernetics and Biomedical Engineering, several charging stations (see figure 1) have been developed to test their commercial purposes. Due to the lack of communication interface, current version that allows charging from an electric network 400 VAC does not meet the requirements on the possibility of energy regulation used for charging. Based on past experience and current demands for enhanced solution, there have been developments on energy measuring module which can be integrated into the existing technology of charging stand, which can expand the possibilities of communication towards the electric car and energy infrastructure of smart building [8-11].

II. Energy Meters Market Research

In line with the development of charging stands, market research has been carried out and its result covers a set of standard components which can be used for realization. Thus, it is possible to reduce the final price by more than 75 percent (without price of work). On the other hand, it is not possible to control the amount of energy supplied to the electric vehicle due to the absence of any communication interfaces with the cars.

Initially, it is necessary to find out where to measure the taken energy. Modern vehicles include the possibility of fast DC charging, and these charging stations must be equipped with additional tools to prevent damage to the entire technology of charging stand or electric vehicle. For this purpose, it was has been determined to measure the electrical energy supplied to the input of the entire charging chain - electrical grid-charging stand-electric car. The total energy consists of energy and operating expenses in the actual charging. Then, we can use standard power meters (wattmeters) with output pulses corresponding with the energy amount per hour or direct connection with the control system via communication bus (RS485).

Figure 1: Charging stand developed at VSB-TU Ostrava. The big display allows to implement additional features as web browser using etc.

The second step is to find a range of energy supplied from the electrical network. For this purpose, there are few known different standards, and their parameters are summarized in Table 1, as the example of one supplier's charging station covered by commercial research. The charging process may initially take a big amount of energy; however, after certain time, this amount decreases; thus, communication between the vehicle and the charging stand can improve the distribution of energy according to actual need [5].

Table 1
Charging Station Variants Example

Stand marking	C	J	G	T
Car to stand communication interface	CCS (Combo)	CHAdeMO	type 2 cable (Mennekes)	type 2 socket (Mennekes)
Maximum output power	20 kW, 50 kW	20 kW, 50 kW	22 kW, 43 kW	22 kW
Output voltage range	50–500 V (DC)	50–500 V (DC)	400 V	400 V
Output current range	60 A, 125 A (DC)	60 A, 125 A (DC)	32 A, 63 A	32 A
Cable length	3,9 m	3,9 m	3,9 m	-
Compatible cars	BMW, Volkswagen , GM, Porsche, Audi	Nissan, Mitsubishi, Peugeot, Citroen, Kia	Renault, Daimler, Tesla, Smart, Mercedes	Renault, Daimler, Tesla, Smart, Mercedes

The result of market research is not satisfactory. We can use a number of electronic wattmeters (mechanic versions are not usable for our purpose) with range 400V AC, 3 phases up to 100A in the standard offer. Due to the limited connectivity of electric network in public space, it is suitable for most cases. Most of them include a display device that allows observing the amount of consumed energy, but this device should be placed after direct intrusion into the distribution board in which the power meter is installed. Alternatively, it is possible to use wattmeter outputs that are designed mostly as:

- Pulse outputs - S0 interface allows to set the amount of pulses up to thousand pulses per kWh. The parameter is adjustable and sufficient for a measurement.
- Extended device for Internet view - this additional device enables to connect the wattmeter to the Internet and to monitor on the website trends of the energy. In many cases, these are commercial solutions which cannot be used for direct charging control.
- Infrared transmission - household wattmeters allow to read the consumed energy through the infrared port, which is built into the wattmeter. This application is more suitable for occasional control than continuous measurement, but it is finally usable.
- M-bus interface - wire asynchronous serial transmission of information about consumed energy.
- ModBus interface - an extension of the physical layer of the RS485 bus with communication protocol with several parameters including the current energy consumption.
- Ethernet interface - rarely used for special automation tasks (expensive solution).

There is not a possibility to send data over existing electric network which is very often used communication for data exchange between several units [4,6,7].

III. Design of Energy Meter's Firmware

Based on the market research and issues relating to the charging of electric vehicles, requirements on the new energy meter were set up, so that the entire solution could improve the current charging stand technology. The basic requirements were as follows:

- Modular implementation for placement on DIN rail
- Providing information to superior system (charging station, smart building, etc) by the digital interface Ethernet
- Measuring the voltage on the three phases
- Measuring the current in the three phases
- Electric energy measurement
- Measurement of the other parameters of electrical network, such as frequency or power factor
- Communication with the electric vehicle for improvement of safety
- Communication with the electric vehicle for the purpose of automating whole charging process
- Service information panel

According to these requirements, the energy meter was developed in several phases. The block diagram of this device is shown in Figure 2. The connection with actual charging stand is also illustrated there.

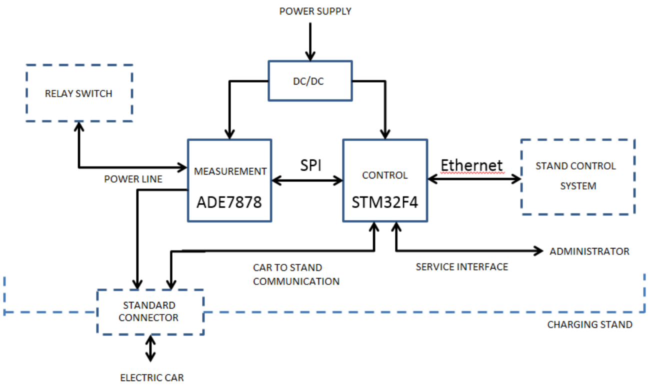

Figure 2: Proposed new architecture of charging stand

The integrated circuit ADE7878 was chosen as the main part of measurement section, and the microcontroller STM32F407 was selected as the main control element. This MCU is based on ARM core Cortex M4, and it contains the periphery for realization communication over Ethernet. The controller is powerful enough for the implementation of various subsequent extensions. For this purpose, it contains a large memory for program instruction and different variables and data too.

The firmware, which ensures the function of the control section, is in contact with the inner part of the energy meter, implying it contains mainly the measurement section with the systems, which are not included into energy meter, for example the superior system. Therefore, the primary task of the firmware is to ensure data transmission and exchange between different parts. This issue can be interpreted based on the illustration of a diagram (see Figure 3).

As shown in Figure 3, there are four parts, which the control application is connected with. Each of them requires other information and different method of their transfer. This can be done by independent parts of the control application.

The entire firmware is based on real time operating system FreeRTOS, which is intended to the microcontrollers. With this operating system, it is possible to divide the control application into the separate tasks. The individual tasks cannot be run simultaneously, because the microcontroller has only one physical core, but the operating system allows them to run pseudo parallel by switching them at very small intervals. The pre-emptive scheduler is used for switching the tasks.

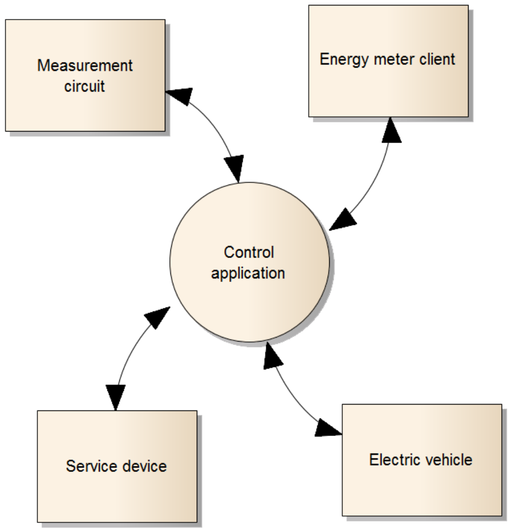

Figure 3: Context diagram of application

This feature was used with the advantage for developing the control application. Each separated tasks is implemented as an individual thread or as an interrupt routine. These parts are connected by data, which they need to exchange. The structure of control application is shown by data flow diagram (see Figure 4). The data exchange between processes is done by IPC, which is part of FreeRTOS.

The SPI communication and TCP Server processes are done according to tasks, for the Service console and Communication with EV are used interrupt routines. The first process, SPI communication, has higher priority than TCP Server, but when there is no request in queue, this task is in blocked state and it does not load the CPU. The task TCP Server is also in blocked state as long as there is no connection from TCP client and any message.

Service console allows the device manager to change some settings via the serial port. In text console, it is possible to change the IP address of device, DHCP settings or read actual values of these parameters from energy meter. These settings are stored in flash memory of microcontroller and they are loaded at power on.

Communication with electric vehicle is done by PWM signal. Its duty determines the maximum value of current, which EV can use for charging. Connected EV is able to change the top value of PWM signal, which corresponds to actual state of EV. This value is measured in interrupt, which is invoked on PWM signal state change.

IV. DISCUSSION & CONCLUSION

At the time of development, there was no chance to test the energy meter directly connected to the electric vehicle. Because of it, standard 60W electric bulb was used as an appliance while measuring the amount of electric energy. The information about that was read by computer connected to Ethernet network during the one hour measurement. The control application provided the information about electric energy according to the sequential diagram in Figure 5.

Based on message from client, the TCP Server inserts requests into the queue. Then the SPI communication task starts sending the request to measuring circuit and after that provides the response from ADE7878 to TCP Server, which transform this data into the message for client [12]. This sequence is shown in Figure 5.

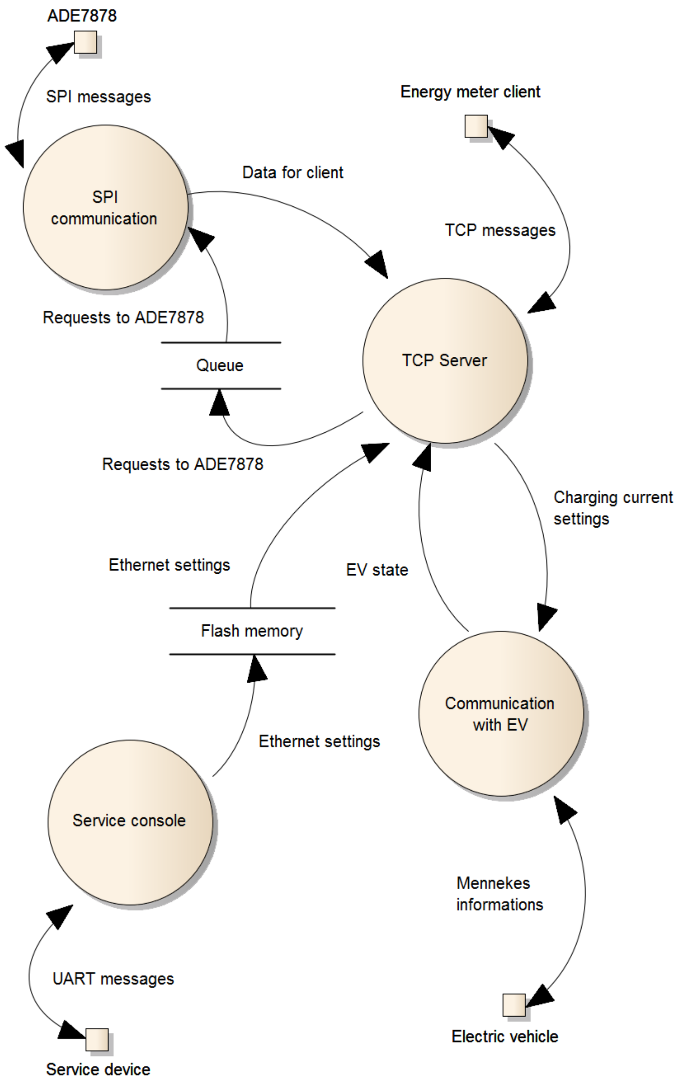

Figure 4: Data flow diagram of application

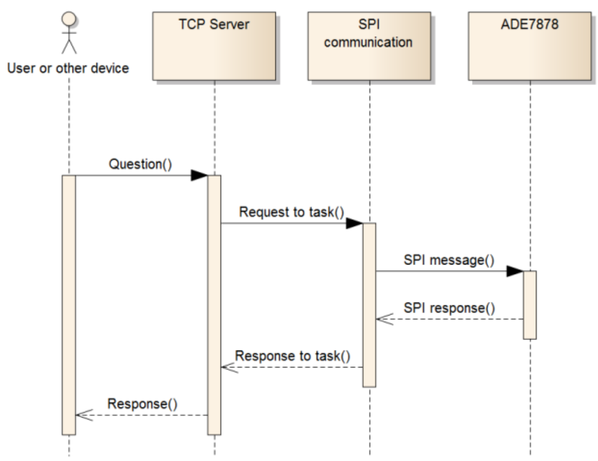

Figure 5: Sequence diagram of communication

The measured amount of energy was 59.706 Wh, as shown in Figure 6. The expected value was slightly higher, 60 Wh, which corresponds to one hour operation of electric bulb with 60 W wattage. The question is whether the error is greater on the side of the bulb technology or on the energy meter, which was not calibrated with use of reference device, only set according to the datasheet and used components.

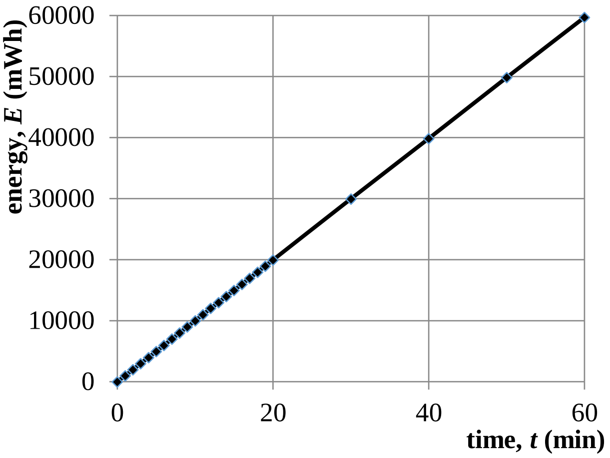

Figure 6: Sequence diagram of communication

Developed energy meter (see Figure 7) can be used with minor adjustments and electronic configuration change and it can be tested on real electric vehicles. Key benefits were mentioned in the text above. Among them are the existence of communication with the superior system based on Ethernet. It is also possible to connect the proposed solution with smart buildings technology and to control energy according to the electric network state. The last benefit is that it should be used for possible bidirectional flows of electric energy between the electric vehicle and energy networks [5], which nowadays is much welcomed feature of charging stands and electric vehicles combination [6], [7]. Respectively, it is possible to use electric vehicles as an energy container in grid-off technologies powered by the sun etc. [8], [9], [10], [11].

Figure 7: Energy meter developed for smart transportation purposes

ACKNOWLEDGMENT

This work was supported by project SP2016/183, ”Control of power systems with renewable and alternative energy sources 2016”, of Student Grant System, VSB-TU Ostrava.

This work was also supported by project SP2016/162, ” Development of algorithms and systems for control, measurement and safety applications II”, of Student Grant System, VSB-TU Ostrava.

REFERENCES

[1] Misak, S. and Prokop, L., "Off-grid power systems," 9th Conference on Environment and Electrical Engineering, EEEIC 2010 , 14-17 (2010).

[2] Ozana, S., Pies, M., Hajovsky, R., Koziorek, J., and Horacek, O., "Application of pil approach for automated transportation center," Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 8838, 501-513 (2014).

[3] Bradac, Z., Kaczmarczyk, V., and Fiedler, P., "Optimal scheduling of domestic appliances via milp," Energies 8(1), 217-232 (2015).

[4] Lesek, F., Ladislav, S., and Zdenek, B., "Modelling transmission lines for the purpose of data transmission over power lines," Procedia Engineering 100(January), 1381-1388 (2015).

[5] Prokop, L. and Misak, S., "Off - grid energy concept of family house," Proceedings of the 13th International Scientic Conference Electric Power Engineering 2012, EPE 2012 2, 753-758 (2012).

[6] Friedrischkova, K., Vala, D., and Horak, B., "Accumulation system of electric vehicle and its secondary exploitation," IYCE 2015 - Proceedings: 2015 5th International Youth Conference on Energy (2015).

[7] Friedrischkova, K., Vala, D., and Horak, B., "The use an electric vehicle as a power source," ICINCO 2015 - 12th International Conference on Informatics in Control, Automation and Robotics, Proceedings 1, 164-170 (2015).

[8] Idzkowski, A., Leoniuk, K., Walendziuk, W., and Budzynski, L., "Monitoring and control system of charging batteries connected to a photovoltaic panel," Proceedings of SPIE - The International Society for Optical Engineering 9662 (2015).

[9] Idzkowski, A., Walendziuk, W., and Borawski, W., "Analysis of the temperature impact on the performance of photovoltaic panel," Proceedings of SPIE - The International Society for Optical Engineering 9662 (2015).

[10] Kaczmarczyk, V., Fiedler, P., tohl, R., and Brad, Z., "Electric vehicles charger as a part of home area network," IFAC Proceedings Volumes (IFAC-PapersOnline) 11(PART 1), 180{185 (2012).

[11] Zezulka, F., Sajdl, O., Bradac, Z., and Sembera, J., "Experimental smart grid," IFAC Proceedings Volumes (IFAC-PapersOnline) 11(PART 1), 416-419 (2012).

[12] Behan, M., Krejcar, O., “Modern smart device-based concept of sensoric networks,” Eurasip Journal on Wireless Communications and Networking, 155 (2013).