COMPARISON OF POWER QUALITY MONITOR DATA TRANSMISSION BETWEEN MODBUS TCP/IP AND IEC 60870-5-104

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Abstract: With deployment of smart devices along the electrical grid key infrastructure points, communication process with regards to its volume and load on communication infrastructure needs to be described and evaluated. This article focuses on protocol Modbus TCP/IP and standard IEC 60870-5-104 with regard to their communication structure and principles within substation connected to network by broadband over power lines modems (BPL). This paper also offers two communication scenarios over BPL network by using real substation power quality monitor. Furthermore, performance of each solution is being summed up in the discussion. Conclusion offers a convenient solution for utilization of key values transmission on limited communication channel.

Keywords: broadband over power lines, IEC 60870-5-104, Modbus TCP/IP, Smart Grid, substation.

1 INTRODUCTION

Over the last years with growing demand for more solid electrical infrastructure, there is a significant effort from electric utility which focuses on deployment of smart devices. By implementing smart devices especially on low-voltage distribution substations, better overview about events and power quality values typical for this part of power grid would be obtained. Detailed information about real-time values also enables finer control for electrical grid operators and an increase in stability and efficiency of the whole electric power distribution process is expected [1].

The concept of Smart Grid takes into account vast field of communication technologies used for transmission of data from smart devices installed along the grid to controlling centers. For the primary distribution (extra high voltage and high voltage grid) and its key parts (power plants, etc.), communication technologies with low latency and high reliability are demanded. For this task, optical network is the most suitable choice. Excellent data throughput and low latency is being also outweighed by expensive and sometimes difficult installation process [2].

On the other hand for distribution grid, which is running on low voltage, smart devices are not already implemented at all grid key points. In this case more precise methods of both controlling and monitoring low voltage grid are required. Such solution is also deployment of power quality monitors into substations, which are smart devices with vast possibilities for grid management [3].

For sending data to grid operator, different technologies can be used. Since some of those substations are at distant locations, technologies such as LPWAN (Low Power Wide Area Network), PLC (Power Line Communication) or cellular networks are being used. These technologies are based on shared communication channel and its data throughput and latency is sometimes limiting [4]. This article mainly focuses on possible solutions of utilization and tries to find convenient communication protocol, which could be used for power quality monitors for its reliable and effective operation under non-ideal conditions.

2 MODBUS TCP/IP

Modbus TCP/IP (Modbus TCP) is a derived version of simple vendor-neutral Modbus protocol family, which was designed to fulfill needs in terms of control and supervision of equipment mostly in automation industry. In its original form Modbus was designed in 1970s to communicate on serial lines with programmable logic controllers. Communication is based on master-slave principle, where slave provides four object types to master: Coil (1 bit, read-write), Discrete input (1 bit, read-only), Input register (16 bits, read-only) and Holding register (16 bits, read-write).

With the growth of ethernet communication and rise of TCP/IP networks, Modbus was modified into Modbus TCP with regard to ethernet specifications, port 502 is being used. Each operation within this protocol are being recognized based on the Function code value. In general Modbus introduces the limit of maximum read/write registers that can be read at once. However in Modbus TCP only 123 registers can be read. To read higher number of registers, multiple reads have to be executed.

3 IEC 60870-5-104

IEC 60870-5-104 is an international standard introduced in the year 2000. Interoperability between devices which conform to this standard is being provided by interoperability list. Communication is of server-client type, based on principles of TCP/IP networks. Standard recognizes two directions: control and monitoring. The standard provides features such as: On-demand transmission, Spontaneous transmissions, Direct command transmission, Clock synchronization and File Transfer.

Communication in this standard is based on three types of units: APDU (Application Protocol Data Unit), APCI (Application Protocol Control Information) and ASDU (Application Service Data Unit). Basic unit APDU consists of APCI and can also consist of ASDU (used for carrying payload). Based on CF values, three formats of APCI are distinguished: I-format (controlling transfer and defying communication), S-format (supervisory functions, confirmations), U-format (Start, Stop and testing of communication line). The standard also specifies TypeID for identification of protocol structure. Under this identification various features are being recognized, such as those mentioned above.

4 MEASUREMENTS

Results in this paper are described by two different scenarios of using Modbus TCP/IP and IEC 60870-5-104 for the same transmission task. Network topology is shown in Fig. 1. BPL modems, PC and real substation device Meg44PAN with its PQ Meg software were used to simulate real conditions.

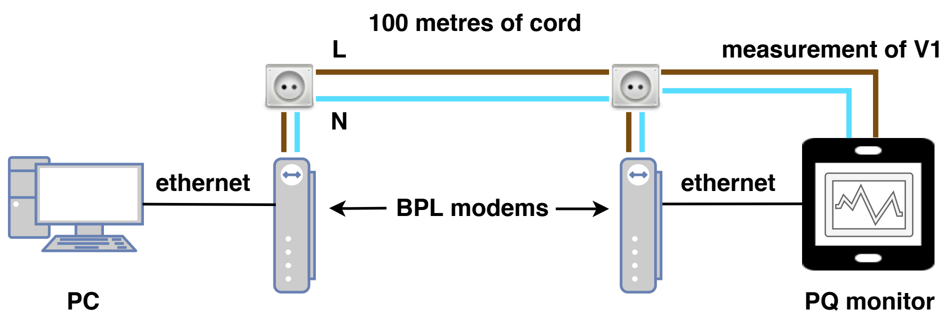

Figure 1: Measurement scheme - network topology.

4.1 Scenario A: download of stored measured values

Device Meg44PAN used for purposes of these measurements is equipped with a built-in memory and a possibility of using SD card. Meg44PAN is able to capture values defining various parameters of power grid. These values can be transmitted by network or can be stored in drive and then downloaded locally or remotely. Fig. 2 describes memory allocation with minimal measurement times by adjustable periods of capture.

In this scenario file containing values was downloaded through network topology as shown in Fig. 1. Both Modbus TCP and IEC 60870-5-104 were used to download .mdat file containing: values of quality of power grid, events due to specification, recorder of energy, rapid voltage changes, ripple control and signal of the ripple control.

For Modbus protocol, results are shown in Table 1, in total 9 475 packets were used to download 196 kB .mdat file. Average size of a packet was 153 B. On the other hand, when IEC 60870-5-104 was used, only 4 957 packets with average size of 235 B were transferred to download the file with the same size, see Table 2. Performance and efficiency of both protocols are summarized in Table 3, value of transmission efficiency is being calculated as a ratio of useful transmitted data to the overall data volume.

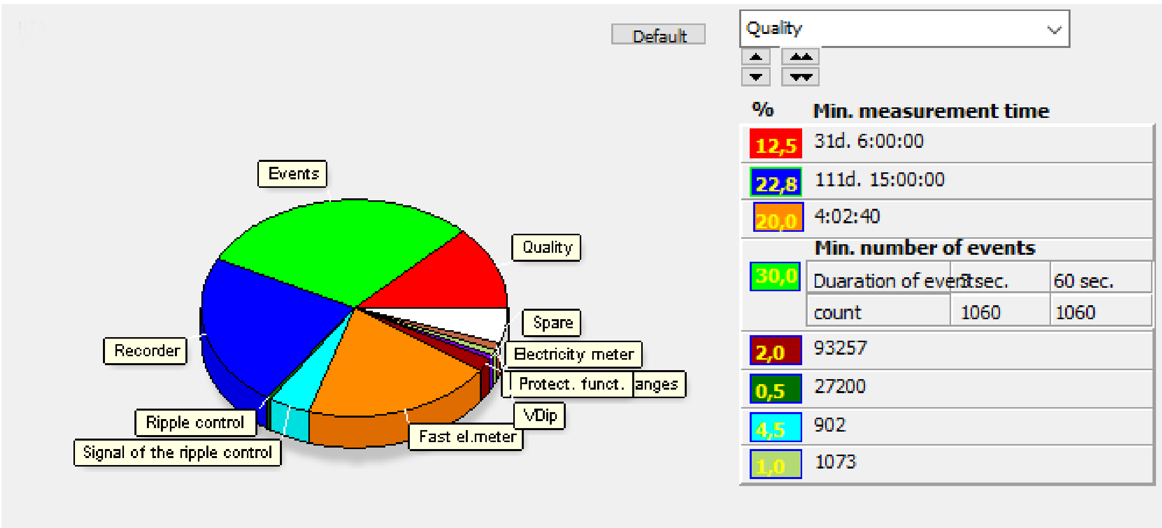

Figure 2: Memory allocation for different data values within Meg44PAN PQ monitor.

4.2 Scenario B: real-time value monitoring

In this scenario simulation of operator monitoring voltage of single phase was used. Capture period was set to value of 5 seconds (option *Slow* on Fig. 3), device also offers options *Mid* (~1 sec) and *Quick* (~200 ms). Values were then being put into a plot, as shown in lower part of Fig. 3.

For protocol Modbus TCP, when 1 hour was used to monitor single phase voltage, 35 004 packets were used to transmit data from power quality monitor. its average size was about 149 B as Table 1 shows. For one data renewal 49 packets (986 packets per second, 7 316 B in total) had to be transmitted causing data flow of 150 kBytes/s for 0.050 of second.

Performance of standard IEC 60870-5-104 was significantly better, only 25 793 packets with average size of 184 B were used under the same 1 hour scenario, see Table 2. Within one data renewal 36 packets (193.7 packets per second, 6 613 B) were transferred with average flow of 35 kBytes/s for 0.186 of second.

Table 1: Results of Scenario A and B for Modbus TCP/IP.

Structure of Modbus TCP communication		**Scenario A**		**Scenario B**	
Function code	Transmitted type of data	packets	aver. size [B]	packets	aver. size [B]
4	Read File Record	10	66	1 440	66
20	Read Input Registers	9 450	153	32 844	155
71	Transmission init	8	72	0	0
-	TCP [ACK]	7	54	720	54
TOTAL		**9 475**	**153**	**35 004**	**149**

Table 2: Results of Scenario A and B for IEC 60870-5-104.

Structure of IEC 60870-5-104		**Scenario A**		**Scenario B**	
Type ID	Transmitted type of data	packets	aver. size [B]	packets	aver. size [B]
120	File ready	10	75	720	75
121	Section ready	10	76	720	76
122	Call dir,sel.file,call file,call sec.	30	73	21 60	73
123	Last section, last segment	20	74	1 440	74
124	Ack file, Ack section	20	73	1 440	73
125	Segment	2 840	368	9 363	359
-	Supervisory	606	60	2 880	60
-	TCP [ACK]	1 421	54	7 070	54
TOTAL:		**4 957**	**235**	**25 793**	**184**

Table 3: Comparison of effectiveness - Scenario A.

Size of transmitted .mdat file	**Modbus TCP transmission**	**IEC 60870-5-104 transmission**
196 kB	1 456.2 kB	1 165.3 kB
Transmission efficiency:	13.46 %	16.82 %
Number of packets:	9 475	4 957

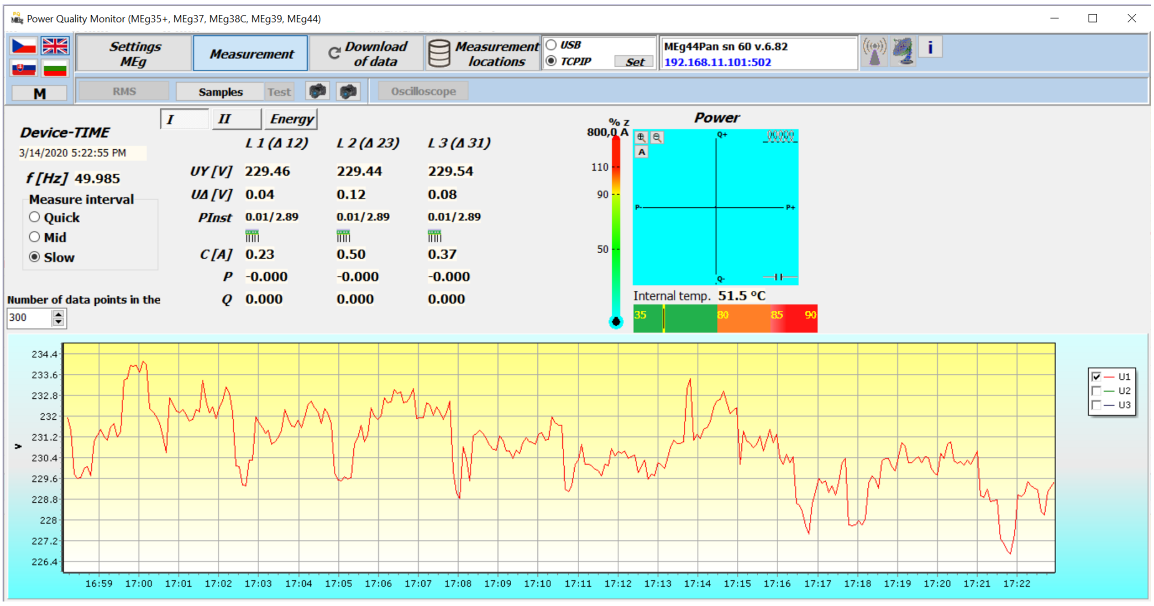

Figure 3: Real-time monitoring of phase V1 Voltage.

5 DISCUSSION

Based on the results presented in this paper, several outcomes can be observed. In comparison of both Modbus TCP and IEC 60870-5-104 used in these measurements, different structure of both determines the performance in different situations. Modbus TCP, based on original Modbus introduced several decades ago, is simple and does not provide very much options and possibilities of data structure definition within the protocol. Modbus TCP tends to use a higher number of packets, where payload which is carried in packets is significantly lower than payload carried by file transfer packets used in IEC 60870-5-104. Based on the results of Scenario B, it is significant that Modbus TCP tends to make bursts when power quality monitor is being interrogated which leads to extreme peaks in packets per second. This phenomenon and its impact might be emphasized especially when more monitors would be interrogated simultaneously at the same BPL line.

Design of standard IEC 60870-5-104 offers more possibilities of managing data transfer which leads to more effective transmission. Modbus which main purpose used to be communication with programmable logic controllers, where data types were limited only to those understood by such devices at that time. Large binary objects were not supported within Modbus.

6 CONCLUSION

This paper offers an insight into commonly discussed question about data volumes involved in controlling low voltage substations. Communication behaviour defines communication needs for further installation of new communication channels. The results of both scenarios described in this article are pointing out that design of standard IEC 60870-5-104 tends to outperform Modbus TCP/IP protocol in better data structure management and effectiveness. It also tends to use a lower number of packets and the overall load on the communication infrastructure is better balanced and spread over time. Nevertheless since IEC 60870-5-104 achieved higher average size of packets in all scenarios Modbus TCP/IP might be preferred in communication scenarios, where obsolete technologies with short frames are involved and fragmentation would be undesirable.

Since development of Smart Grids is being recognized with strong consensus, thorough understanding of communication needs and requirements leads to more convenient choices and faster progress in implementation phase. With massive deployment of such devices with its communication protocols, higher effectiveness of the whole controlled system should be achieved especially under worsened communication conditions.

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