Ways of Telecommunications Interaction Arrangement for Microprocessor Devices of Different Types in Composition of Multi-Motor Electric Drives

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Abstract. The article covers a consideration of various state-of-the-art industrial data transfer protocols, e.g. Modbus, Profibus, Industrial Ethernet and CAN. Their pros and cons are analyzed and conclusions made on advisability of the use of each protocol. It is shown that for the arrangement of effective telecommunication interaction of microprocessor devices of different types in the composition of multi-motor electric drives, it is advisable to use high-level CAN-protocols, such as CANopen and DeviceNet.

1. Introduction
At present, a lot of data transfer protocols are used for the arrangement of interaction between electric drives and industrial networks buildout on the whole. In the course of development of the industrial microprocessor network, a team of developers is faced with an important task of correct selection of these protocols. An ability to provide a high level of speed and security of data transmission between microcontrollers, sensors and actuators depends on solving of this problem.

The most common industrial communication protocols are Modbus, Profibus, Industrial Ethernet and CAN. These protocols are developed considering the features of production and technical systems, which allows them to provide reliable connection and high accuracy of data transfer between different devices. However, not all of them can ensure high efficiency of telecommunication interaction of microprocessor devices directly in the composition of a multi-motor electric drive.

The paper considers various protocols for data exchange with respect to their adaptability to industrial information and control network buildout for the multi-motor electric drive.

2. Industrial Protocols

2.1. Modbus
Modbus is a communication protocol that uses a client-server architecture for establishment of communication between microcontroller- or microprocessor-based devices. It can be used both in TCP/IP networks (Modbus TCP) and on serial communication lines, e.g. RS-232, RS-485 (ASCII and RTU). A network based on RS-485 allows one to combine up to 32 slave devices, but there may be more, if this is permissible based on the load capability of the transmitters and the input resistance of the receivers. The maximum length of the trunk cable at a transfer rate of 9,600 bps is 1,200 m, and...
the drop cables of the trunk cable should not be longer than 20 m. The speed can be increased up to 115 Kbps due to reducing the trunk length.

The main feature of the protocol is the presence of one master device in the network. Only the master device can poll the remaining slave devices of the network. The slave device can not initiate the transfer of data or request any data from other devices by itself, i.e. the network operation is based only on the request-response principle. The master device can also distribute a broadcast request addressed to all the network devices; in such case the response message is not sent [1]. At the link layer, the Modbus protocol allows the presence of one master and up to 247 slave devices in the structure.

The advantages of the Modbus protocol are the simplicity of its software implementation on various devices, the absence of need for special interface controllers (as distinct from CAN and Profibus), as well as the high degree of protocol openness. All this significantly reduces the costs of integration the protocol and standard adoption by systems integrators.

The disadvantage of the protocol is that Modbus performs a network exchange exclusively based on the master/slave principle; herewith the transmission of messages initiated by the slave device is excluded, and only one device can act as the master one. Also, the protocol does not provide a way for slave device to detect a loss of communication with the master one. Along with that, the request length in Modbus is limited, and the data itself can be requested only from consecutive registers. This increases delays and overhead expenses when using the network, because in order to obtain data from registers located far from each other in the address space, the master should either request unnecessary data or use several requests.

2.2. Profibus

Profibus is an open industrial protocol, which is widely used in Europe nowadays, especially in machine building and industrial equipment management. This protocol allows one to combine odd automation devices into united system at the level of sensors and actuators. There are a few different Profibus versions compatible with each other: Profibus-DP, Profibus-PA and Profibus-FMS. All the protocols use the same data transfer technology and common bus access method, so they can be used on the same bus.

The Profibus-DP standard allows one to develop systems with one or more master devices. In this case, a hybrid bus access method is implemented. Herewith, a decentralized token exchange between the active participants (Masters) is provided, as well as a centralized Master-Slave exchange is provided too. Active participants are ordered in accordance with their addresses increasing in a logical token ring. In this ring, the token, as well as the right to access the bus, is transmitted between the active participants via a special token-telegram [3]. Any master device can read input or source images. Only one master (which is set during configuration) can write data to a known DP device. The bus cycle in systems with several master devices is greater in comparison with systems with the only one master device.

The advantages of the Profibus family protocols include a high range of data transfer rates, the possibility of multi-mastering, as well as protocols openness. The main disadvantage of Profibus is its high consumption in the transmission of short messages, the lack of power on the bus and the higher cost as opposed to other buses.

2.3. Industrial Ethernet

Industrial Ethernet is a powerful top-level communication network that is most commonly used for data exchange between programmable controllers and human-machine interface systems, and less often for data exchange between controllers, as well as for connecting of remote equipment, such as sensors and actuators.

Industrial Ethernet is a high-speed information management network; the data transfer rate in it reaches 10 Mbps. The procedure for accessing the Industrial Ethernet network involves the CSMA/CD protocol. Such method of access is a decentralized one, i.e. all the master devices connected to the
network with the use of it have equal rights. Before sending the data, each master device verifies first if the data is transmitted by other master devices over the communication channel, and starts sending only if the communication channel is not engaged by them. If the master device detects that the transmission medium is already in use, it should wait till the communication channel becomes free. Thus, if several master devices plan to transmit data simultaneously and detect that the communication channel is free, they will start to transmit and a collision will occur a short time afterwards. Industrial Ethernet provides mechanisms allowing detecting such collisions. If they are detected, all the master devices stop to transmit data, the network delay is calculated for each of them, and only then the transmission attempt is repeated considering the delays. A device with the lower calculated delay will block all other transmissions and start to send data first.

Industrial Ethernet is focused on the use of 3 standard segments: 10BASE5, 10BASE-T and 10BASE-FL. In industry, the most common one is 10BASE-T, which is a shielded cable with two twisted pairs that provides data transfer rates of up to 10 Mbps. The twisted pair allows one to establish a point-to-point connection between two electrically active components. The maximum segment length should not exceed 100 m. Each pair of wires transmits information in one direction only. The use of counter-directed pairs simplifies the task of collisions detecting. The collision is detected when there is an input signal in the transmission time [4].

In spite of the high data transfer rate, Ethernet cannot provide the real-time operation of the system because it uses the CSMA/CD access mechanism which makes it impossible to guarantee the exchange of a small amount of information (a few bytes) with a high frequency (millisecond exchange cycles). However, there are Ethernet compatible real-time protocols, such as EtherNet/IP, EtherCAT, Powerlink and PROFINET.

The advantages of Industrial Ethernet include a relatively low price, a high transfer rate of large amounts of data and wide distribution. The disadvantages of the network include high costs for small volume data transmission, as well as the lack of supply voltage over the network cable. The main disadvantage is that the conventional Industrial Ethernet network does not feature determinism and stability of electrical performance (repeatability). In other words, there is no guarantee of timely delivery in traditional Ethernet. However, there are a number of ways to buildout the completely deterministic Ethernet based systems on the basis of above listed Ethernet compatible protocols. The disadvantage of these protocols is their complexity and closeness, which significantly increases the cost of their integration and adoption by system integrators.

3. CAN

The CAN technology was developed by Bosch in the early 1980s in order to simplify the cabling process in Mercedes cars. The advantages of CAN networks include low cost of the network itself and for its development, ease of network configuring and scaling, and absence of theoretical limitations with respect to number of nodes. The main advantage of CAN is the effectively implemented real-time mode which is possible due to multi-mastering, broadcasting, bitwise arbitration and high data rate in the CAN network. Thereafter, a specific feature of CAN networks is their high degree of reliability according to effective mechanisms of error detection, duplication of erroneous messages, self-isolation of faulty nodes and high resistance to electromagnetic interference.

However, the base CAN standard defines only the first two ISO/OSI levels, namely the physical and the channel one, which severely limits its use in complex networks usually used in industrial automation. This is connected with the fact that the physical and channel layers do not provide the solution for such important tasks as addressing of nodes, distribution of identifiers between them, data transfer of more than 8 bytes in length and other tasks inherent in higher levels.

In order to eliminate the described disadvantages inherent in low levels, various independent companies and associations for industrial automation have developed a number of high-level CAN-protocols – CAN HLP (Higher Level Protocol). From this variety, CANopen and DeviceNet have proven themselves especially. These protocols feature a compressed three-level architecture which includes physical and channel CAN layers, as well as an application layer. Service functions of
intermediate levels are either absent or included in the application layer. Meeting the full hierarchy of the OSI/ISO reference model levels in control systems is not required; furthermore, the presence of additional isolating interlayer interfaces would lead to a loss of system performance in real-time mode and would make the delays of the messages transmission in the network much less predictable [5].

The main difference between CANopen and other protocols based on the master-slave principle is the ability of any network node to access the bus independently and perform the data exchange directly with any other node bypassing the master device. The maximum length of the line using the CANopen protocol does not exceed 2,500 m, and the data transfer rate varies from 20 Kbps to 1 Mbps subject to the line length. Optimal data transfer rates (125 Kbps and above) are achieved with a line length of not more than 500 m, but a speed of 20 Kbps is mandatory for all CANopen modules.

An important advantage of the DeviceNet protocol is the ability to buildout an autonomous network independent of the external power supply availability or quality. This is achieved by the possibility of modules power supply directly from the network cable. It is also possible to have several power supply sources (as opposed to other CAN-based standards), for example, for redundancy purposes, at any point on the bus. This allows you to connect and disconnect modules in the DeviceNet network with no need of prior de-energizing of it, and it's also easy to dismantle and re-deploy the system in a new location. The maximum number of nodes in the DeviceNet network, as well as in the CANopen network, is 64. However, the total number of input-output devices can reach 2,048 (by 32 per node). The data transfer rate varies from 125 to 500 Kbps depending on the line length, which should not exceed 500 m.

Depending on the need for exchange and the capabilities of the modules, there are master-slave, multi-master or peer-to-peer modes of device interworking. Thus, the network modules can be either of UCMM type capable of interacting with other modules on a peer-to-peer basis (direct data exchanging without prior sending information to the master device) or of Predefined Master/Slave type, which cannot arbitrarily choose a connection path.

If one compares data transfer rates of CAN networks with the rate of, for example, Profibus-DP (up to 12 Mbps), then the first one loses very much. The loss in data transfer rate is connected with the physical principle of data transfer over the CAN network. The CAN network allows collisions (simultaneous activation of two or more network devices for transmission) by the method of non-destructive arbitration. This method allows one to determine the transmitting device of the highest priority without losing time for resolving a collision. In other words, in the CAN network it is allowed for several devices to start transmission of messages simultaneously, but this is absolutely unacceptable in high-speed networks; that is why the master-slave technology is used for them. In the Profibus-DP network, each master of the network should scan each device in turn to obtain its data and determine its state [7].

Thus, in spite of some disadvantages of CAN protocols, such as limited length of the line, limited bandwidth and limited size of messages, they have a number of significant advantages that play an important role in buildout of the arrangement of telecommunication interaction of microprocessor devices of various types in multi-motor electric drives. In the first place, these advantages include the ability to have several leading devices on the network, due to the use of multi-master or peer-to-peer modes. Thereafter, the important advantages of CAN networks include the high data transfer rate (up to 1 Mbps), reliable error detection and correction system, and in the case of DeviceNet, the possibility of buildout of autonomous network independent of the presence or quality of external power supply. It should be noted that limited bandwidth of CAN network is compensated by its sustainable use through the CSMA/CA access method, which combines the minimum delay of data transfer along with an effective arbitration of situations, where multiple nodes start to transmit data simultaneously. This is what guarantees the delivery of messages and makes the system deterministic.

4. Conclusion
In order to arrange the telecommunications interaction of microprocessor devices directly in multi-motor electric drives, it is necessary to use real-time networks. Foremost, this is due to the fact that the
multi-motor electric drive is a complex electromechanical system in which the control system should continuously collect data on the performance parameters of several electric motors at once and, as a rule, ensure their quick, well-coordinated interaction considering changes not only of the own load, but also load of each other. In such case, any delay can lead to severe consequences. Thus, the operation of a real-time system primarily involves executing of a task within a given time period. The data transfer protocol implemented in the network is responsible for execution of this task to a large extent.

Among the different protocol solutions discussed in the present paper, such as Modbus, Profibus, CAN and Industrial Ethernet, it is the most reasonable to use high-level CAN protocols (such as CANopen and DeviceNet) to buildout a real-time network and arrange an information-control interaction of microprocessor devices in multi-motor electric drives. This causes a number of advantages inherent in CAN networks based on these protocol solutions, namely the ability to have several master devices in the topology of one network, the use of the CSMA/CA access method, which provides a minimum delay in the transmission of information with the efficient arbitration of situations, as well as the reliable detection and error correction system. Due to this, data transmission with strictly regulated delivery time is guaranteed. Thereafter, an important advantage of the CAN network is a rather high data transfer rate of up to 1 Mbps.

Talking about known disadvantages of CAN networks, such as limited bandwidth and message size, a few factors are to be taken into account. The limited capacity of the CAN network is compensated for by its reasonable use, and the small packet size is the first sign of the CAN network as a real-time network, because each package does not take a lot of time and high priority messages can be wedged between low-priority messages, which reach the destination quickly due to effective arbitration of situations.

Thus, the use of CAN networks is the most effective one for arrangement of telecommunications interaction of microprocessor devices in multi-motor electric drives.

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