Remote Control System Based on Power Line Communication

2021 IEEE 27th International Symposium for Design and Technology in Electronic Packaging (SIITME) | 978-1-6654-2110-2/21/$31.00 ©2021 IEEE | DOI: 10.1109/SIITME53254.2021.9663427

Daniel Alexandru Visan
Electronics, Computers and Electrical Engineering Department
University of Pitesti
Pitesti, Romania
daniel.visan@upit.ro

Adrian Ioan Lita
Axiplus Engineering SRL
Bucuresti, Romania
ioan.lita@upit.ro

***Abstract*—In this paper is presented a versatile control system with remote operation that is implemented on the basis of power line communication technology. The proposed design is intended to be used in a wide range of applications including industrial and home automation, smart grid control, smart metering etc. In the prototype configuration, which is presented in this paper, the system comprises two modules, a transmitter and a receiver, which are both realized around a pair of Arduino Uno development boards having as main components two ATmega328 microcontrollers. More complex configurations, based on multiple transmission and receiving units are also possible. The implementation of the communication part of the control system is based on the narrowband KQ-330 modems that operates on the existing cable infrastructure used for distribution of electric power. By using a modern architecture which integrate versatile microcontrollers and highly efficient and reliable communication modules, the proposed system achieves very good performances in comparison with classical implementations. In addition, the control system is characterized by an improved scalability, flexibility and low implementation costs mainly due to the reuse of existing power lines as communication network infrastructure.**

Keywords— remote control, power line communication, network infrastructure

I. INTRODUCTION

The power line communications (PLC) represent a very promising technology for implementing complex mesh networks that are required for achieving enhanced connectivity between different elements that compose various distributed systems. Reusing the existing power lines for data transmission purposes offers important advantages regarding the cost minimization and the availability of network infrastructure. The idea of using power lines for data transmission occurred initially as a method for improving the level of interconnectivity and control in power utility systems. But in time, this technology evolved significantly and extended his range of application in various domains including home and industrial automation, smart grid, multimedia systems and data interfaces for electric vehicles. Each of these applications require sophisticated transmission methods capable to achieve high data rates using a difficult communication channel as it is a high-voltage power line. Using advanced signal processing in combination with the latest modulations based on spread spectrum and multicarrier techniques, become possible the integration the PLC technology in existing IT infrastructure. The integration the PLC technology in complex systems represents a key element for further achievements in this domain. In this context this paper presents an application regarding a remote control system based on the power line communication concept.

II. POWER LINE COMMUNICATIONS TECHNOLOGY

Communications through the existing power lines implies the use of modulated signals for transferring data. The carrier signals are added into the power lines through a coupling circuit and are extracted at the receiver side by filtering. Basically, the main components of a standard PLC system are: PLC modem, coupling circuit, controller and power supply. In practice, capacitive or inductive couplings are most commonly used for interconnecting the PLC to the transmission media. Inductive coupling is safer than capacitive coupling because avoid the direct contact with the power lines. The data transmission is realized using single carrier techniques, spread spectrum modulation or multicarrier schemes like orthogonal frequency-division multiplexing (OFDM) based on offset quadrature amplitude modulation (OQAM). Also, another solution for implementing performant PLC system relies on the use of ultra-wide band impulse modulation and multiple input multiple output (MIMO) approach. However, the transmission channel, which is not specifically designed for data communications, creates important limitations in PLC systems. From this perspective, the power lines represent a relatively harsh transmission medium, characterized by high levels of noise, variability and frequency selectivity. In addition, the power grid has a different structure in indoor and outdoor environments. For this reasons, dedicated implementation solutions and improved channel models were developed for make possible the operation of PLC systems over low-voltage indoor power grids or high-voltage outdoor networks. Being a system in which the transmission media is usually not shielded, the power line communications can be influenced and also can influence other sensitive devices. Those, the electromagnetic compatibility of PLC systems is another important aspect that must take into account for obtaining a reliable and stable operation of such systems. The IEEE P1775 is a standard which refers to the techniques that can be used for testing and measuring PLC devices form the point of view of electromagnetic compatibility. Regarding the achievable data transmission rate, the power line communications classify as ultra-narrowband, low speed narrowband, high speed narrowband and broadband. The common standards for automation based on narrowband PLC are: X10, KNX, LONWorks, AMIS CX1. Broadband PLC operates in a frequency domain of 1,8MHz to 250 MHz which makes possible high-speed application like video streaming, multimedia and networking. For example, IEEE 1901 is a standard for high-speed PLC that specify data transmission rates above 200Mbits/s. Also, in the recent developments, based on MIMO architecture, the broad-band PLC can achieve data transmission rate of up to 1Gb/s [1], [2].

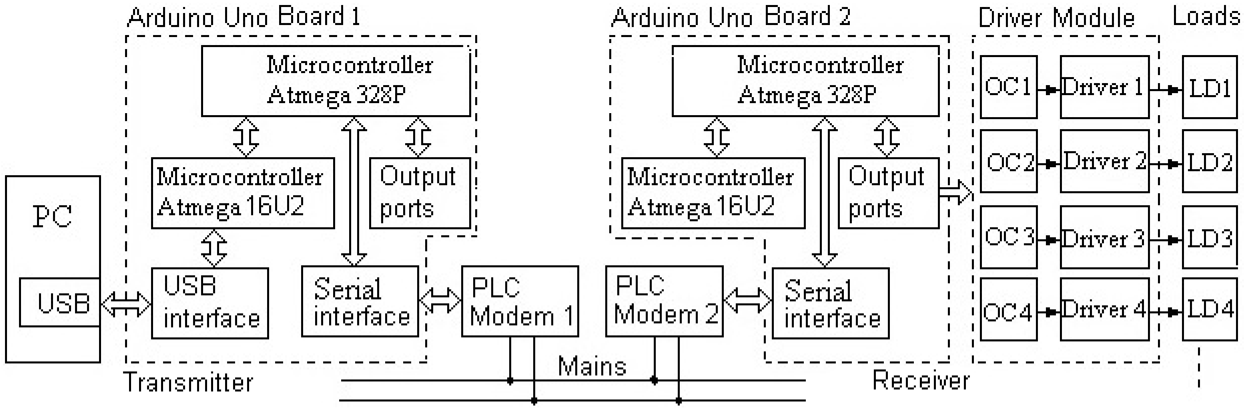

Fig. 1. The simplified structure of the remote control system based on power line communication.

III. The Structure of the System

In Fig. 1 is presented the simplified architecture of the proposed control system that operate by sending data through the mains for remotely controlling various loads. The receiver and transmitter modules that compose the system are realized with two Arduino Uno development boards and few adjacent components. The receiver and transmitter have an important part of they hardware structure very similar. In the proposed implementation the system is capable to control four loads operating at 220Vac and requiring a maximum current of 10A. The Arduino Uno Board 1 together with the PLC Modem 1 implements the transmitter of the remote control system. The communication between the Arduino Uno Board 1 and PC is realized through the USB interface.

The receiver part of the control system comprises the Arduino Uno Board 2, the PLC Modem 2 and the driver module with four channels. Between the loads and the Arduino board are placed a series of galvanic insulation circuits realized with optocouplers. Using this arrangement are avoided the possible unwanted influences between the power and control sections of the receiver. The execution part of the system is represented by the drivers which are realized using bipolar transistors in common emitter configurations and relays with characteristics that are in accordance with the requirements of the controlled loads. The whole system is scalable, being easily extendable to cope with a larger number of loads that eventually would be necessary in other, more complex applications. The bidirectional data communication between the distant modules that compose the system is ensured by two PLC modems. Being a control application, that would not require a high data transfer rate, the proposed system was implemented using two narrowband PLC modems of type KQ-330 [3], [4].

The operation of the control system is defined by the proprietary software programs that are stored in the internal memories of the ATmega328 microcontrollers from the Arduino boards. The programs were written in C++ language and uploaded into the flash memories of the microcontrollers using the dedicated software tool Arduino IDE. In Fig. 2 is presented the simplified structure of the state diagram for software program that controls the operation of the transmission part of the system. As can be remarked, the program begins with a stage of initialization followed by displaying system's menu and the activation of serial and USB communications ports. The main loop of the program consists in a sequence of commands and tests that continuous verify the data read from PC and act for sending the information to the remote module for execution. A simple and efficient protocol based on retransmission was implemented for compensate the communication errors that could arise in the data transfer between the remote modules of the control system. By accessing the settings menu, the user can control the key parameters of the system. In this case the system is programmed to stop all previous actions and to wait until the settings are updated and saved by the user. For example, the user can change the transmission speed, the serial communication parameters, the number of retransmissions in case of communication errors, the active control channels etc.

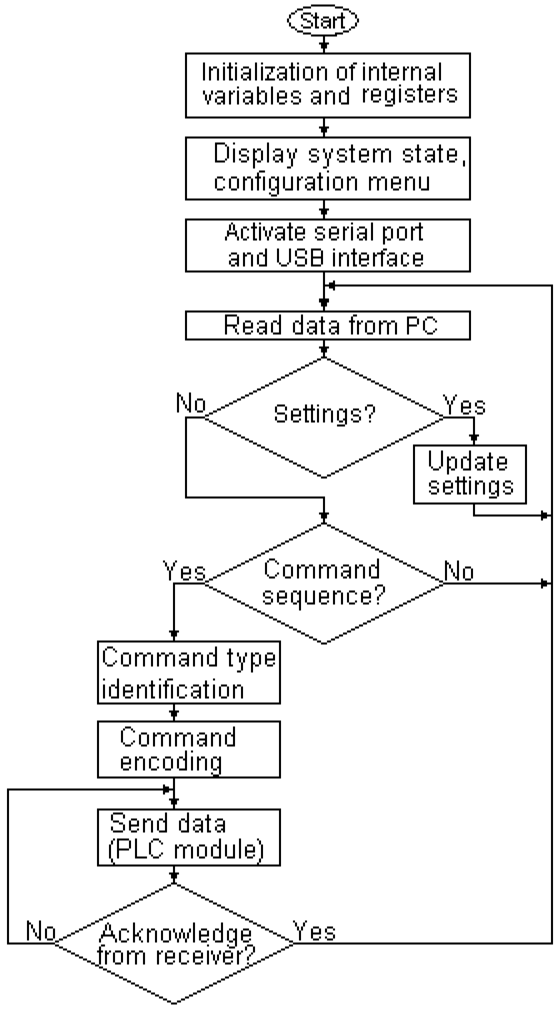

Fig. 2. The state diagram for the software program that controls the operation of the transmission part of the remote control system.

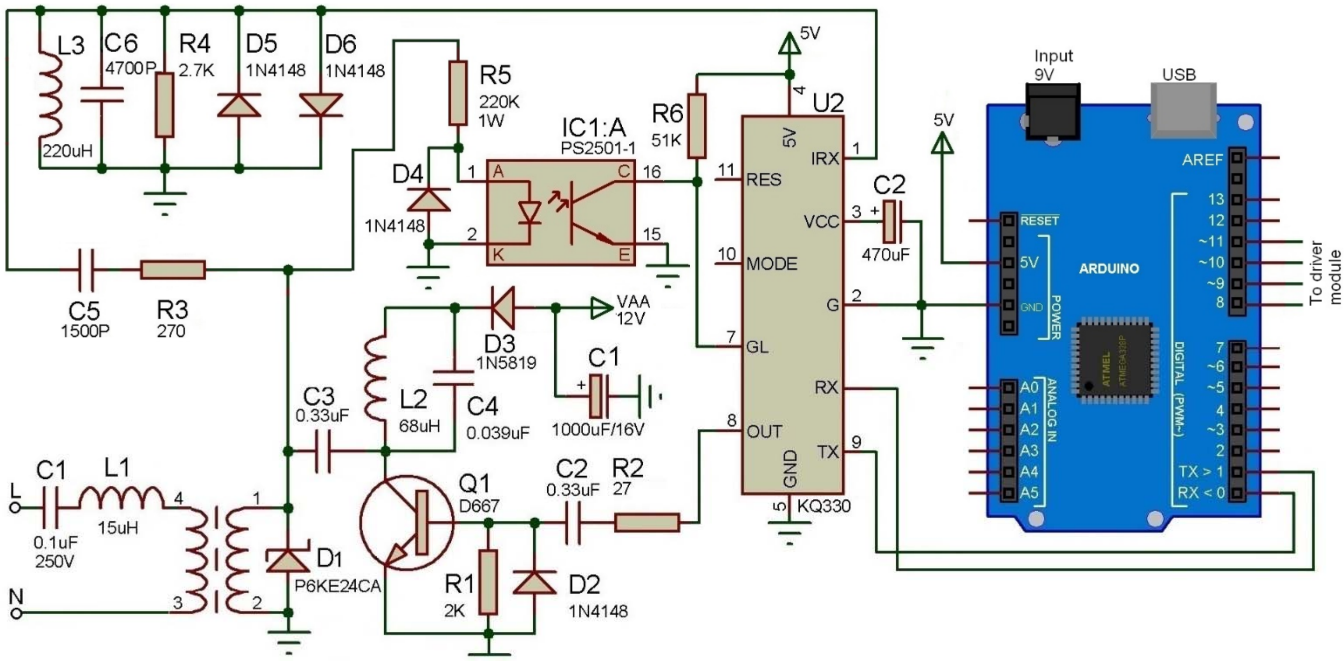

Fig. 3. The hardware structure of the receiver/transmitter module used for implementing the remote control system.

IV. Implementation and Results

The practical tests for verifying the correct operation of the remote control system based on power line communication technology were realized using few experimental boards grouped in two units: a receiver and a transmitter. The common part of the hardware structure of the receiver and transmitter modules that compose the proposed control system can be observed in Fig. 3. It consists of three elements: a logical unit, a power line communication modem and a driver module. The logical unit of the receiver is realized with the Arduino Uno development board having as main component the versatile ATmega328 microcontroller. The management of the communication with the remote module of the control system and the decoding and identification of commands are the main tasks performed by the logical unit of the receiver. The actual data transfer between transmission and receiver part of the presented control system is realized with the narrowband KQ-330 modems. On the schematic presented in Fig. 3 we can identify two paths that are used for processing the signal transferred over power lines. First is the signal path formed through the filtering network with R_3 and C_3 and the subsequent resonant circuit composed by L_3 and C_6 followed by the voltage limiter represented by diodes D_5 and D_6. The obtained signal enters into the KQ-330 modem trough the pin denoted IRX and is demodulated. The resulted bit stream is supplied to the Arduino Board through Tx port for further processing [5], [6].

The second signal path is composed by the filter R_2, C_2 and the tuned amplifier represented by the Q_1 transistor. This group of components has the role to increase the level of modulated signal that is injected in the transmission line. As can be easily observed, both signal paths have a common point, being together connected to a coupling circuit that play the role of an interface between the system and the 220V power line. The coupling of the receiver/transmitter to the mains is realized with the serial resonant circuit compose by C_1 and L_1, tuned on the central operation frequency of the system which is in the range between 120kHz and 135KHz. The galvanic insulation is realized using inductive coupling based on transformer.

For synchronizing the operation of the KQ-330 modem, an additional zero-crossing detection circuit was introduced in the schematic presented in Fig. 3. The elements R_5 and D_4, together with the subsequent optocoupler, detects and limit the amplitude of sinusoidal voltage received on the line and generate a square wave signal that is used by the modem to improve the stability of the communication.

The driver module is realized on a separate board and is connected directly to outputs of the receiver, as can be seen in the left side of the schematic presented in Fig. 3. The schematic of driver module, considering a single control channel, is presented in Fig. 4. As can be observed, the command from Arduino board is transferred to the load using a chain of three elements: an optocoupler, a bipolar transistor and a relay. The state of the control channels is optically signaled using light emitting diodes connected in series with the inputs of the optocouplers [7], [8].

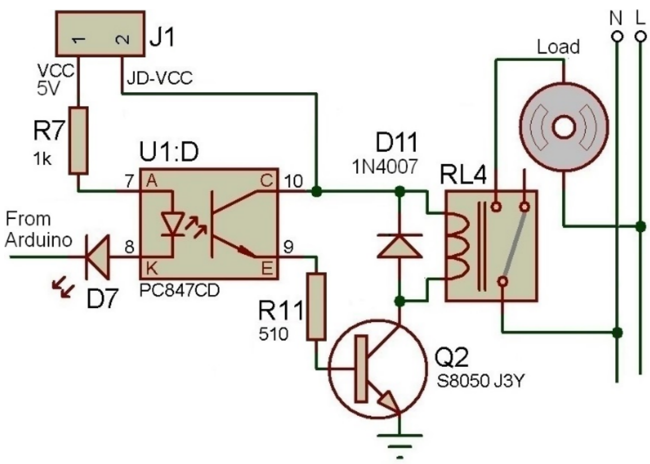

Fig. 4. The structure of driver module for a single control channel.

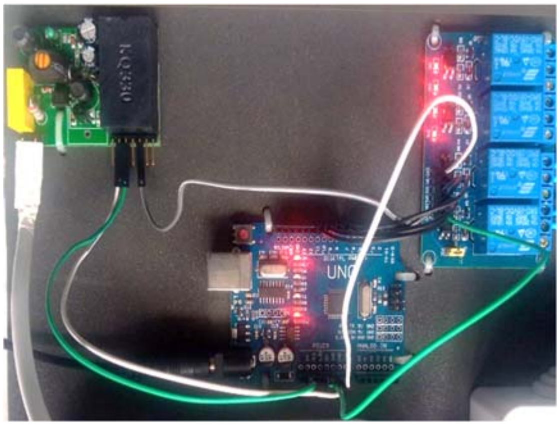

Fig. 5. The implementation of the receiver unit of the control system.

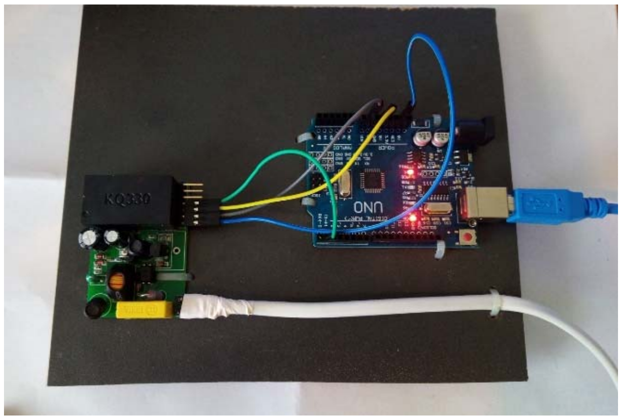

Fig. 6. The implementation of the transmission unit of the control system.

The practical implementation of the receiver section of the remote control system is shown in Fig. 5. In this image can be identified the main elements of the equipment: the PLC communication module with KQ-330 modem, the logical unit represented by the Arduino Uno board and the driver module. In the proposed implementation, a four-channel driver module with galvanic insulation was used for controlling various loads (electric motors, lights, electromagnets etc.) that requires currents until 10A at a supply voltage of 220V. In the proposed design all channels of the driver were implemented in a similar manner. The number of channels for the driver module can be easily scaled up or down with minimum modifications in the structure of the system. The implementation of the transmission unit of the control system, presented in Fig. 6, is almost similar with the structure of the receiver, the only notable difference being the absence of driver module and the different software program stored into the ATmega 328 microcontroller. The transmission module is connected to the PC through USB interface. The narrowband KQ-330 modems that are used in the proposed design operates with a carrier frequency of 135kHz at a baud rate of 9,6kb/s. The data are sent in frames with a maximum length of 252 bytes, the value being configurable by user. The modulation technique employed in the data transmission is orthogonal frequency-division multiplexing (OFDM). The receiver's sensitivity is under 1mV and the rejection of out-of-band signals exceed 60dB. The KQ-330 modems are characterized by an increased insulation resistance of more than 500MΩ when operating on a power lines with a maximum voltage that don't exceed $500V_{rms}$. The energy consumption of the KQ-330 modems is relatively low, requiring only a $5V_{dc}$ voltage and a maximum level of current of 230mA when operate in transmission mode. The modem is connected to the Arduino development board through serial interface and is capable to transmit data over the 220V alternate current power grid even in very harsh condition, characterized by high levels of interference and strong attenuation (SNR<5dB). This performance makes modem KQ-330 capable to operate stable and reliable using long data transmission lines. In addition, although the speed of this narrow-band PLC is relatively reduced, due to the reduced operation band, also the level of interference is smaller in comparison with a broadband PLC. As a consequence, the electromagnetic compatibility constraints are less stringent is this case. This are among the most relevant reasons why KQ-330 module was selected for developing the proposed control system [9].

V. Conclusions

Despite the inherent difficulties for ensuring a stable and high data transmission rate, in conditions of high levels of noise and interference, the power line communication technology gained a significant importance in the actual context which demand increased levels of connectivity and integration for every type of system. In this context, this paper presented a solution for implementing a remote control system using the concept of power line communication. The proposed design proves to be a reliable and economical implementation that is capable to control various loads especially that encountered in home automation systems. Besides it's intrinsic practical utility for home applications, the proposed design can serv also as a basis for other, more complex approaches, in various domains including for example the industrial control, machines automation and smart metering.

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