

Quality Evaluation of Voice Transmission Using BPL Communication System in MV Mine Cable Network

Grzegorz Debita^{1,*}, Przemysław Falkowski-Gilski², Marcin Habrych³, Bogdan Miedzinski⁴,
Janusz Wandzio⁵, Przemysław Jedlikowski⁶

¹*General Tadeusz Kosciuszko Military University of Land Forces,
Czajkowskiego 109, 51-147 Wrocław, Poland*

²*Faculty of Electronics, Telecommunications and Informatics, Gdansk University of Technology,
Narutowicza 11/12, 80-233 Gdansk, Poland*

³*Faculty of Electrical Engineering, Wrocław University of Science and Technology,
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland*

⁴*Institute of Innovative Technologies EMAG,
40-189 Katowice ul Leopolda 31, Poland*

⁵*KGHM Polska Miedz S.A.,
Sklodowskiej-Curie 48, 59-301 Lubin, Poland*

⁶*Faculty of Electronics, Wrocław University of Science and Technology,
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland
grzegorz.debita@awl.edu.pl*

Abstract—This article presents results of a quality evaluation study, considering voice transmission in a 6 kV medium voltage cable network using the BPL (Broadband over Power Line) communication system. The tests are carried out under real mining conditions for the selected power cable without voltage, earthed at both sides. Such a method of monitoring work conditions is of great importance, especially during a disaster. Power cables are potentially resistant to mechanical damage and, thus, ensure continuity of transmission, also, in cases of electricity stoppage and partial damage (interruption) of the phase conductors. The voice transmission quality is tested for a relatively low bitrate of 8 kbps–48 kbps using both induction and mixed induction-capacitive coupling with the power cable. Such a solution should provide both reliable and high-quality services, considering clear and understandable voice messages to people. The quality evaluation is carried out on a group of 15 people aged between 25–35 years old. The tested signal samples consist of voice messages in British English, German, and Polish. On the basis of the investigated results, respective conclusions are formulated.

Index Terms—BPL communication system; MV cable network; Quality evaluation; Signal processing; Voice transmission.

I. INTRODUCTION

Reliable and efficient transmission of different types of content is a crucial requirement for any underground mine system. In order to provide secure operating conditions for people, various types of transmissions, both wired and wireless, are used and duplicated for safety purposes.

Recently, the transmission of so-called power line communication (PLC) from low (up to 150 kHz) to high (between 3 MHz–32 MHz) frequency (BPL - Broadband over Power Line) is gaining popularity [1]–[4]. Its main advantage is the possibility to utilize the existing infrastructure of electric networks, both low and high voltage conductors, as well as mine cables without the need to incur additional costs related to operator's fees.

In addition, the probability of a total mechanical damage of the mining cable, especially the medium voltage one, under various sidewalk and pit collapse incidents seems to be relatively low. The BPL transmission is then performed through the armor and/or shielding of the cable with the interrupted phase conductors. This applies especially to the inductive coupling of modems with the cable when using batteries. Whenever an emergency situation occurs, particularly in the underground environment, it is crucial to ensure and maintain the continuity of the voice transmission.

In this paper, we focus on transmitting voice messages of an appropriate quality using the BPL communication system of a medium voltage cable (6 kV) under real operating conditions in an underground mine environment, what is a scientific novelty of the paper. The unidirectional transmission tests are performed in a scenario when the 6 kV cable operates under emergency (lack of voltage, short circuit, earthed cable input and output). A suitable set of a digital transmitter and receiver connected to BPL modems are developed for this purpose. Note, that nowadays, due to the bandwidth restrictions, the main goal of any digital communication system is to deliver high-quality content with the lowest possible bitrate. This bitrate depends on a set of

factors, including the type of medium, delay related with distance, error rate, etc.

Effective BPL transmission also requires the selection of the appropriate mode (bandwidth) depending on the cable parameters (characteristic impedance, attenuation, etc.) and the optimal operation of the coupling used [1]–[4]. For this reason, tests are carried out for in the range of frequency of 2 MHz–7 MHz and at the different bitrates for voice transmission up to 48 kbps. The evaluation of voice quality is carried out on a selected group of people. Then, obtained data is subjected to the statistical treatment. Based on these results, practical conclusions are formulated.

II. UNDERGROUND ENVIRONMENTS

The cable feeder with the installed BPL communication system consisted of several different types of cables connected to each other at the respective substation busbars. It was located both in the shaft and the underground pavement at a depth of approximately 1100 m as shown in Fig. 1.

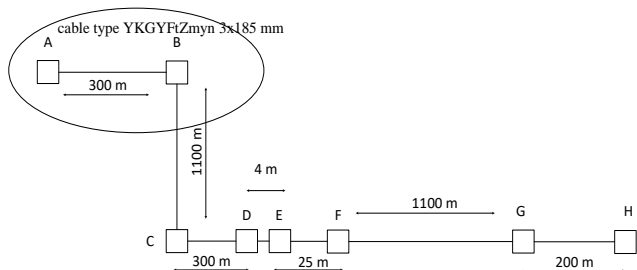


Fig. 1. Tested 6 kV cable line with marked section of the selected test cable located in the mine shaft headroom.

Each section of the line was, therefore, exposed to different environmental conditions (temperature and humidity). A section of the YKGYFtZmyn 3 x 185 mm cable with a medium voltage line of 6 kV, about 300 m long, located in the mine shaft head was selected for the tests as indicated in Fig.1. The ambient temperature during the tests was equal to 11.4°C, whereas humidity did not exceed 60 %.

III. ABOUT THE TEST

In the proposed scenario, tests were carried out for the unilateral voice transmission from point A to point B of the cable line located in the mine shaft headroom. Test was performed under the operating power line (6 kV, current around 25 Arms, THD_u up to 3 %, THD_i around 10 %) and without voltage for its earthing at both sides. Both induction coupling of the BPL modems with a cable on both sides (Fig. 2) and capacitive-induction ones (Fig. 3) were used. The method of installing capacitive couplers (at point A), and induction couplers (at points A and B) is shown in Fig. 4–Fig. 6, respectively.

The PC located at point A with the UBUNTU operating system worked as the server with the IC CAST software installed. Whereas, at point B, the Raspberry Pi microcomputer was used (due to spatial limitations in the mine's sidewalk) with the RASBIAN operating system installed. It performed as the client, along with the VLC software. Voice samples received from the server were

recorded at the Pi client side.

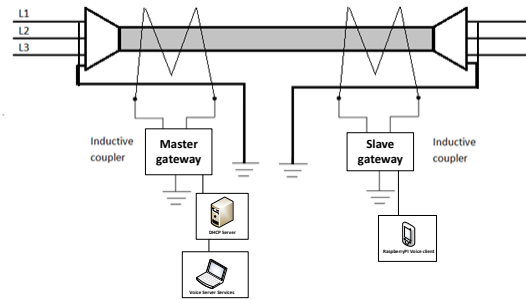


Fig. 2. Tested connection for induction-induction coupling (Test 2).

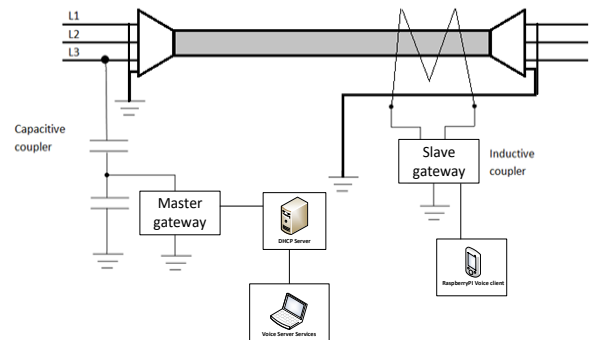


Fig. 3. Tested connection for capacitive-induction coupling (Test 1).

The developed transmitter and digital receiver were connected to BPL modems, respectively (Fig. 2 and Fig. 3). The BPL transmission system operated in the frequency range of 2 MHz–7 MHz, whereas the bitrate of voice services ranged from 8 kbps–48 kbps. A single session, considering sending, receiving, and recording voice messages for each of the selected 5 different bitrates (8 kbps, 16 kbps, 24 kbps, 32 kbps, and 48 kbps) took about 10 minutes, respectively.



Fig. 4. Capacitive couplers installed at point A.



Fig. 5. Inductive couplers installed at point A.



Fig. 6. Inductive couplers installed at point B.

IV. QUALITY EVALUATION

The human perception differs from person to person. In this test, a group of 15 people aged between 25–35 years old is selected. This group meets the average age of workers present in the company. Of course, any subjective judgement is affected not only by the sound quality itself, but also age and hearing defects of an individual. In this case, none of them has hearing disorders.

In the proposed scenario, the system should provide clear and understandable voice messages to people. In order to design such a system, one needs to know how many bits are sufficient to deliver such a message. Moreover, the bandwidth fluctuations, the packet loss or the delay can cause the degradation in quality understood as network QoS (Quality of Service) or user QoE (Quality of Experience).

A. Signal Samples

For the purpose of this test, a set of signal samples were selected. These files were sourced from ITU (International Telecommunication Union) [5]. The description of the selected speech samples in British English, German, and Polish from Annex B (Speech and Noise Signals Clause B) is shown in Table I.

From the set of available languages, both male and female samples were utilized. The sourced audio material, of 7 s–8 s duration each, was WAV 16-bit PCM (Pulse Code Modulation) files with sampling frequency set to 32 kHz. Each file was then processed using the OGG coding algorithm, transmitted through the wired medium, and recorded on the receiving side.

TABLE I. SPEECH SIGNALS USED DURING TEST.

File name	Language
ENfemale1	British English
ENfemale2	
ENmale1	
ENmale2	
GEfemale1	German
GEfemale2	
GEmale1	
GEmale2	
PLfemale1	Polish
PLfemale2	
PLmale1	
PLmale2	

The speech signal samples were processed in 5 different bitrates, namely: 8 kbps, 16 kbps, 24 kbps, 32 kbps, and 48 kbps. Previous studies concerning delivering speech audio signals showed that a bitrate of 48 kbps–64 kbps

enables to deliver high-quality commercial services [6]–[8]. Additional information on speech signal processing may be found in [9].

B. Subjective Quality Assessment

Tests were carried out in turns, one participant after another, according to [10]. A single session took approximately 20 min. All 15 listeners took a training phase before starting the essential study in order to become familiar with the test scenario and acquaint with the listening equipment. The subjective quality was assessed using the Beyerdynamic Custom One Pro headphones. Further information on testing audio signals may be found in [11], whereas the principles considering speech coding, especially at low bitrates, are available in [12]–[14].

However, after a few tests, the number of evaluated signal samples was limited to 3 bitrates, i.e., 8 kbps, 16 kbps, and 24 kbps. Quite surprisingly, the subjective judgements for bitrates higher than 24 kbps did not differ much. That is why the bitrates of 32 kbps and 48 kbps were omitted from the assessment. Due to this fact, a single session was limited to approximately 12 minutes.

The results of the subjective quality evaluation concerning the overall quality of the voice messages transmitted over the BPL cable network in British English, German, and Polish are shown in Figs. 7–9. In this case, Test 1 refers to the communication using capacitive-induction coupling, whereas Test 2 refers to the case of the inductive-inductive coupling.

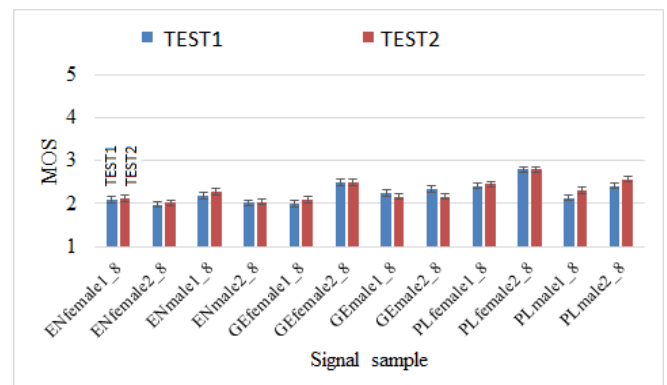


Fig. 7. Quality evaluation for speech signal samples transmitted at 8 kbps.

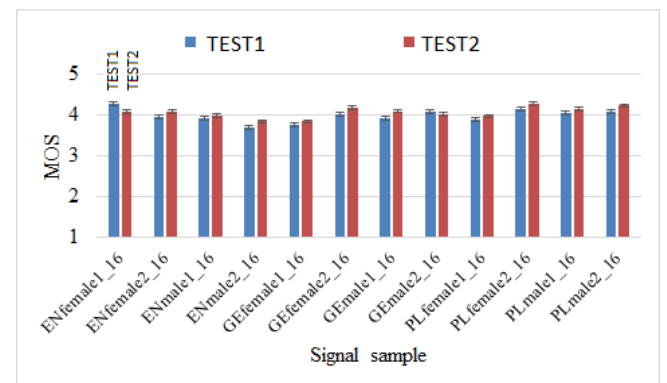


Fig. 8. Quality evaluation for speech signal samples transmitted at 16 kbps.

The obtained subjective results were treated with the ANOVA (Analysis of Variance) statistical analysis as shown in Table II. The confidence interval α was set to 95 %, whereas F_{crit} was equal to 1.75.

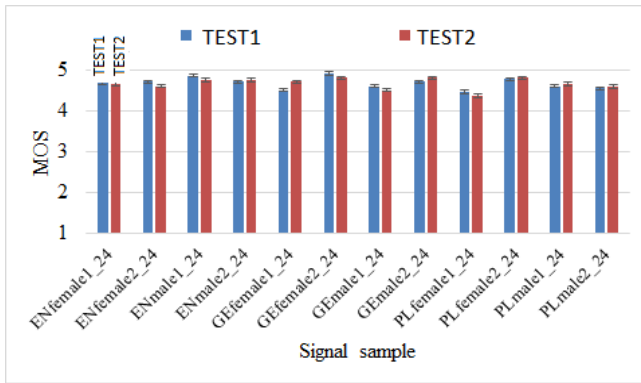


Fig. 9. Quality evaluation for speech signal samples transmitted at 24 kbps.

TABLE II. ANOVA TEST RESULTS.

Data set	P	F
Capacitive coupling 8 kbps	0.08	2.26
Capacitive coupling 16 kbps	0.30	1.18
Capacitive coupling 24 kbps	0.67	0.81
Inductive coupling 8 kbps	0.12	1.48
Inductive coupling 16 kbps	0.79	0.69
Inductive coupling 24 kbps	0.46	1.00

According to the obtained results, in each case the P value was not less than α . Additionally, the F value did not exceed F_{crit} .

V. CONCLUSIONS

Studies show, that in case of broadcasting and streaming services, speech signals are perceived as of high quality for a bitrate of 48 kbps–64 kbps, whereas, for music signals, the required bitrate ranges from 96 kbps to 128 kbps. However, this bitrate is necessary for regular commercial audio services. When transmitting voice messages in an underground communication system, the bandwidth requirements can be lowered.

In case of the lowest bitrate of 8 kbps, due to high distortions, sentences spoken by both male and female lecturers prove to be unacceptable. Furthermore, as indicated by the listeners, the female voice is found to be more understandable. For 16 kbps, an increase in subjective quality is clearly noticeable. However, not all samples are perceived as of good quality. According to the obtained results, a clear and understandable voice message can be provided for a bitrate equal to 24 kbps. High overall quality resembling a MOS score of 4.0 and above is observed regardless of the spoken language.

The spoken language of the presented voice messages, whether it is British English, German, or Polish, does not have a significant impact on the results obtained. In case of

each participant, Polish language is indicated as the mother tongue, whereas English is the second language of choice, in which they most often communicate abroad. German is the third language of choice. Additionally, as pointed out by the listeners, sentences spoken by a male lecturer seem more appealing.

This is independent of the type of BPL modem coupling used with the mining cable. In general, when it comes to maintaining a connection between the supervisor and the crew members, it can be concluded, based on the subjective judgements, that the male voice is preferred more. Nevertheless, the topic of the designing high-quality and reliable services considering different types of wired media still remains a challenge.

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