

A Novel DC Power Line Carrier Technology for the Technological Process of Water Distributor in Water Injection Well

Deli Jia^{1,2}, Xiaohan Pei¹, He Liu¹, Caihao Cui², Yong Yu² and Meiqi Liu²

¹*China Research institute of oil exploration and development (RIPED), Petro China, Beijing 100083, China*

²*School of Automation, Harbin University of Science & Technology, Harbin 150080, China*

jiadeli@hrbust.edu.cn

Abstract

In order to optimize the technological process of the water distributor and do further sturdy about the interference pattern of the injection layers in China, we needs reasonable and reliable methods to obtain the dynamic parameters of water injection layers. In this paper, a novel DC power line carrier technology based on the Orthogonal Frequency Division Multiplexing (OFDM) technology is proposed, aiming to save the difficult communication problem between the underground and the surface. Using the signals on the power line, it includes the modulation and demodulation techniques and filter encoding technology to transmit the data. Experimental results show that this new communication technology has high noise resistance and low error rate, provides reliable technology support and data to optimize the injection process and build the model of the dynamic parameters change among all the layers.

Keywords: *DC power line carrier; OFDM; modulation; demodulation; filter; encoding*

1. Introduction

China has entered the late stage of oilfield development. The most important task right now is to recover the remaining oil and 80% work depends on the technological process of water distributor, which means how to inject water properly and effectively in the well has been the key value of the whole technological research [1]. How to analysis the inference of the layers and avoid the useless water circulation have become the key factors to set the layer distributed water quantity and the open size of the water nozzle reasonably and precisely [2]. Thus, establishing the interpretation model of dynamic parameters under the influence of the interlayer interference becomes extremely urgent.

Nowadays the sampling technology of the water injection well's underground layer is well developed, and the accuracy of the data meets the standard of the demand. But still there is no uniformed communication standard made for the underground and surface equipment right now [3-4]. When the common digital power pine carrier technique from the industrial market is used directly in well communication, it faces the complex situations which cause the disadvantages such as poor anti-interference ability and high error rate. Thus, it is important to study a new communication technology for the technological process of the water injection well [5-6].

In this paper we proposed a novel DC power line carrier technology, it only need to a little reconstruction work to the connector of the water distributor's power line cable to make the communication process steady. By using the OFDM technique and other technology such as modulation-demodulation and filer encoding technologies, it become much easy to measure

and adjust the water injection well, which makes a significant meaning to measure and adjust the water injection well and to build the interpretation model of the dynamic inference of the different layers.

2. Communication System of the Multilayer Water Injection Well

2.1. The Structure of the System

The layered water injection technology means using packers to separate the oil layers whose permeability are significant different by comparing with others. Then use the water distributors to manage the water quantity in each layer. High permeability layer are under control and the other layers' injection water are enhanced, so different categories oil layer could all work together and increase the reserves [7]. The commonly used string in multilayer water injection well includes fixed layered water distributing pipes, concentric layered water distributing pipes and bridge eccentric distributing pipe.

Take the bridge eccentric distributing pipes as example. This technological process achieves the aims of multilayer and multi-hierarchical quantitative control in water well, and it has achieved very good results. In the past time using the technological process of the injection well needs the working group to sample the flows and pressures of different layers under the well. It needs to put measuring instruments and equipment in the down-hole, which own multi-disadvantages such as high construction, high cost and long-term monitoring.

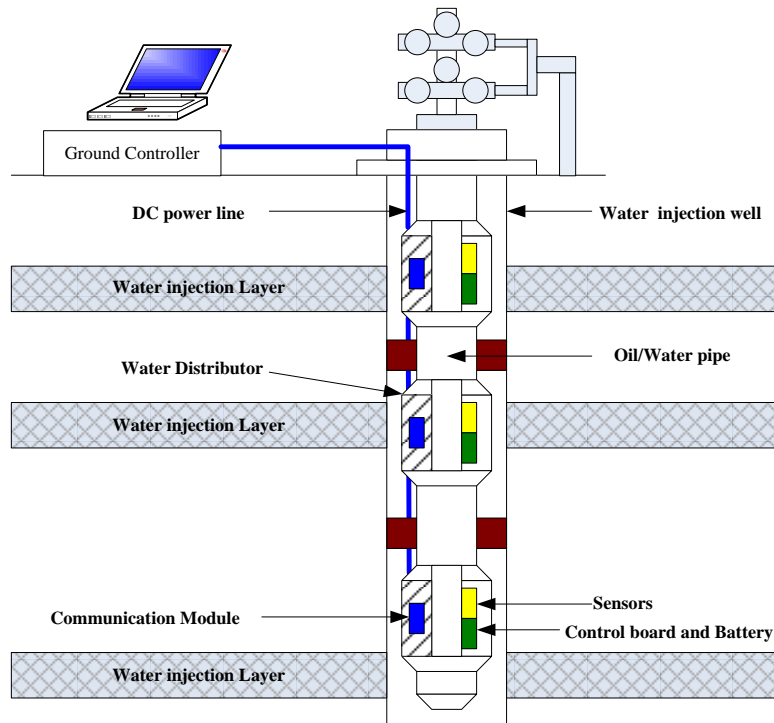


Figure 1. Communication System Scheme of Multilayer Water Injection Well

In this paper, the structure of the proposed DC power line carrier (DCPLC) technology shows in Figure 1. It includes ground cable and control equipment and down-hole injection layer monitoring communications equipment. The first consist of the cable carrier controller, as well as the second consist of water distributor, sensor control circuit, communication

module and battery modules. Ground equipment sends command to the down-hole equipment through the DC voltage modulation module by the cable. The down-hole equipment injects the dynamic parameter layer data by changing the load current. The ground equipment will notice the changing current and demodulate the data.

2.2. Communication Process

The DC-PLC process mainly contains two parts, the first is the ground equipment send orders to the down-hole equipment, and the second part is the down-hole equipment sent back the dynamic data. Since all the devices are connected by the bus, the communication method is working in half duplex bus function and have to transmit data in quit mode. First of all the command send by the ground equipment was passed through the encoder and modulator and end in voltage controller, which cause the voltage fluctuations in the cable.

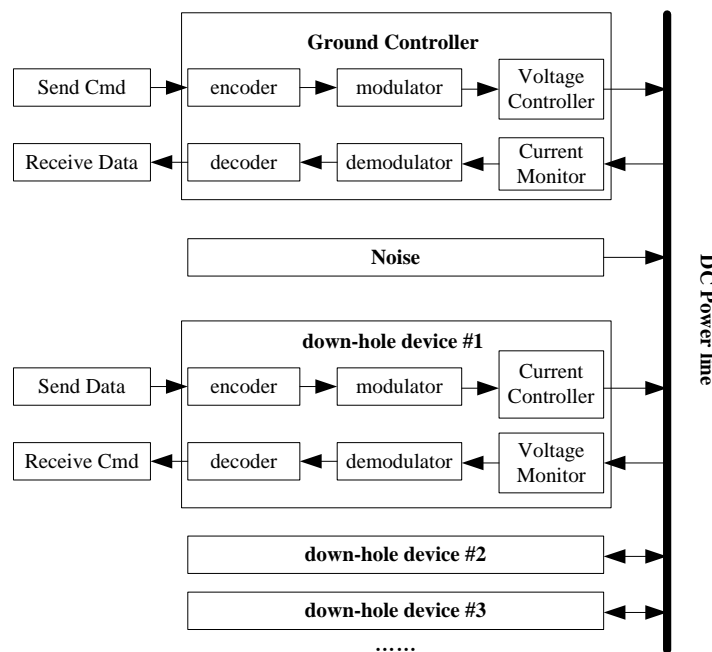


Figure 2. Communication Process Scheme

Then the down-hole device get the command through the voltage signals using the demodulator and decoder by a voltage monitor. It will determine whether the command and their position match, if not it will not respond. If the command matches with device, it will send its parameters of this layer through the encoder and modulator and end in current controller which changes the current value of the cable. The ground controller's current monitor will detect the change of the current. With the help of demodulator and decoder, the data will be got from the water injection layer. Figure 2 illustrates the scheme of communication process.

3. DC-PLC Communication System based on OFDM Technology

The energy of the signal in the cable will decay between the sender and the receiver during the communication [8]. This loss is caused by the energy dissipation and signal attenuation.

At the same time, another important reason influencing the efficiency of data transmission is noise; it can cause the analog signal and digital signal distortion or error. The main source of the noise in signals comes from the power supply terminal or the movement interference of the motor nearby.

In this paper, we apply OFDM technique to modulate the signals for the communication system, the basic idea is than by dividing the channel into multiple distributed and orthogonal sub-channels with narrowband, the modulation and demodulation processes are carried out in these sub-channels. Because the spectrum of the sub-channel may appear to be overlapped, by encoding the sub carrier, the efficiency of the transmission process is improved, as well as the resistance of the inter-symbol interference increases greatly [9].

The key problem in the system is how to transmit the modulated data on the power line. The Orthogonal frequency division multiplexing (OFDM) is used in a parallel modulation method, by simultaneously on a set of N data modulation, which reduce the symbol rate to the original 1/N, prolonged the duration to the original N times, the duration is greater than the signal fading time, thereby reducing the damage of parallel symbol. The symbol is restored after the receiver error correction process, which make the overall sensitivity of the multi path problem lower in the signal transmission.

Considering the time limited complex exponential signal $\{e^{j2\pi f_k t}\}_{k=0}^{N-1}$, they represent the OFDM signal in different sub carrier frequencies $f_k = k / T_{sym}$, where $0 \leq t \leq T_{sym}$, T_{sym} is the duration of a single OFDM symbol. If the integral of these signals in public cycle are zero, then they will be defined as orthogonal, i.e.

$$\frac{1}{T_{sym}} \int_0^{T_{sym}} e^{j2\pi f_k t} e^{-j2\pi f_i t} dt = \begin{cases} 1, & \forall k = i \\ 0, & \text{else} \end{cases} \quad (1)$$

When we discrete sampling at $t = nT_s = nT_{sym} / N$, $n = 0, 1, 2, \dots, N-1$, the Equation 1 could be rewritten as:

$$\frac{1}{N} \sum_{n=0}^{N-1} e^{j2\pi \frac{k}{T_{sym}} nT_s} e^{-j2\pi \frac{i}{T_{sym}} nT_s} dt = \begin{cases} 1, & \forall k = i \\ 0, & \text{else} \end{cases} \quad (2)$$

For the OFDM transmitter, data will firstly be converted into a set of bit stream, and mapped into a phase shift keying (PSK) sequence or quadrature amplitude modulation (QAM) symbol sequence. The symbol sequence will be converted into a N parallel stream. Each bit stream will be modeled by different sub carrier.

$X_l[k]$ denotes the k sub carrier of the symbol l, where $l = 0, 1, 2, \dots, N-1$. Because of the conversion, the total time cost of N symbols is expended into NT_s , and it also is the duration T_{sym} of a single OFDM symbol, thus $T_{sym} = NT_s$. Suppose $\psi_{l,k}(t)$ denotes the l signal of the OFDM symbol on the k sub carrier:

$$\psi_{l,k}(t) = \begin{cases} e^{j2\pi f_k (t - T_{sym})}, & 0 \leq t \leq T_{sym} \\ 0, & \text{else} \end{cases} \quad (3)$$

The continuous time bandpass and baseband signal can be expressed as

$$x_i(t) = \text{Re} \left\{ \frac{1}{T_{sym}} \sum_{l=0}^{\infty} \left\{ \sum_{k=0}^{N-1} X_l[k] \psi_{l,k}(t) \right\} \right\} \quad (4)$$

and

$$x_l(t) = \sum_{l=0}^{\infty} \sum_{k=0}^{N-1} X_l[k] e^{j2\pi f_k(t-lT_{sym})} \quad (5)$$

When $t = lT_{sym} + nT_s$, $T_s = T_{sym} / N$, $f_k = k / T_{sym}$, OFDM symbols can be obtained corresponding to the discrete time, by using the Equation (4) and (5) to sample the signal.

$$\begin{cases} x_l[n] = \sum_{k=0}^{N-1} X_l[k] e^{j2\pi kn/N} \\ n = 0, 1, \dots, N-1 \end{cases} \quad (6)$$

It proved that Equation(6) is the N points IDFT of the PSK and QAM data symbol $\{X_l[k]\}_{k=0}^{N-1}$, and it can be calculated by using the IFFT algorithm.

Considering the OFDM baseband received symbols $y_l(t) = \sum_{k=0}^{N-1} X_l[k] e^{j2\pi f_k(t-lT_{sym})}$, $lT_{sym} < t < lT_{sym} + nT_s$, the original transmitted symbols $X_l[k]$ can be reconstructed by using the orthogonal properties of the carrier in Equation(1).

$$\begin{aligned} Y_l[k] &= \frac{1}{T_{sym}} \int_{-\infty}^{\infty} y_l e^{-j2\pi k f_k(t-lT_{sym})} dt = \frac{1}{T_{sym}} \int_{-\infty}^{\infty} \sum_{k=0}^{N-1} \left\{ X_l[k] e^{j2\pi f_k(t-lT_{sym})} \right\} e^{-j2\pi k f_k(t-lT_{sym})} dt \\ &= \sum_{i=0}^{N-1} X_l[i] \left\{ \frac{1}{T_{sym}} \int_0^{T_{sym}} e^{j2\pi(f_i-f_k)(t-lT_{sym})} dt \right\} = X_l[k] \end{aligned} \quad (7)$$

Equation (7) does not consider the influence of the channel and the noise. $\{y_l[n]\}_{n=0}^{N-1}$ is the received symbol $y_l(t)$ of OFDM when sample time are $t = lT_{sym} + nT_s$. In Equation (7) the modulation process can be expressed in discrete time form as follows:

$$\begin{aligned} Y_l[k] &= \sum_{n=0}^{N-1} y_l[n] e^{j2\pi kn/N} = \sum_{n=0}^{N-1} \left\{ \frac{1}{N} \sum_{i=0}^{N-1} X_l[i] e^{j2\pi in/N} \right\} e^{-j2\pi kn/N} \\ &= \frac{1}{N} \sum_{n=0}^{N-1} \sum_{i=0}^{N-1} X_l[i] e^{j2\pi(i-k)n/N} = X_l[k] \end{aligned} \quad (8)$$

In face the Equation (8) is N points DFT of $\{y_l[n]\}_{n=0}^{N-1}$, it can be calculated effectively using FFT algorithm.

In the advanced OFDM system, during the modulation and demodulation processes the protection interval between the symbols is needed to make the pulse with different length easy to be identified. The protection intervals, being commonly used, are zero postfix (ZP), cyclic prefix (CP) and cyclic postfix (CS) methods. Figure 3 illustrates the OFDM signal structure with CP and CS, and T denotes the time span.

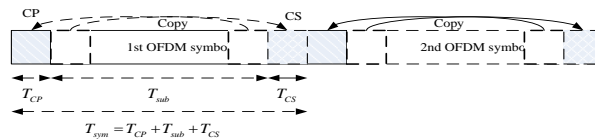


Figure 3. OFDM Symbol with CP and CS

The power spectrum is the sum of many frequency shift functions with relatively large power, leading to cause adjacent channel interference (ACI) [10]. In order to reduce the ACI, a protective tape is required in OFDM system. As shown in Figure 4, the OFDM symbols use the RC window method to reduce the power loss. When the roll-off factor β of RC window increases, the excessive part of the signal becomes smoother, it will extend the interval and effectively reduce ACI.

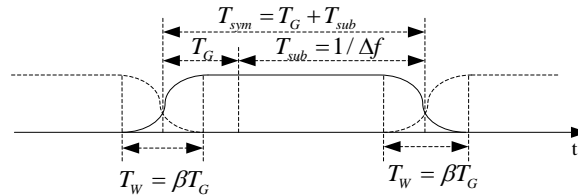


Figure 4. OFDM Symbol with RC Window

4. Experiment and Data Analysis

This simulation is to test the OFDM DC-PLC communication system, all parameters of this experiment are set as follows: the number subcarriers is 16, the number of symbols for each subcarrier contains 8 bits per symbol, which is 4; The input of the system using 16QAM modulation generate bit stream with a 512 point FFT and IFFT transform; In common the protection interval is 1/6~1/4 of the OFDM data; The equivalent of the CP length is 128; The RC window the roll-off factor is 1/32 and the CS length is 20; Set the signal-to-noise ratio 15. The number of binary bits send in the simulation is 512, equivalent to the current 512 bit modulation.

Figure 5 shows the time domain waveform signal after the IFFT transform. It illustrates three type OFDM symbol waveforms. The first signal for the original OFDM symbol waveform, the second shows the OFDM symbol with CP and CS added waveform. The third waveform displays the symbols added RC raised cosine window waveform based on the second, it is clearly to see the amplitude of the waveform are weakened at both ends.

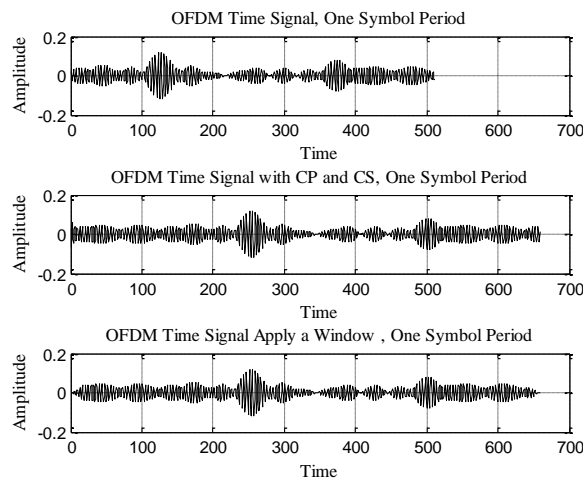


Figure 5. OFDM Symbol Waveform (Original, CP CS added, Windowed)

The whole signal shows in Figure 6. The first subplot shows the data stream with window, the CP and CS do not produce cycle superposition phenomenon. The second subplot shows the opposite. From the spectral distribution point of view, the data stream without the window cause much higher power loss, as shown in Figure 7.

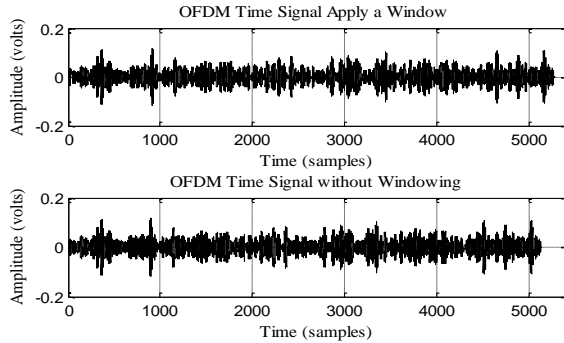


Figure 6. OFDM Waveform (Window and without Window)

The environmental noise in the well is simulated by adding the normal distribution sequence whose signal-noise ratio is 15. The useful signal matrix can be calculated after the conversion of the received data stream and remove the CP and CS part. Using the FFT transform, the sub carrier signal end could be remapped.

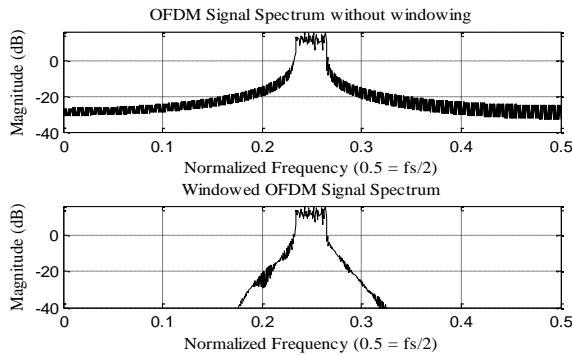


Figure 7. Power Spectrum of the OFDM Symbol

Finally after the 16QAM decoding, we can obtain the output data. As shown in Figure 8.

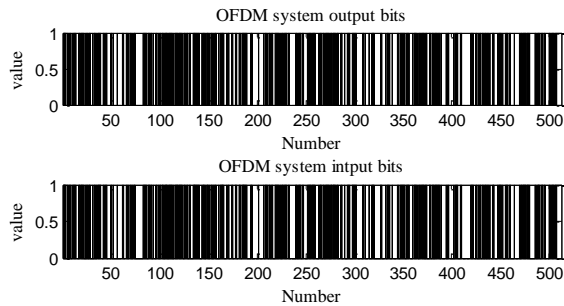


Figure 8. Input / Output Results of the Experimental Test

The first subplot displays the received data and the second shows the sending data. It is clear to see the data consistent with each other, while the bit error rate and the wrong bit number are both zero. This simulation proved that the simulation system is stable and accuracy.

5. Conclusion

Most multi-layer water injection wells in China are being operated in very complex circumstances, which result that the direct application of the common PLC equipment in communication process has some disadvantages such as high noise inference and bit error rate. This paper proposed a novel DC power line carrier communication technology, the overall structure and algorithm of the system in detail. Using experimental test proved the advantages of this technique which has high anti-noise ability and low error rate.

In sum, this novel DC power line carrier technology provides a reliable technical support and accurate data insurance for optimization of water injection process and dynamic parameter monitor model.

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