Design and application of multi-channel simultaneous detection system for well-earth potential

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Abstract
Well-earth ERT (electrical resistance tomography) technology is an important geophysical exploration method which studies the location distribution of remaining oil. Based on virtual instrument technology, the author designs a set of multi-channel simultaneous detection system. It adopts multi-channel simultaneous sampling, bipolar and differential inputs, analog LPF (low pass filter), FIR digital filter, and linear accumulated digital averaging method or techniques to suppress electromagnetic noise and improve SNR (signal-to-noise ratio); uses digital signal process method to remove the overshoot, avoided huge errors and improved accuracy of measurement; adopts feedback compensative method to exclude the influence of SP(spontaneous potential) and cover a wide dynamic measurable scope; spectrum analysis method is used for judging all electrodes earthing situation correctly; the USB2.0 technique is used to solve the problem of bulky multi-channel data transmission to achieve high-speed data transmission between hardware and PC. The Liao He oilfield survey results show that the system is characterized with high efficiency, portable and strong antijamming capability.

PACS

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1. Introduction
At present, most of oilfields have entered into the period of the high-cut-water. Hydraulic fracturing is an important way to open up oilfields and find the remaining oil in this period. There are few tools used to directly measure the major parameters of the hydraulic fractures and affect the causes of analyzing the results of hydraulic fracturing and the advance of water injection propelling. In 1987, Shima first put forward the word “resistivity tomography (RT)” and the method of inversion interpretation [1]. Around 1992, worldwide study on the theory and technology of “resistivity tomography (RT)” made a breakthrough (Shima, 1990; Sasaki, 1992; Barker, 1992) [2-4]. Resistivity tomography has distinctive advantages: source of the field is easy to find and implement, has no
destruction to the site, high resolution (compared with normal resistivity) deep penetration (compared with electromagnetic wave CT), economic but practical (compared with seismic wave CT). Therefore, well-earth ERT technology is suitable to measure the major parameters of the hydraulic fractures.

2. System principle
Its underlying principle is the technique by which a strong current is applied to the casing of the waterflood input well on the surface of the earth, the current floods to layer through the earth surface consolidated well segment without cement and perforation interval, forms a non-uniform field in underground layer, and changes the potential distribution of the earth surface. The theoretical formula of finite line source in homogeneous full or half-space is shown as in (1).

$$V_p = \frac{\rho l_1}{2\pi(l_2 - l_1)} \int_0^{l_2} \frac{1}{\sqrt{(z - z_p)^2 + r_p^2}} dz$$

(1)

$$= \frac{\rho l_1}{2\pi(l_2 - l_1)} \ln \left\{ \frac{l_2 - z_p + \sqrt{(l_2 - z_p)^2 + r_p^2}}{l_1 - z_p + \sqrt{(l_1 - z_p)^2 + r_p^2}} \right\}$$

Where, \(\rho\) — stratum apparent resistivity
\(l_1\) and \(l_2\) — top and bottom embedded depth of current supply casing
\(z_p\) — embedded depth of survey point
\(r_p\) — radial distance between survey point and linear source
\(I\) — strength of supply current
\(V_p\) — potential of any point \(p(r, z_p)\)

It reflects underground resistivity distribution by measuring the electrical potential distribution of the earth surface [5]. Therefore, associating the distribution of the underground layer precipitation facies, lithologic characteristics and stratum water salinity, it could make qualitative and semi-quantitative research on propelling front edge of water flooding and the distribution of underground layer residual oil and gas by making use of the resistivity differences [6].

Usually, with the detected-well as center, it measures from inner to outer part at a regular interval. Each time it detects well-earth potentials at 18 measuring points where situated at the same circle and distributed evenly in 360 degrees, as shown in figure 1.

![Practical survey mode sketch map](image)

Figure 1. Practical survey mode sketch map.

3. Structure of the system and key techniques

3.1. Structure of the system
Detection system is designed based on virtual instrument technology. Virtual instrument technology is the product of computer technology, measurement and control technology and electronic technology. It indicates the developing direction to the science instruments. The entire system is composed of hardware and measurement and control software in PC. Under controlling of software, hardware acquires signal from the electrodes. The USB2.0 technique is used to solve the problem of bulky multi-channel data transmission to achieve high-speed data transmission between hardware and PC. Data analysis, potential calculation, spectrum analysis, display and storage are completed by the measurement and control software.

3.2. Interference suppressing
What is the effect of geophysical exploration method used in field? The anti-jamming ability is one of the key factors.

Detection system adopts multi-channel simultaneous sampling ADC to sample with 18 fully differential input channels at the same time in order to suppress the electromagnetic noise and improve efficiency of field work.
Since input signal is bipolar, preamplifier adopts bipolar input and single-ended output. It means that there is no signal passing through ground when a signal is applied between two input wires. When the CMN (common mode noise) between two wires is suppressed by instrument amplifier, only bipolar signal is amplified, therefore restricts noise validly.

50Hz industrial interference is the main noise source, the scheme of analog fourth-order active LPF exposes a preliminary suppression on the industrial noise and attenuates near 40dB. FIR digital filter in the measurement and control software could be set as different types, orders and windows. It suppresses industrial interference, goes a step further and reaches to 63dB.

Beyond 50Hz interference, there are many kinds of incidental interference. Digital average method can suppress noise, therefore improve SNR. According to $\sqrt{N}$ principle, when polluted noise is white noise, $SNR=SNR_0/SNR_i$ ($SNR_0$ is signal noise ratio of output signal after accumulative, $SNR_i$ is signal noise ratio before averaging). Accumulative mean of $N$ times of sampling data at different times brings on improved $SNR$ by $\sqrt{N}$ times. Due to the mean of $N$ sampling data is calculated by computer, linear accumulate average method is adopted. The mean could be demonstrated as in (2) [7].

$$A(N) = \frac{1}{N} \sum_{n=0}^{N-1} x(n)$$ (2)

3.3. Processing of the signal with overshoot
Because of transmit system itself, signal passing through the earth and electrodes poor earthing and so on, overshoot may be present in the detection system signal. It influences veracity seriously and must be wiped out. In view of measurement signal overshoot phenomena, the system uses digital signal process method to avoid serious errors, and improves the accuracy of measurement.

For a set of data $X_0$ with sampling rate $f_i$ and sampling number $n_0$, in order to get rid of redundant data at the end of $X_0$ firstly, then receive $X_i$, assure $X_i$ has integer-period samples $n_i=[n_0 \times f_i^{-1}] f_i$ ( [ ] denotes round numbers operate). The absolute value of $X_i$ is $X_2=\{x_0, x_1 \ldots x_n\}$. Choose $r$ as the width of the window. Let

$$M_0 = x_0 + x_1 + \cdots + x_{r-1}$$
$$M_i = x_i + x_{i+1} + \cdots + x_i$$ \hspace{1cm} (3)
$$\vdots$$
$$M_{n-r} = x_{n-r} + x_{n-r+1} + \cdots + x_n$$

As in (3), suppose $M_m$ ($0 \leq m \leq n-r$) is the minimum value among $M_0 \ldots M_{n-r}$, so $M_m$ is the nearest $M$ to zero and its midpoint $m+r/2$ can be recognized as the nearest $x$ to zero. $(m+r/2)/f_i$ is the beginning position of complete period. Combine $f_i/4$ sampling data from the mid position of positive and negative semi-period, that is, wipe out overshoot from original signal, and thus obtain the relative smooth signal.

3.4. SP exclusion
SP, polarized potential and poor earthing interfered with normal measuring. The main interference is SP, and the second important is polarized potential on electrodes (include polarized potential during the process of alternant power supply and measuring). System regards accumulative summation of all kinds of potential mentioned above as SP [8]. Influenced by SP, the different degree DC offset exists in acquired signal. It drives up or recedes signal, leading to signal amplitude overstep dynamic measurable range of the detection system. To solve this problem, the system designs feedback compensative circuit in hardware. Upper PC software figures out DC offset, then feed them back to conditioning circuit, therefore counteract DC offset, and the signal is always in the dynamic measurable range.

3.5. Electrodes earthing situation detection
In fieldwork, the differences of earthing conditions are significant; the electrodes are sparsely and distantly disposed, therefore the system must detect all electrodes earthing situation before working.

Signal is amplified to a suitable range, and then its spectrum is analyzed. The frequency of Transmit signal is known, so earthing situation can be detected by judging whether the frequency matched or not.

The front-end of the System adopts bipolar and differential input mode, so signal may
interfere with other channels through the reference electrode, and electrodes earthing situation detection produced errors. Put reverse end of input channel on to system ground, bipolar input changes into single-ended. It could keep signal not interfering with other channels when the system detected and got the correct information of electrode earthing situation.

3.6. USB2.0 communication mode
It is required that system was portable in fieldwork and transform data at a high speed between system and computer. Moreover, the system is designed based on virtual instrument, so the design adopts USB2.0 technique to realize communicating between hardware and measurement and control software. This design not only solves the problem of bulky multi-channel data transmission, but also directs the operations of entire system such as control, data acquisition, analysis, display and storage to complete based on measurement and control software in PC. It has favorable modifiability and expandability and shows decided superiority and strong vitality of virtual instrument technology.

4. Application example

4.1. Field work execution method
Make the casing of the waterflood input well the power supply electrode A, earth surface electrode beyond 1500 meter away from the well the circumfluence electrode B. Reference electrode N situates near the observation center. For straight well, take the mouth of the well as observation center. For deviated well, take projection point of the objective layer as observation center. It adopts radial observation system whose angle between each two adjacent survey lines is 20 degree. Dispose 18 radial lines around the well. There were 9 measuring points on each survey line and 50 meters between two points, as shown in figure 1. Detect separately in the same area before and after the fracturing of waterflood well.

4.2. Measurement result
System was applied to Hao63-51 well. Well-earth potentials were detected separately in the same area before and after the fracturing. Figure 2 is the potential isograms plots drawn from the measurement results before fracturing tests. Figure 3 is the potential isograms after fracturing tests. The grid origin is the well position. The comparison of two pictures shows clearly the change of potential around waterflood well before and after fracturing. High potential distribution areas of figure 3 indicate the propelling front edge of water flooding.

5. Conclusion
This paper has described the multi-channel simultaneous detection system for the measurement of well-earth potential, and laid
stress on introducing some key techniques of the system, such as interference suppressing or SP exclusion. Compared with the traditional instrument, well-earth potential detection system based on virtual instrument can measure well-earth potential from 18 channels simultaneously. Large scale simultaneous data sampling and real-time transmission have increased the detection efficiency substantially. With the data increasing, well-earth potential information has become more abundant correspondingly. It has laid the foundations for well-earth ERT technology. Oilfield applications showed that the system is characterized with high efficiency, portable and strong antijamming capability.

References

[1] Shima H and Sakayama T. 1987 Resistivity tomography: An approach to 2-D resistivity inverse problems[J]. Expanded Abstracts of 57th Annual Internat SEG Mtg (New Orleans), 204–207

[2] Barker R. 1992 A simple algorithm for electrical imaging of the sub-surface[J]. First Break 10(2):53-62

[3] Shima H. 1990 Two-dimensional automatic resistivity inversion technique using alpha centers[J]. Geophysics 55(6):628-94

[4] Sasaki Y. 1992 Resolution of resistivity tomography inferred from numerical simulation[J]. Geophysical Prospecting 40:453-63

[5] Zhou Q, Becke A and Morrison H F. 1993 Audio-frequency Electromagnetic Tomography in 2-D[J]. Geophysics 58(4):482-95

[6] Hoversten G M, Newman G A and Morisson H F et al. 2001 Reservoir characterization using crosswell electromagnetic inversion: A feasibility study for the Snorre field, North Sea[J]. Geophysics 66(4):1177-89

[7] Gao Jin-zhan 2004 Detection of weak signal (Beijing: Tsinghua university press) pp 226-33

[8] Li Zhi-wu, Zhou Yan-yun and Feng Rui 2004,4 Data-collecting system for resistivity tomography[J], Progress in geophysics 19:812-18