Optimal High-Voltage Generator Design for Electropulse Drilling of Deep Wells

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Abstract. In this paper we analyzed the existing schemes of high-voltage generators, which can be used in electric pulse drilling for finding the most optimal design. To determine the criteria that such a generator should meet, a detailed review of existing electric pulse drilling technologies was carried out. It showed that downhole generator is most effective way for drilling deep wells. The creation of such type generator is greatly hampered by many factors. By analyzing these factors, we have formulated the basic requirements for high-voltage generator. After comparing the strengths and weaknesses of existing oscillator circuits, the downhole generator optimal design was chosen.

1. Introduction
Finding and development of technology to provide reliable and environmentally friendly energy sources is one of the main tasks of modern power. Therefore, many countries have projects for the alternative energy sources development such as solar, wind, tidal, geothermal, fusion. The geothermal power which is based on use of heat taken from Earth crust is most attractive by ecological, technological and economic reasons. According to the expert research, one well with a diameter of 500 mm and a depth of 8-10 km can provide continuous stable power of 1 MW of electricity and 8 MW of thermal energy for an unlimited time [1].

However, drilling of such a deep well by traditional drilling methods is economically inexpedient. The most effective alternative to a traditional rotary drilling method, according to the world scientific community,[2] is electropulse drilling which theoretically has higher penetration rate and less expensive in comparison with all other known drilling methods.

The effect of electropulse destruction of solid material was discovered in the 20th century. It consists in applying an electrical pulse with a big pulse rise rate (this value depends on the parameters of the dielectric fluid and solid). Process of destruction is divided into three main stages (Figure 1a).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{The effect of electropulse destruction of a rock: a – stages of destruction process, b – temporary conditions for the destruction.}
\end{figure}
Creating an efficient generator for electric drilling is a difficult technical task. The choice of the generator optimal architecture is the key to successful solution of the problem.

2. Review of the existing technologies for electropulse drilling

Previously developed generators for electric pulse drilling technology were designed by the well-known Marx voltage-multiplying circuit. According to the technological scheme of the electropulse drilling rig [3] (Figure 2a), Marx’s generator is on the surface, and a voltage pulse is applied to the drill head through long current conductor. This technology is quite simple: it is possible to use a lot of space for the generator, easy to find and repair.

![Figure 2](image)

Figure 2. Technical plan of the electropulse drilling: a – with the land generator, b – with the downhole generator. 1 – drilling bit, 2 – high-voltage generator, 3 – current conductor, 4 – mud system.

However, it is obvious that with increasing depth of drilling increases the length of the current conductor. This leads to increased energy loss and smoothing of the pulse front. With decreasing pulse rise time, the probability of the discharge arc penetrating into a solid and the efficiency of this method decreases significantly. And when the pulse rise time is less than a certain criterion line (Figure 1b), the arc penetration effect completely disappears.

The second way to implement pulse drilling - using a downhole generator (Figure 2b). Such a generator is placed in the borehole and drive into the ground. This method allows you to drill deep without significant energy dissipation for transportation of energy. The pulse shape of the downhole generator remains constant at any depth, since the formation of a high-voltage pulse occurs close to the bit. Therefore, the volume of the broken rock remains almost constant at any depth of the well. Placing high-voltage equipment in the well minimizes the amount of ground-based high-voltage equipment. This increases the safety of drilling operations. The disadvantages of this technology are the complexity of designing a high-voltage generator. Therefore, it is necessary to conduct a thorough
analysis of existing oscillator circuit to identify the most feasible and effective high voltage generator design.

3. Existing design of downhole generators
Currently, there are several large-scale projects to develop a submersible generator for rock drilling. All these projects use different designs of the generator.

3.1. Downhole Generator Based on the Marx Design
Creating a small-sized Marx generator is a logical continuation of existing operational plant (Figure 3a). M. Voigt et al.[4] describes the design of such a generator and gives some test results. This type of generator is well known and has several advantages such as:

- A possibility of pulse parameters variation by selecting the required number of stages and capacitance
- Long output pulse of generator, which has a positive effect on the volume of the broken rock.
- Ease of operation.

However, the Marx generator has a number of disadvantages due to the design. With an increase in the number of stages the number of spark gaps also increases. Large generator internal resistance reduces the energy released in the load, which reduces the efficiency. Reliable operation requires a complex and massive insulating structure that can isolate high voltage. A large number of circuit elements dramatically reduce the life of this device. Scaling of this generator circuit aggravates identified drawbacks.

3.2. Downhole Generator Based on a Pulse Transformer
The possibility of using a pulse transformer for rock drilling was confirmed [5]. The main advantage of this design compared to Marx generator - it does not require complicated insulating structures. Therefore, it is possible to reduce the size of the generator and get a small-sized device. Currently in Russia there is a project for the development and improvement of the pulse generator based on the pulse transformer [6](Figure 3b). According to this study, all the components of the generator can be placed in a single case, the diameter of which will not exceed 500 mm. As it is known that the process of destruction is divided into two stages (Figure 1b), the use of two power sources (C1 and C2) allows you to increase the efficiency of energy deposition in the discharge channel [7].

3.3. Downhole Generator Based on a Linear Pulse Transformer
The possibility of using a linear pulse transformer (Figure 3c) for destruction of rocks was confirmed in Ref. 8. This generator is compact and can be placed in a well with a diameter of 300 mm. Linear pulse transformer (LIT) generator shows the possibility of using two power source to increase the efficiency of drilling. Compared to the design of a pulse transformer, the LIT generator consists of a smaller number of circuit elements, which increases its reliability.
4. Discussion
Analyzing the existing methods of well production, we can conclude: the use of a downhole generator is the most effective method for drilling deep wells. However, implementation of such an approach requires the development of a new type of high-voltage generator. Such a generator must meet the following requirements:

- Small dimensions, for installation of all elements of the generator in a limited space of the well.
- High reliability. This will reduce the number of round trips and reduce the cost of drilling.
- High drilling efficiency

Based on these qualities, it is possible to analyze the designs of high-voltage generators presented in the previous chapter. All mentioned generators can be compactly placed in a well with a diameter of less than 500 mm. Comparing the Marx generator with the generators based on a pulse transformer and LIT, it can be noted that a lot of surge gap are involved in its design. Need of adjustment accuracy of each spark gap creates high risk of failure of the entire generator. According to the presented schemes Figure 3b and Figure 3c the design of LIT generator is the simplest. It does not use a three-electrode gas switch, and the high-voltage winding of the transformer works as a magnetic key. Since the reliability of the circuit directly depends on the number of its elements, it can be concluded that the LIT generator has the greatest lifetime.

Comparing the efficiency of drilling, it can be noted that the output parameters of the Marx generator cannot be optimized for the destruction of various types of rocks. Changing the pulse parameters means changing the parameters of all structural elements of the generator. In pulse transformer and LIT generator designs, the output parameters of the pulses can vary over a wide range without changing the circuit elements. Therefore, impulse parameters can be customized to each type of a stone.

It should be noted that due to the peculiarities LIT generator circuit has a small internal resistance (approximately 0.36 Ohm) that increases the amount of power released in the load and increases efficiency of the scheme.

Summarizing, we can conclude that designs of the generators based on pulse transformer and LIT are the most suitable for creating an immersion generator, but due to the greater reliability of the LIT generator is optimal for electropulse drilling of deep wells.

5. Conclusion
In this work the main problems of deep wells drilling by an electropulse method were analysed. Since the smoothing of the pulse limits the maximum depth of the well, the downhole generator type was chosen. The main requirements to such type of generators allowed to estimate the existing oscillator circuit. Comparing the advantages and disadvantages of these schemes, we confirmed the benefits of using the design of the generator based on a pulse transformer and LIT. But comparison of these two designs showed that scheme with the LIT generator has simpler and reliable structure. Development of this type of generator will allow to realize electropulse drilling of deep wells for geothermal energy.

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7. References
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