All Sciences Proceedings
http://as-proceeding.com/

1st International Conference on Contemporary Academic Research
May 17-19, 2023 : Konya, Turkey

ICCAR
https://as-proceeding.com/index.php/iccar

An Overview of Downhole Electrical Machines and their Benefits

Danish Nouman*, Mian Farhan Ullah [2], Syed Hammd Haider [3], M. Bilal Khalid Keyani [4]

[1]Electrical/University of Engineering and Technology, Taxila, Pakistan
[2] Electrical /University of Wah, Pakistan
[3] Electrical / CECOS University, Pakistan
[4] Electrical / University of Wah, Pakistan

*(danishnouman1@gmail.com)

Abstract **–** New technology to the deeper offshore areas and to the exploitation of deep offshore reserves and deep offshore reserves must offer safe, economically viable and ecologically acceptable solutions to increase oil and gas recoveries. The use of electricity in downhole applications has shown to be beneficial. This article discusses the advantages of electrical machines in downhole applications that are already available or developing. For downhole applications, permanent magnet devices are mostly used.

Keywords – Induction Motor, Permanent M agent Motor, Positive Displacement Motor, Drilling Motor

I. Introduction

In the coming decades, many of the growth in gas and oil output will come from two sources: expanding older fields and developing deep and ultra-deep water stock or reservoirs [1]-[3]. Currently, the production in ageing is gradually declining and the fields will be constantly closed if new technologies and facilities are not applied to better recovery and less costly management and care [4]. The price of preferred constant or buoyant processing provision for deep offshore gas & oil deposits, that are presently broadly used, skyrockets. As a result, the development of many deep-water resources may be uneconomical. Topside processing through methods of transfer or onshore to downhole, may typically improve production and treatment performance, even if environmental impacts are reduced [5]-[6]. Pressurized gas, mechanical roll connection, hydraulic and electrical systems are genuinely utilized to strength downhole packages from the top [7]-[8]. Deep wells, particularly deep-water offshore wells, have proved to be potential for electrically bottom-driven downhole applications, which are currently being exploited [9]. The benefits of electrical machines in currently extant and developing downhole applications, as well as the brand new fashion for electrical downhole machines, are mentioned in this research.

II. Use of Electrical Machines in Downhole

A. *Subsurface Valve (SSV)*

The contemporary electro-hydraulic SSVs and hydraulic SSVs in addition to rising electric powered cable subsurface valves and destiny cable-free electric powered SSVs as shown in Fig 1. Two hydraulic lines are required for every valve. Simple and easy valve designs & well-proven technology & methodology are advantages of this method [10]. The primary issue is that lengthy hydraulic lines have a poor reaction time [11]. An electro-hydraulic device can circumvent these dangers by utilizing electric indications or signals to change signal pressure supply to shuttle control valves, therefore starting hydraulic strength to carry out the operation of the device. This technique increases reliability, shortens the reaction time and reduces the necessary number of lines compared to only hydraulic systems. SSV constructions are seeking for hydraulic as well as electrical units (HPU) [12]. A large amount of top space is needed for the hydraulic power unit (HPU), which is crucial for offshore applications. Moreover, because of high fluid leaking rates, non-hydraulic lines ran between the surface and the control settings often fail, but they also cost a great deal to install. As Fig. 1, 1 c and d demonstrate. High-torque electrical motors are used to drive the valves, resulting in faster reaction times and a large volume of the HPU at the top. (The pipes are utilized for transportation signals and power during the development of electronic cable and cable less electric SSVs. Electric SSVs provide a number of advantages [13]:

- Mechanical strength, tension or compression in the tube should not be involved in operating the valve.
- The valve, independent of tube or wellbore pressure, may move in any position whether the tube is under stress or compression.

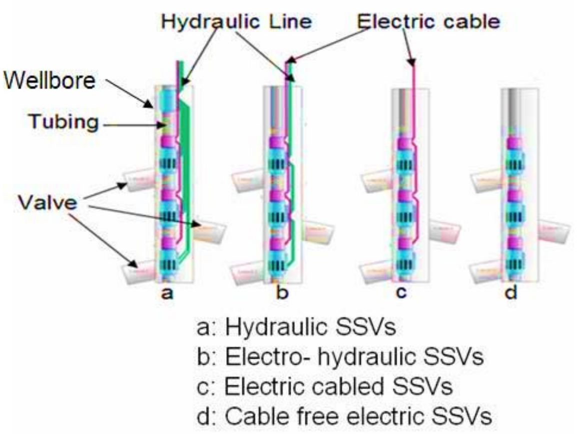

Fig. 1. SSV technologies [14].

B. *Progressing Cavity Pumps and Driving Rod Pumps*

Production of petroleum by means of a surface motor through a long flexible stain system has long been acknowledged as inefficient, utilizing sucker rod pumps or progressive cavity (PCs) [15]-[16]. Pumps and the rod that links them to the downhole pump are not only expensive, but the rod grinds against the tubing in several places & breaks frequently since most wells are not precisely "straight." The above-described disadvantages may readily be solved by employing downhole electric linear motors to drive rotary pumps and rotating electric motors to drive progressing cavity pumps. Electrically mounted pumps not only take away the problem of rod breaks and reduce tube wear significantly, they also improve production by avoiding the necessity of connections, centralizers and rod strings that surface-mounted pumps require [17]. Fig 2 shows the schematic diagram of PC Pump. The tube flow loss simulated for a progressive PCP and a PCP rod-based electrical divergent pump is illustrated in Fig. 3.

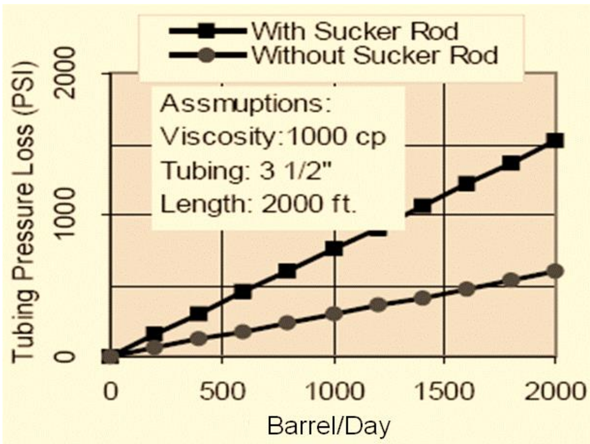

Fig 2: Schematic diagram of PC Pump.

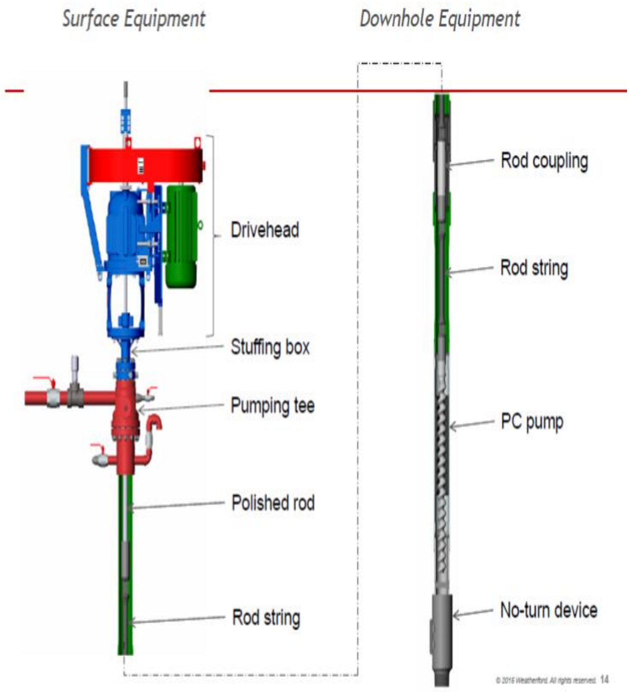

Fig. 3. Tubing flow losses [18].

C. *Driving Downhole Gas Compressors*

The goal of the Downhole Gas Compressors is to improve the gas pressure by placing a compressor in proximity to the gas tank source [19]. In addition to normal centralized gas compression, this can lead to considerable savings in hydrocarbon recovery. A software simulation graph for prospective downhole gas compression output improvements [20] is presented in Fig. 5. For these applications, shaft speeds of 5,000 to 20,000 rpm are needed, far more rapidly than the rated rates of conventional induction motors (IM). Standard electric motors should be connected to a speed-growing gearbox to achieve application speed. This is also a difficulty since building a dependable gearbox in such a small borehole diameter is both difficult and costly. A high-speed PM motor was built and tests for downhole gas compressors were carried out for the removal of the gearbox system, as illustrated in Fig. 8.

Some of the advantages of a PM-powered compressor [21] are:

- More compact
- Improved dependability
- Improved output

D. *Drilling Motor*

In many boiling services, positive displacement motors supply downhole power (PDMs). The PDMs are, on the contrary, disadvantaged, including short motor life, negative overall high-temperature performance, and limited drilling materials, so the fluid programmer has to be compromise between boiling and training requirements [22]. Boiler and training requirements. This reduces the efficiency of PDMs in many cases, whereas an electric drilling engine is a more efficient and reliable option. The two types of PM boilers [23]-[24].

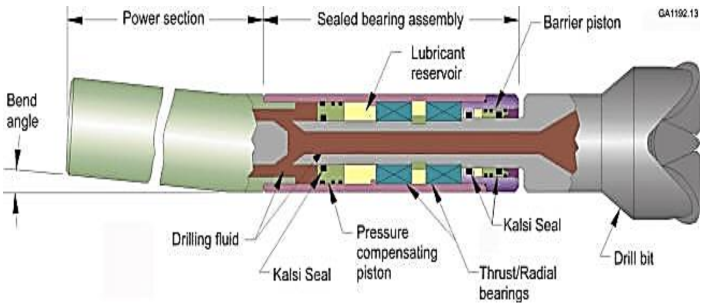

Fig. 4. Downhole Drilling Motor

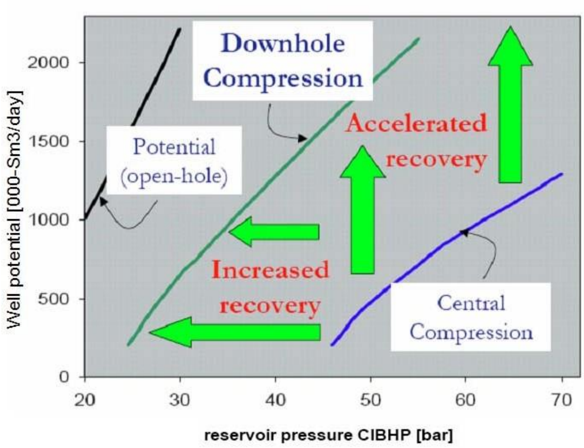

Fig. 5. Downhole gas compression potential to enhance yield [25].

Electrical drilling has a number of advantages [26]-[27]:

- Increment in the dependability of drilling motor increases the period between drilling string failures & lowers drilling expenses.
- A direct control operator shall keep the drilling bit speed independent of the flow rate of fluid, therefore enhancing the control and flexibility of the Bottom Box assemblies.
- Suitable for a greater variety of drilling circumstances, especially for deep-water activity. Electrical engines, like energy-efficient fluids, can use different boiler media than PDMs.
- This makes it excellent for aggressively underbalanced drilling and in deep-water operations. Electrical motors, as opposed to PDMs, can drill with a larger variety of drilling media, including electrified fluids. Electrical motors are suitable for vigorous under-balanced drilling and deep-water activities because of this.

- With new materials, electrical motors may withstand temperatures of up to 200°C.
- A higher penetration rate is possible.

E. *Downhole Generator*

Batteries, usually lithium-ion batteries with a limit of 180°C [28], provide the most downhole equipment today. The instrumented BHA is essential for very deep wells, but battery life and greater downhole temperatures limit its utilization. The most feasible and promising approach to power smart downhole in high-temperature conditions is to have the turbine generator, which uses the hydraulic energy to transfer rotor electricity through electrical generators (HPHT) [29]. Power supplied by an HTHP downhole generator has the following advantages [30]:

- Reliable in HTHP configuration.
- Deep well suitable.

F. *Intervention Tools*

Aside from the uses listed above, electrical motors can be used in conjunction with a variety of other downhole intervention instruments [31]. Typically, these electric motors have a smaller power range but a high yield torque, and their properties are highly depending on the application.

III. Standard Induction Downhole Machines

Due to the difficult environment and the excessive costs of the replacement of failure in offshore down-holed applications, a strong or robust structure and the remarkable reliability of the electrical downhole device should be available. The three-phase squirrel cage induction motor (IM) is now the standard electric downhole motor, due to its high reliability, durability and easy production. Fig 6 shows the building of a common downhole induction multi-rotor motor. The stator is wrapped as a single unit, to match the slender construction, but the rotor consists of a large number of electrically distinct rotors and there are bearings between them. Oil-filled downhole engines are frequent and the low compressibility of the oil enable them to resist strong external downhole pressure. It also provides bearing lubrication as well as an effective heat transmission for radially external loss dissipation via the motor case. The outside diameter often ranges from 100 mm to 300 mm and the length is normally from 5 to 10 m, although it can reach up to 20 meters or more. The most usual power supply is from 40 to 200 kW. More power may be acquired by adding more motors. Typically, operating temperatures are limited to 180°C, however some properly constructed engines may handle temperatures up to 218°C. Their efficiency ranges from 70 percent to 89 percent for high-speed applications, and from 60 percent to 73 percent for low-speed, high-torque applications (see Table 1). Induction motors, on the other hand, are unsuitable to low-speed and high-torque applications, such as driving PCPs. As a result, most modern systems use a gearbox to match the motor's normal running speed and torque to the characteristics of the pump. Not only is the reintroduced gear system more expensive and complex to produce, but it also decreases the system's overall efficiency.

IV. Current New Downhole Machines

The machines used in the past to replace conventional machines in industrial applications have almost the same strength and reliability as standard induction motors, but higher efficiencies, higher torque densities, smaller volumes, but few were developed for downhole high and high temperature (HPT) applications because of PM materials [32]. The oil and gas industries are increasingly interested in creating PM machines for down-hole applications through the development of advanced technologies with the usage of high temperature magnets. According to the research [33], PM downhole engines consume 23% less energy on average than IMs. Table 1 demonstrates that the efficacy of PM motors in high-speed applications is considerably higher than in IMs, with 91-9 3% and 85%-89% in high torque applications. Furthermore, PM motors may produce strong torque across the whole operating range, including start-up. A brushless PMDC downhole motor is shown in Fig 7. Its speed is controlled by the top-side adjustment of the DC current without VSD. As a consequence, this sort of engine serves mostly onshore applications.

Table 1. Comparison of the Efficiency of Downhole Motors

Company	Motor Type	Efficiency	Application
Borets	**IM**	**77-85%**	**Driving ESP**
Borets	**IM**	**60-73%**	**Driving PCP**
Woodgroup	**IM**	**70-89%**	**Driving ESP**
Borets	**PMDC**	**91-93%**	**Driving ESP**
Borets	**PMDC**	**85-89%**	**Driving PCP**
(Research)	**PMSM**	**95%**	**Driving PCP**
(Research)	**PMSM**	**92%**	

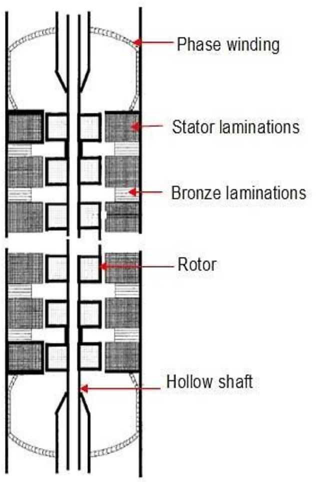

Fig. 6. Typical construction of a multi-rotor induction engine [34].

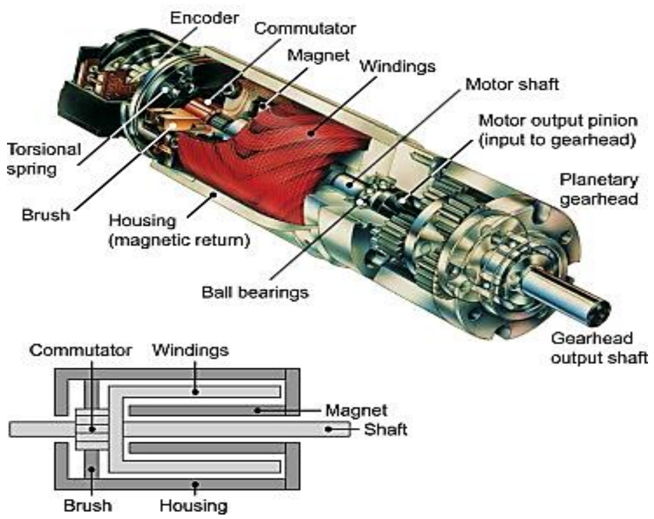

Fig. 7. A PMDC downhole engine/motor [35].

Down-holes for the synchronous magnet permanent magnet (PMSM) and the magnet brushless permanent (BLDC) machine have become popular as a result of enhancements in VSD technology [36]. A high torque, BLDC capable of withstanding temperatures up to 230°C has been designed and tested for electro-boiling [23]-[24]. The engine has a length of 2.7 and a diameter of 80 m. The torque is 420 Nm and its highest output is around 20 kW. A high speed brushless downhole gas compression DC engine is presented in Fig 8 [20]. The 10-pol PMSM installed inside is displayed for driving PCPs in Fig 9. In [37], the PM machine for downhole applications have a lot of potential, but it's still in its early stages.

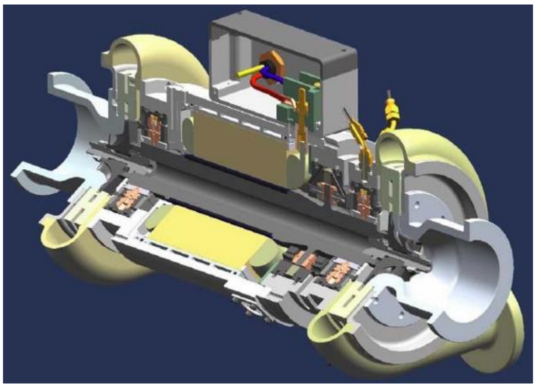

Fig 8: A BLDC downhole motor with a high speed [20].

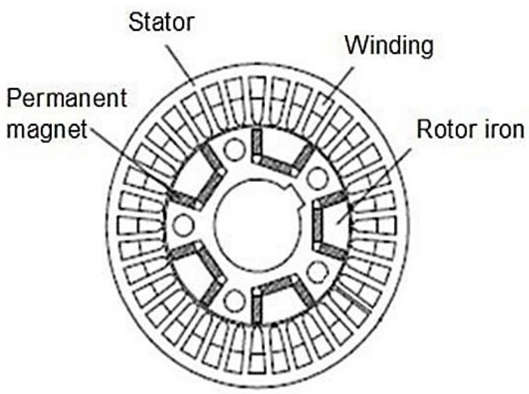

Fig. 9. A downhole PMSM [37].

Table 2: Short Overview of the Downhole Electrical Driven Pumps and their advantages

Motor	Advantages
Electric SSVs	• Quick reaction time and fewer transmission lines • More efficient systems with less upkeep. • It is more environmentally friendly.
Electrically Bottom-Driven Pumps	• Eliminate the rod breakage issue and drastically minimize tube wear. • Increase the production
PM Motor Driven Compressor	• More compact. • Increased reliability. • Increased production.
Electrical Drilling	• With new materials, electrical motors may withstand temperatures of up to 200°C. • A higher penetration rate.
Power Supply from a HTHP Downhole Generator	• Suitable for deep wells and more dependable in HTHP environments.
Standard Induction Downhole Motors	• High level of dependability. • Stability & simplicity.
PM Machines	• Same robustness and dependability as traditional induction motors • Higher efficiency • Higher torque density • Smaller volumes

V. Conclusion

The advantages of electrical machines in downhole applications were discussed in this study. Downhole electrification provides a number of advantages, notably for deep-water offshore reserves, which are now being exploited by the oil and gas sectors. Standard electrical downhole motors are inefficient in terms of energy consumption. For downhole applications, the PM motor has become the norm.

Acknowledgment

I am grateful to Dr. Munira Batool for their support in this paper. I'd also want to Engr. Mian Farhan Ullah and to my group members for their encouragement and support. Without their wonderful encouragement and assistance, I would never have been able to complete this research project.

References

[1] Gupta, Rimzhim, and Sebastian C. Peter. "CO2 capture and sequestration-A solution for enhanced recoveries of unconventional gasses and liquids." Energy and Climate Change 1 (2020): 100003.

[2] Chen, Zheng, Jin Wang, and Libing Zhou. "Design and Analysis of Permanent Magnet Vernier Motors for Downhole Applications." In 2020 IEEE 1st China International Youth Conference on Electrical Engineering (CIYCEE), pp. 1-6. IEEE, 2020.

[3] Shepard, Michael, Michael Betz, and Anastasia Snyder. "The shale boom and family structure: Oil and gas employment growth relationship to marriage, divorce, and cohabitation." Rural Sociology 85, no. 3 (2020): 623-657.

[4] Manfroni, Michele, Sandra GF Bukkens, and Mario Giampietro. "The declining performance of the oil sector: Implications for global climate change mitigation." Applied Energy 298 (2021): 117210.

[5] Kazemi, Nasser, Siavash Nejadi, Jean Auriol, Jordan Curkan, Roman J. Shor, Kristopher A. Innanen, Stephen M. Hubbard, and Ian D. Gates. "Advanced sensing and imaging for efficient energy exploration in complex reservoirs." Energy Reports 6 (2020): 3104-3118.

[6] Tan, Yi, Hong Xian Li, Jack CP Cheng, Jun Wang, Boya Jiang, Yongze Song, and Xiangyu Wang. "Cost and environmental impact estimation methodology and potential impact factors in offshore oil and gas platform decommissioning: A review." Environmental Impact Assessment Review 87 (2021): 106536.

[7] Epelle, Emmanuel I., and Dimitrios I. Gerogiorgis. "A review of technological advances and open challenges for oil and gas drilling systems engineering." AIChE Journal 66, no. 4 (2020): e16842.

[8] Romagnoli, Raffaele, and Dovrannazar Alkychyyev. "Innovative Drilling and Completion Technologies." PhD diss., Ph. D. Thesis, Politecnico di Torino, Turin, Italy, 2020.

[9] Shentu, Leixuan, Yiming Ma, Jin Wang, Jia Zhou, Libing Zhou, and Kun Qian. "Design and Analysis of a Direct-Drive Permanent Magnet Vernier Motor for Electric Drilling Applications." In 2018 21st International Conference on Electrical Machines and Systems (ICEMS), pp. 81-86. IEEE, 2018.

[10] Wagner, Alan N. "Capillary based surface controlled subsurface safety valve systems solution for problematic wells." In SPE Middle East Oil & Gas Show and Conference. OnePetro, 2017.

[11] Liu, Xuehao, Qi Li, Ranran Song, Zhiming Fang, and Xiaochun Li. "A multilevel U-tube sampler for subsurface environmental monitoring." Environmental Earth Sciences 75, no. 16 (2016): 1-13.

[12] Jacob, Suresh, Nibras Abdulbaqi, Chandresh Verma, and Rabih Younes. "Case Study of Intelligent Completion with New Generation Electro-Hydraulic Downhole Control System." In SPE Kingdom of Saudi Arabia Annual Technical

Symposium and Exhibition. Society of Petroleum Engineers, 2016.
[13] Wilson, Adam. "All-electric subsea well brings benefits vs. traditional hydraulic technology." Journal of Petroleum Technology 70, no. 04 (2018): 65-66.
[14] Electricwell.com
[15] Garcia-James, C. J. "Experience with Progressive Cavity Pumps in the Soldado Field, Offshore Trinidad." In SPE Trinidad and Tobago Section Energy Resources Conference. OnePetro, 2016.
[16] Yan, Tingjun, Haoqiang Ti, and Xianmin Wu. "Test System for Node Efficiency of Progressive Cavity Pump Based on Wireless Communication Technology." Sensors & Transducers 160, no. 12 (2013): 368.
[17] Hassan, Ahmed Hassan Ismael, Hamid Ahmed Ibrahim Ramadan, Hamid Suleiman Hamid Turja, and Mohammed Ali Mohammed Alamin. "Prediction Production Performance of Progressive Cavity Pump for High Viscous Oil." PhD diss., Sudan University of Science & Technology, 2017.
[18] "High Volume Down-Hole Progressing Cavity Pumps with Electrical Submersible Motors", R&M energy systems, a unit of tobbins and myers inc, Paper 18, ESP WORKSHOP, 1998
[19] Malkawi, Ameen, Ahmed AlAdawy, Rajesh Kumar V. Gadamsetty, and Rafael Lastra Melo. "Compression Technology Selection for Downhole Application in Gas Wells." In Turbo Expo: Power for Land, Sea, and Air, vol. 58721, p. V009T27A019. American Society of Mechanical Engineers, 2019.
[20] "Downhole gas compression", PTAC technical information session, 27, November 2003.
[21] Li, Zhixiong, Quanli Zhang, Huaidong Luo, Hongwei Wang, Jin Wang, Fei Han, Aiguo Wang, Xicai Liu, Xiaoming Yu, and Libing Zhou. "Sensorless Starting Control of Permanent Magnet Synchronous Motors with Step-up Transformer for Downhole Electric Drilling." In IECON 2018-44th Annual Conference of the IEEE Industrial Electronics Society, pp. 689-694. IEEE, 2018.
[22] Li, Fei, Rohan V. Neelgund, David L. Smith, and Wesley Blackman. "Drilling Dynamics Measurements on Positive Displacement Motors PDM Enhance Performances and Reliability." In International Petroleum Technology Conference. OnePetro, 2019.
[23] Dan Turner, Philip Head and Mike Yuratich, "New DC motor for Downhole Drilling and Pumping Applications", Society of petroleum engineers paper 68489, March 2001, Houston, Texas.
[24] D.R Turner, T.W.R Harris, M. Slater, M.A. Yuratich and P.F. Head, "Electric paper 52791, March 1999, Amsterdam, Holland.
[25] Ummaneni Ravindra Babu, Nilssen Robert and Brennvall, J.E, "Force Analysis in Design of High Power Linear Permanent Magnet Actuator with Gas Springs in Drilling Applications", Electric Machines & Drives Conference, 2007, IEMDC'07, IEEE International.
[26] Anyuan Chen Ravindra babu. Ummaneni Robert Nilssen Arne Nysveen. "Power Electronics and Motion Control" EPE-PEMC 2008. 13th IEEE International 2008.
[27] Sanat Kumar, F. N. U. "PRACTICAL DESIGN OF A HIGH-VOLTAGE PULSED POWER SUPPLY FOR DOWNHOLE PLASMA ENHANCED GEOTHERMAL DRILLING." PhD diss., 2021.
[28] Molchanov, D., V. Vazhov, I. Lavrinovich, V. Lavrinovich, and N. Ratakhin. "Downhole generator based on a line pulse transformer for electro pulse drilling." In 2017 IEEE 21st International Conference on Pulsed Power (PPC), pp. 1-4. IEEE, 2017.
[29] Timothy F. Price, "Development of a High-Pressure/High- Temperature Downhole Turbine Generator", Dexter Magnetic Technologies Inc., DE-FC26-05NT42655, March 27, 2007.
[30] Yang, Mou, Dayu Luo, Yuanhang Chen, Gao Li, Daqian Tang, and Yingfeng Meng. "Establishing a practical method to accurately determine and manage wellbore thermal behavior in high-temperature drilling." Applied Energy 238 (2019): 1471-1483.
[31] Malarev, Vadim I., Alexandra V. Kopteva, and Vladimir Yu Koptev. "Electric power supply system development for down-hole electric steam generators to produce high-viscosity oil." In 2018 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon), pp. 1-4. IEEE, 2018.
[32] Newman, Kenneth Ray, Timm Gleen Burnett, John Carlton Pursell, and Ouahab Gouasmia. "Modeling the affect of a downhole vibrator." In SPE/ICoTA Coiled Tubing & Well Intervention Conference and Exhibition. OnePetro, 2009.
[33] Chen, Anyuan, Robert Nilssen, and Arne Nysveen. "Investigation of a three-phase flux-switching permanent magnet machine for downhole applications." In The XIX International Conference on Electrical Machines-ICEM 2010, pp. 1-5. IEEE, 2010.
[34] NTK-BP Technology magazine, October-November 2007, Russian, pp.27-31.
[35] J.R.Smith, D.M.Grant, A-AI-Mashgari and R.D.Slater, Operation of subsea electrical submersible pumps supplied over extended length cable systems, IEE Proc.-Electr, Power Appl., Vol. 147, No. 6, November 2000.
[36] D. Nouman, I. A. Sajjad, A. Ali, "Distribution Network Voltage Improvement using Dynamic Voltage Restorer with Smooth Super Twisting Sliding Mode Control", 1st International Conference on Scientific and Innovative Studies (ICSIS), Vol.1, April-2023.
[37] Zhang Binyi, Liang Binxue, Feng Guihong and Zhuang Fuyu, "Research of Multipolar Permanent Magnet Synchronous Submersible Motor for Screw pump", Proceedings of 2007 IEEE International Conference on Mechatronics and Automation, August 5-8, 2007 Harbin, China, pp.1011-1016, 2007.