

Direct Current motors with permanent magnets - more downhole flexibility

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Introduction

Today, most electric submersible pump (ESP) and downhole powered progressive cavity pump (PCP) systems are driven by two pole, three-phase, squirrel cage, induction motors using AC current. A new submersible electric motor technology has been developed based on a different principle which offers numerous advantages over the existing traditional motor.

Borets Company has developed a motor which incorporates permanent magnets and is driven using constant direct current (DC). This new DC motor technology offers several options and advantages, such as:

- Ability to regulate speed of rotation from 250 to 2000 rpm useful for progressive cavity pumps (PCP) and from 2000-6000 rpm, useful for electric submersible pumps.
- A minimum 10% saving in power requirements compared to conventional ESP motors due to higher efficiency of the motor
- High flexibility in the case of instability of power supply system
- Decreased heat generation
- Improved power factor
- Reduction in operational problems with DC current
- Significantly decreases system dimensions (length)
- Very accurate motor speed adjustment and control of parameters
- Constant torque

This paper gives an overview of the new technology, results gained from field pilot tests and ongoing work aimed at leveraging the ability to adjust the motor speed using current regulation at surface, to develop a fully integrated control system which will be adaptive to variable reservoir and well conditions for optimization of well production.

DC Motor Performance and Surface Control

The submersible, three phase oil filled DC motor incorporates permanent magnets made from sintered materials which are placed in laminated rotor packs made from electrical plates.

In order to provide control of downhole equipment, the new downhole motors leverage the constant current principle in order to regulate rotation speed using current a stabilizer at surface. The required regulation of motors is provided by an inverter with extensive impulse commutation of electric field. This system requires filters on the input and output of the control unit, as shown on the Figure 1. The surface control system is designed to provide effective application and speed adjustment of electrical submersible pumping system using DC motors.

A principal advantage of the new DC motor system is that there is no need for additional filters because the amplitudes of the input and output current are constant

The rotation speed of the shaft in AC motors is always less than the shaft frequency because of the slip effect which depends on the current load. From the reason the shaft rotation speed can't be precisely determined, even if frequency is known

The DC motor is supplied by a current of constant amplitude providing the best regulative performance of the system. Figure 2 shows an oscillogram which indicates that the current and the voltage of the motor have controlled amplitude, mirroring the commutator device. The frequency of phase switching for the DC motor and the frequency on the motor shaft coincide in the whole range of the motor load. If a switching frequency of the phases can be measured then, the shaft rotation speed is automatically determined. This represents the base principle of shaft rotation speed regulation.

The highly energized permanent magnets used for DC motor gives magnetic flux which essentially doesn't depend on anchor current (I_M). The torque of the motor is determined by equation:

$$I_m = K \cdot \phi_m \cdot I_m$$

Where:

I_m - motor current (A)

Φ_m -Magnetic flux

K- Torque coefficient

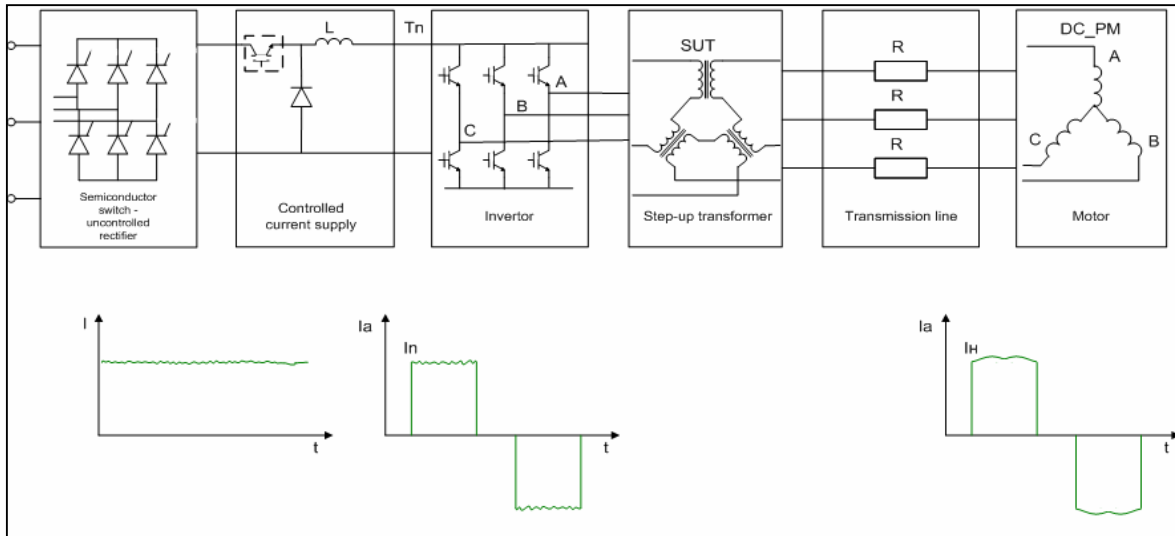


Figure 1- New control system of DC motor with permanent magnets

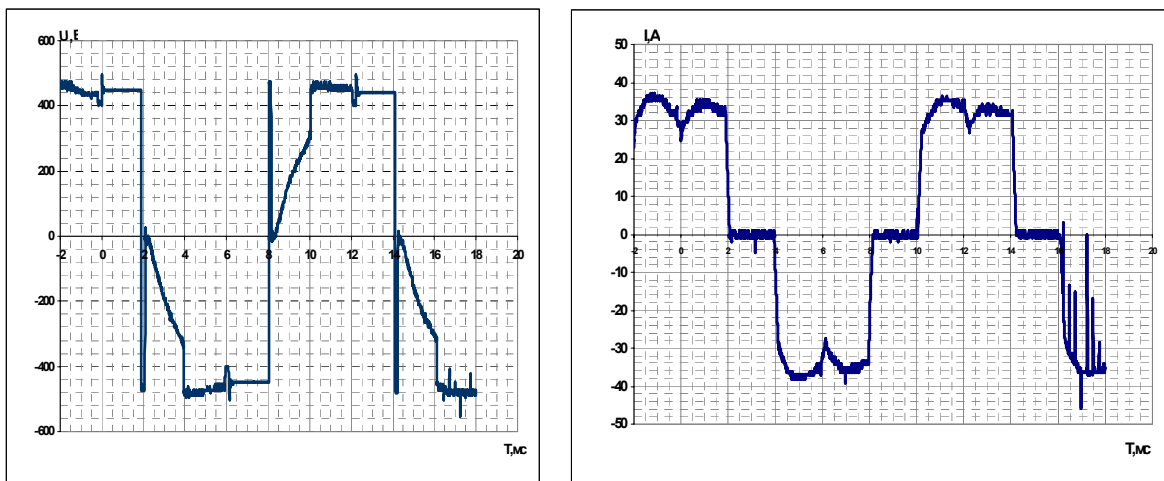


Figure 2- Oscillograms

Figures 3, 4 and 5 show the functional dependence between rotation speed, shaft torque, power factor ($\cos\phi$) and current for DC and AC motors. It is easy to see that for DC motor at zero torque (non-run) current is 2.4 A. The switchboard is set-up to control the current with accuracy of $\pm 0.1\text{A}$. In this way, the motor torque on shaft will be recorded with accuracy of $\pm 0.5\text{Nm}$, which is less than 1%.

A nonlinear dependence of the current varies from 11 to 25 A. At nominal current of , the torque is 118 Nm. To know the torque on the motor shaft from recorded current, a mathematical model is required to accomplish high accuracy control. In the case of DC motor, fine tuning is provided by more simple mathematical models.

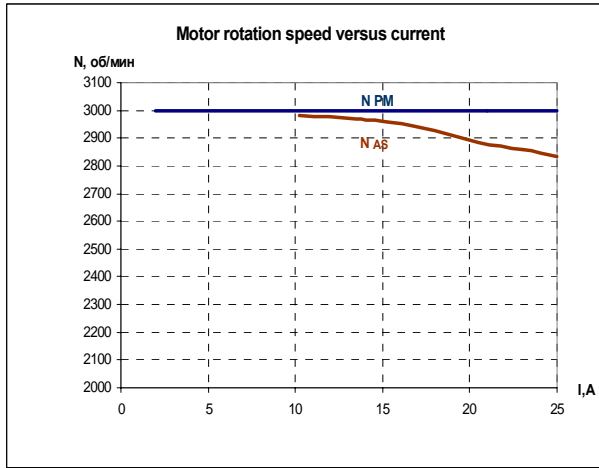


Figure 3- Motor shaft torque vs. current

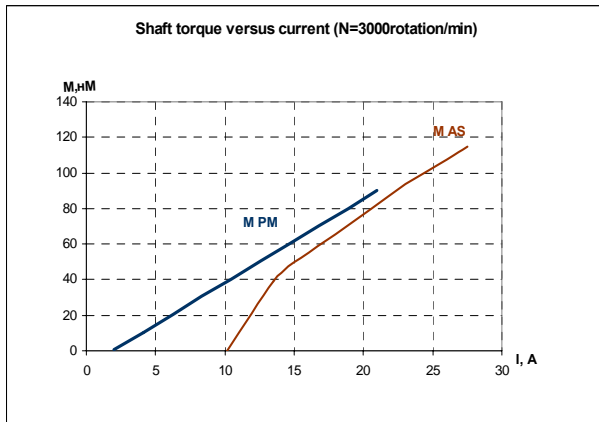


Figure 4- DC vs. AC motor (slippage)

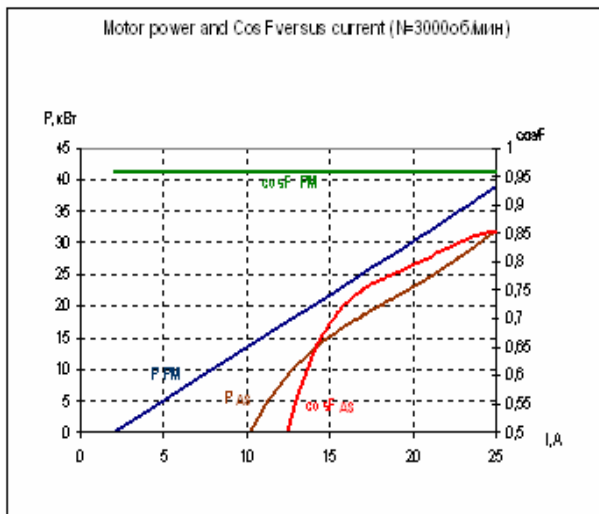


Figure 5- DC vs. AC motor (slippage)

Pilot Tests and Results

Over the course of 15 months, DC motors have been installed in more than 20 wells in both ESP and PCP applications. The primary objectives of these pilot projects, agreed with respective operating companies were to:

- Compare the performance and equipment efficiency of DC vs. AC motors under changeable production conditions in selected wells.
- Estimate the possibility to operate in the problematic environment (high water content with scaling tendency, high solids content, gassy conditions, emulsion and viscosity problems).
- Prevent the premature failures and increase the run life of the system by direct investigation and analysis of various operational parameters.
- Increase the production of low productivity wells with the regulation abilities of the new control system
- Acquire information required for development of a new monitoring and regulation system.

The pilot tests have been performed according to test programs in which include detailed well candidate selection according to well and reservoir conditions and problems noted during the well production and operation history. The equipment selections were based on detailed analysis of current and expected conditions.

The following table (Table 1) shows the average parameters of selected wells used for analysis and equipment design and final equipment selection.

Table 1- Average reservoir and well parameters

Reservoir and Well Data	Static Pressure (atm)	100-169
	BHP (atm)	50-85
	Fluid Level (m)	800-2200
	Reservoir Temperature, C	60-88
	Productivity Index (m3/day/atm)	0.15-0.7
	Average Production Rate (m3/d)	15-120
	Water Content (%)	10-90
	Well depth (m)	1700-2700
Fluid Properties	Well type (Vert./Slant/Horiz.)	Vertical and Slant
	Deviation angle (deg)	30-50
	Casing (O.D.) - mm	146-168
	Tubing (O.D.) - mm	73
	Dead oil gravity (kg/m3)	0.775-0.836
	Dead oil viscosity (mPas)	1.15-4
	Saturated oil viscosity (mPas)	0.8-1.4
	Specific gravity gas	0.7-0.8
	Bubble point pressure (atm)	92-258
	GOR (m3/m3)	60-307
Water gravity (kg/m3)	1005-1018	
Paraffin (%)	No	
Asphaltenes (%)	No	
Abrasive (mg/lit)	80-1200	

The integrated surface control unit allows the system to be 'adaptive' to changing reservoir and well conditions through real-time control and production optimization. Figures 6 and 7 show some examples of the real – time data acquired from the surface control unit

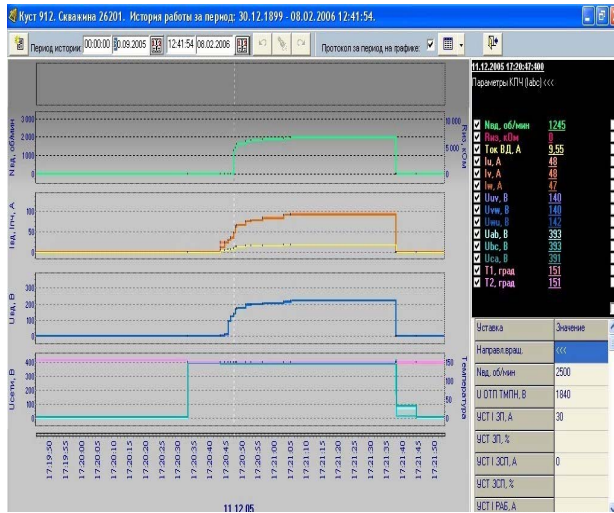


Figure 6- History of run-in operation

Table 2 and Figure 8 show the observed results for selected wells. From the data in the table and Figure, it can be seen that at similar conditions, amperage and power requirements decrease in the range of 12-20% for DC. In some wells the fluid production was increased depending on well/reservoir potential.

As the pilot tests are still in progress, it is early for making comparative analysis of run life and mean time between failure (MTBF).

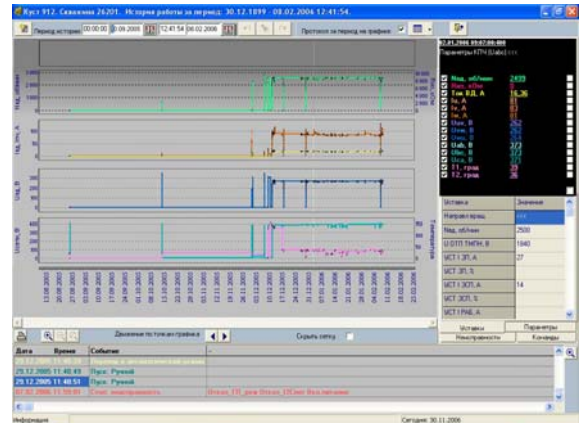


Figure 7- Motor current changes to optimize system operation

Table 2- Results of application for selected wells at different stages of pilot tests

Downhole equipment and operation parameters	Well 1									Well 2									Well 3								
	Before			After-Stage1			After Stage2			Before			After-Stage1			After Stage2			Before			After-Stage1			After Stage2		
Pump (O,H)	35-1550			35-1600			35-1600			35-1550			35-1600			35-1600			50-1750			125-1650			125-1650		
Motor (kW, Type)	32-117			1 VEDBT 32-117			1 VEDBT 32-117			Atlas 32-117			1 VEDBT 32-117			1 VEDBT 32-11			PED-32 TRM2 Privo			1 VEDBT 72-117			1 VEDBT 72-117		
Current (A)	17.0	17.0	17.0	13.0	12.4	12.3	12.5	12.3	11.5	18.0	18.0	18.0	10.5	10.3	10.2	13	14	15	22	22	22	16	15.8	16	21	21	21
Qav(m3/d)	35.0	35.0	35.0	36.0	35.0	34.0	34.0	36.0	31.0	40.0	40.0	40.0	35.0	35.0	33.0	44	42	43	75	75	75	39	100	99	157	143	138
Rotation speed (RPM)	2910	2910	2910	2728	2722	2723	2700	2731	2705	2910	2910	2910	2519	2510	2432	2731	2729	2722	2910	2910	2910	2512	2492	2493	2970	2934	2930

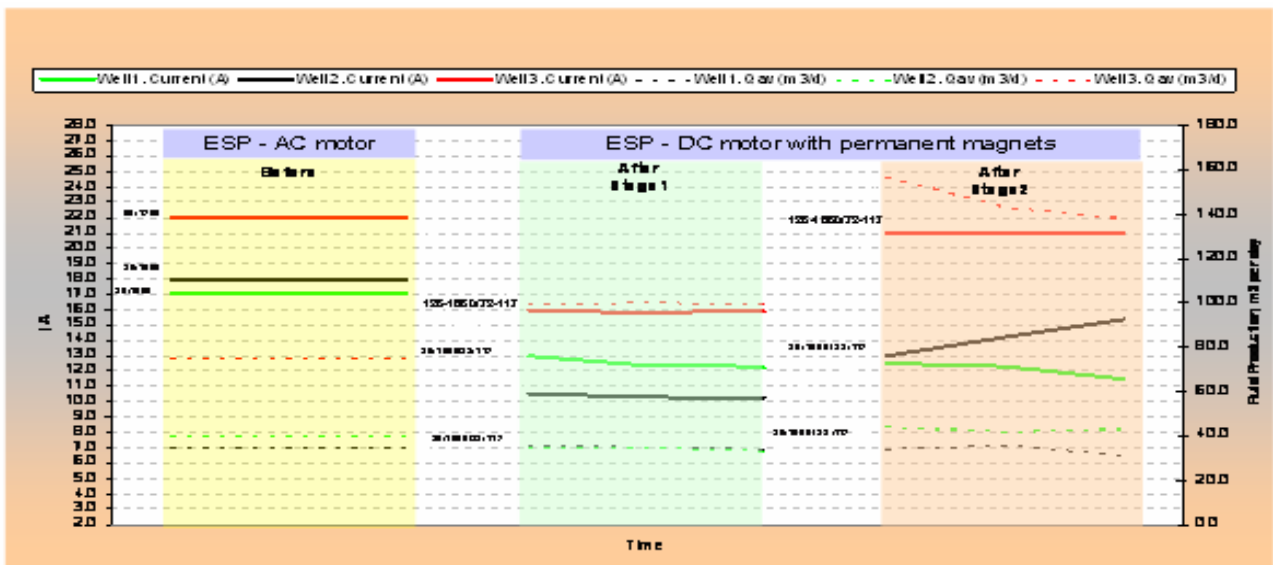


Figure 8- Comparative analysis before and after DC_PM application

The results of comparative analysis of power consumption between AC and DC motors for two wells in Western Siberia are shown in table 3.

The comparison was made in field conditions for similar power rating of motors installed in the wells with approximately identical parameters. The measured DC motor power consumption was compared with AC motor power consumption, as it is shown in Table 3. The

difference of power consumption between AC and DC motors is in the range of 10-30 %. (The total estimated power consumption difference on a monthly and yearly basis has been extrapolated and is included in the table). Significant reduction of operating costs would be achieved if the AC motors were to be replaced with DC motors.

Table 3- Measured power consumption (AC vs. DC motors)

Case	Well	Switchboard	Submersible Motor			Power Consumption				
			Motor Type	Power kW	Measured kW/day	Difference AC vs DC				
						kW/day	%	kW/month	kW/yr	
1	Well #1	Borets VD40	1VEDBT32-117	DC	32	584.19				
	Well #2	Borets-D1 MV-250	32-117 Vendor M1	AC	32	672.76	88.58	13.17	2,657.26	32,300.00
	Well #3	Vendor_SB1	32-117 Vendor M1	AC	32	718.67	134.49	18.71	4,034.64	49,088.17
	Well #4	Vendor_SB2	32-103 Vendor M1	AC	32	653.28	69.10	10.58	2,072.89	25,220.15
2	Well #5	Borets VD40	1VEDBT72-117	DC	72	1,165.87				
	Well #6	Vendor_SB2	70-117 Borets	AC	70	1,681.99	516.12	30.69	15,483.66	188,384.50
	Well #7	Vendor_SB1	63-117 Borets	AC	63	1,400.89	235.03	16.78	7,050.75	85,784.13

Future development

Based on the results obtained to date, Borets has started the development of a new adaptive algorithm that will be incorporated in the new generation of the control unit. This system is based on the ability to adjust rotation speed

in a relatively wide operating range making the system very flexible for various types of applications. To regulate and control the operation of the wells producing with ESP or PCP systems using DC motors, optimization should integrate the variables of rate (Q), total dynamic head (H) and current (I) as shown on Figure 9. Relatively simple mathematical models describe the relationship between IQH due to their linear dependence between speed of rotation (frequency) and torque which is determined the motor power. These algorithms can be used as a powerful tool for a system of 'self-adaptive' regulation.

The potential benefits of this self adaptive system can be realized in a variety of well applications including: -

- In low productivity wells with relatively unstable fluid inflow characteristics.
- In wells where the system is not appropriately sized selected (e.g. is a pump is oversized, an optimal rotation speed of motor for continual operation can be determined using the adaptive algorithm).
- In a situation where continual operation is not possible, the system can be switched to intermittent operation with option to estimate both, required time for liquid accumulation in casing annulus, as well as a pump operation time.

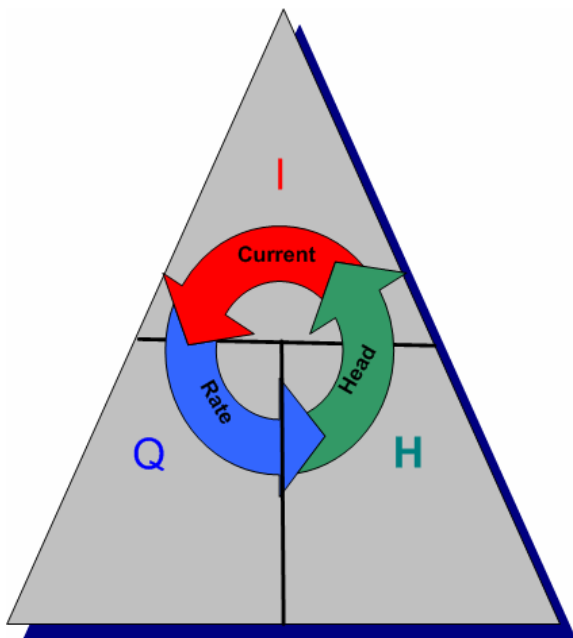


Figure 9- IQH relation paradigm

Conclusion

A submersible motor for ESP and PCP applications has been developed utilizing DC current which has the potential to reduce operating costs and offer numerous operating advantages.

- Results from pilot tests have shown a significant reduction in power requirements ranging from 10%-20% can be obtained depending on specific well conditions.
- System flexibility makes the control system on surface applicable in problematic wells with normally unpredictable dynamic conditions.
- Adaptive algorithms as a part of control unit will potentially allow full control of well operation by changing the rotation speed depending of current recorded at the surface. The ability to adjust the rotation speed in a wide operating range makes the system very flexible for various type of applications.

References

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