A TORQUE ESTIMATION METHOD TO AID AN INTELLIGENT MANAGEMENT SYSTEM FOR OIL WELLS AUTOMATED

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Abstract: This article presents a contribution for an oil wells intelligent management system called **SGPA** that nowadays manages about 700 oil wells using the rod pumping lift method at Bahia State, Brazil. The intelligent management system will be applied on oil wells using the gradual pumping method. In this oil pumping method, the torque on the rod is very important for detection of operational problems. It will be considered that the well is driven by an induction motor. A torque estimation method on rod and some results from laboratory are presented.

1 INTRODUCTION

In oil reservoirs, usually the pressure of bottom is not enough to move oil to surface, either for its natural characteristic or the end of its productive life. In this case, artificial lift systems are used to move oil to surface. To select the fittest lift method, it is necessary to know the conditions of the wells and to take in considerate several factors:

- Characteristics of the well such as porosity, permeability, sand rate, gas rate, pressure, temperature, production forecast, diameter of the covering and depth;
- Recovery methods for the well due to alterations of behavior during the operational life;
- Fluid properties such as density, viscosity, paraffin rate and sand rate;
- Energy available such as electric energy, gas or fuel;
- Localization, number of wells and resources from the field;
- Legal restrictions such as ambient standards;
- Economic evaluation of the project;

The main artificial lift methods are:

Continuous and Intermittent Gas-lift: The gas-lift (**CGL** or **IGL**) uses the energy of gas compressed to move the oil to surface. The gas is used to gasify the oil (**GLC**) or to throw it (**GLI**) of the deep until the surface.

Submerged Centrifugal Pump: The Submerged Centrifugal Pump consists of a centrifugal pump of several stages in serie, in accordance with the pressure of the bottom of the well. Motors projected to work under high temperature and high pressure are used into this lift system;

Rod Pumping: In the Rod Pumping (**RP**), an electric motor or a combustion motor drives an apparatus to convert the rotational movement into linear movement to a rod. This rod drives a piston pump at the bottom of the well.

Gradual Pump: The Gradual Pump (**GP**) uses a pump with a steel screw rotor and a stator of soft material, usually an elastomer. The pump is used in the bottom of the well working submerged into oil. The rotational movement of the pump dislocates the oil gradually in the direction of the surface. Without necessity of valves, the pump can be driven from the surface with the rotational movement transmitted by a rod. Electric motors can be used to drive the pump.

An oil extraction field can have a lot of wells. For example, the Bahia Extraction Field, at Brazil, has about 4000 wells. Such numbers of well produces a lot of information such that its analysis by engineers is very difficult. Some times, this analysis are necessary to intervene in the well operation. Specialists

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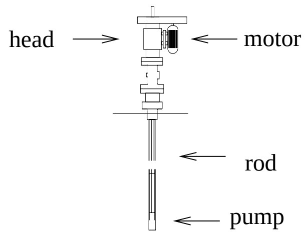

Figure 1: Gradual pump system (GP).

have proposed the use of intelligent system approach to aid the management of oil wells (Alegre et al., 1993; Hosn et al., 2001; Nikravesh and Aminzadeh, 2001; Cerqueira et al., 2002b; Cerqueira et al., 2002c; Cerqueira et al., 2002a; Cerqueira et al., 2003).

The torque variable is very important to supervise the wells. The torque analysis supplies information about the load of the electric motor. This makes possible preventive actions to avoid that the system operates in a dangerous situation.

The goal of this paper is to present a torque estimation method to aid the supervision of **GP** in oil well. The torque estimated at head of the well can warn operational problems. The **GP** system is driven by induction motor in the surface that transmits the rotating movement for the pump at the bottom of the well by a rod coupled with a gear train (see figure 1). Currently, a frequency inverter can be used to control the motor speed.

The paper is organized this way. In section 2 are presented operational problems in **GP**. In section 3 is presented an intelligent distributed system used to manage oil wells, the **SGPA**. In section 4 the torque estimation method for induction motor is described in mathematical format. The hardware/software architecture used to estimate the torque is presented in section 5. In sections 6 and 7 are presented some experiment results and the conclusions of the paper respectively.

2 OPERATIONAL PROBLEMS

Excess of torque on the rod that moves the pump in the bottom of the well can break the rod or the gear train coupled with motor and to stop the oil pumping. For repair a broken pump/rod set is necessary to remove a rod with hundreds of meters and to capture the pump fallen at bottom of the well using special equipment and specialized people. Sometimes, the well recovery can delay weeks and to cause losses of production and of cash.

On the other hand, a very small torque on the rod causes low power factor of power on the electric system and can indicate that the pump is not pumping the fluid. This situation could damage the elastomer of the stator hindering the perfect rotation of the rod and leading the system to the previous situation, with high torque. Additionally, when the fluid is pumped, it lubricates and refrigeration of the mechanical subsystem of bottom of the well.

A previous fault detention allows the planning of the maintenance of the lift system, in order to attenuate the impacts provoked for the operation stops and to reduce the maintenance costs.

It is necessary accompaniment of other variable of the system such as the noise level in the head, the pressure in the top of the well and the electric current on the motor during the pumping of the oil. These variable are also important for fault detection in lift system, but they are not approached in this paper.

3 THE INTELLIGENT MANAGEMENT SYSTEM

Researchers of Universidade Federal da Bahia in Brazil joint with engineers of Brazilian petroleum company (PETROBRAS) have applied concept of expert systems into an automated lift well management system, called **SGPA** - Sistema de Gerenciamento de Poços Automatizados (Cerqueira et al., 2002b; Cerqueira et al., 2002c; Cerqueira et al., 2002a; Cerqueira et al., 2003). The **SGPA** consists of three levels of management:

Level 1: Where a programmable logical controller (**PLC**), sensors and actuators work directly in the supervision and control of the well. The electric motor is supplied by electronic inverter. This level of management and automation is local and the well become automated;

Level 2: Where intelligent supervisor system receives the information from level 1 by radio communication link. The intelligent supervisor manages group of wells of an extraction field from a control room;

Level 3: Where are made analysis, diagnostics and recovery actions are chosen for the lift systems. In this level is added information about production costs, economic information, operational historical of the wells, and information from previous levels.

In this management model, Artificial Intelligence techniques such as Symbolic Neural Nets and Fuzzy Logical are used for application of knowledge get from specialists in petroleum engineering.

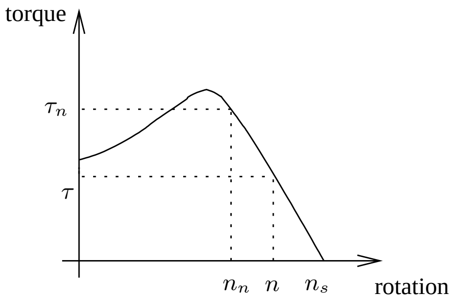

Figure 2: Curve torque × rotation for induction motor.

For torque measurement from rod in **GP** method, a torquimeter could be installed in the rod. However, a torquimeter is not a robust equipment and has high cost, mainly considering that must be installed in the well surface and submitted to weather action. The same inconvenience is observed when is analyzed the possibility of insertion of a torquimeter in the gear train or in the electrical motor or in the bottom of the well. The insertion of a torquimeter in the motor would had advantage the torquimeter works with lesser torques.

A torque estimation method developed for the induction motor from the spectrum analysis of the electric current is presented as option for torque estimation in the rod and to supervise the **GP** method. This estimation method does not modify the mechanical structure of the wells. Therefore, the method is not intrusive. Petroleum engineers can use the torque estimated to study problemas in the wells.

The torque estimation from the current spectrum offers satisfactory accuracy, practically without intrusion in the system, but it requires sophisticated analysis. The identification of a specific frequency harmonic component of the electrical current on the electric motor is necessary. This frequencies are function of the rotor speed. With this, the slip of the induction motor can be obtained. The slip has an almost linear relation with the torque into operational region. From this linear relation, the torque can be estimated.

4 THE TORQUE ESTIMATION METHOD

In curve torque × rotation for induction motor is verified that near to the synchronous speed the curve can be approached by a straight line with negative angular coefficient, as shown in figure 2, where: n_n is the nominal speed; τ_n is the nominal torque; n_s is the synchronous speed; n is the speed; and τ is the torque.

From nameplate data, the torque can be estimated by the expression

$$\tau = \frac{(n_s - n)}{(n_s - n_n)} \frac{P_n}{0.10466\, n_n} \qquad (1)$$

where P_n is nominal power and the speeds are in rpm (rotation per minute).

This expression is gotten from a other expression used for estimation of the power output of the induction motor and indicated by technical standards (IEEE Standard, 1991; Damasceno, 2002; Damasceno et al., 2002a; Damasceno et al., 2002b). For torque estimation, the information about electric motor speed is necessary.

4.1 SPEED ESTIMATION

The speed measurement in induction motor is as difficult as torque measurement in the **GP** system. Mechanical considerations and noise make the use of tachometer or encoders connected to the axle of the motor a solution does not appropriate. An alternative is the speed estimation from spectrum of the electric current signal of any electrical phases that supply the motor, as described for (Hurst and Habetler, 1996; Blasco-Gimenez et al., 1996; Benbouzid, 2000).

Because interactions between magnetic fields into the induction motor and constructive imperfections - as the slots in the rotor where the squirrel cage is built - the spectrum of the electrical current is rich in harmonic components. Some of these components are related to the slip in the form

$$\mathtt{f}_{sh} = \mathtt{f}_s \left[(k\, R \pm n_d) \left(\frac{1-s}{\left(\frac{P}{2}\right)} \right) \pm n_w \right] \qquad (2)$$

where $\mathtt{f}_s$ is electrical fundamental frequency, $\mathtt{f}_{sh}$ is frequency multiple of the fundamental frequency, R is the number of rotor slots, n_d it is the eccentricity, P it is the pole number of the stator, n_w is a harmonic order and k is a any multiple.

The method works as follows. For $s = 0$, values for k, n_d and n_w are attributed. With this, a frequency called $\mathtt{f}_{sh_0}$ is determined. A maximum slip value $s_{\max}$ is attributed and applied in equation 2. This determines a frequency $\mathtt{f}_{sh_{\min}}$. So, a spectral window from $\mathtt{f}_{sh_{\min}}$ to $\mathtt{f}_{sh_0}$ can specified where $\mathtt{f}_{sh}$ will be always the maximum amplitude component. The motor slip can be determined from expression

$$s = 1 - \frac{\left(\frac{\mathtt{f}_{sh}}{\mathtt{f}_s} - n_w \right) \frac{p}{2}}{k\, R \pm n_d}. \qquad (3)$$

The motor speed can be determined in rpm from expression

$$n = (1 - s) \left(\frac{120\, \mathtt{f}_s}{p} \right). \qquad (4)$$

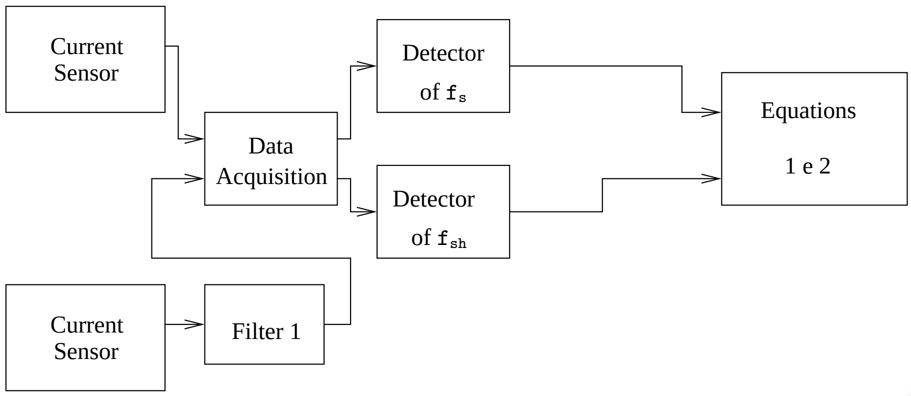

Figure 3: System Blocks Diagram.

This estimation method has accuracy enough to be used in torque estimation. Details about implementation of speed estimation method can be found in (Santos, 2002; Santos and Oliveira, 2002).

5 THE SYSTEM ARCHITECTURE

The systems built from three subsystem: one of data acquisition; one of hardware for data processing; and one third of software.

The data acquisition subsystem is composed of current sensors and a data acquisition hardware with sample-hold and analog-to-digital converter.

The processing subsystem is constituted of a personal computer. The software subsystem was implemented using resources of the LABVIEW® package.

Figure 3 illustrates the organization of the system. Two current sensors are used. A sensors is used for current signal acquisition and subsequent detention of electrical signal fundamental frequency, f_s. The other sensor is used for current signal acquisition and subsequent detention of the frequency that carries the information about the induction motor slip, f_{sh}

For detention of f_{sh}, the current signal is filtered by an pass-band analog filter, represented in the figure for filter 1. This filter objectives to eliminate in order the fundamental component of the electrical signal, f_s and the high frequencies. In sequence, the data acquisition is made. The digital signal is processed for detection of the component f_{sh}. After the detention of f_s and of f_{sh}, the information about R, P_n, n_n and P_n are used to estimate the speed and the torque in the induction motor attributing values for k, n_w and n_d into expressions (1)-(4).

From the speed reduction on the gear train the torque in well head is gotten. Petroleum engineers use this torque to estimate the torque at some points of the rod. The **SGPA** can be implemented adding in order these information with other about the working of the wells.

6 EXPERIMENTAL RESULTS

Laboratory tests was done for validation of the theoretical developments presented in this text. In the test system, a continuous current generator simulates a mechanical load in the axle of the three-phase induction motor corresponding to mechanical load on rod in the **GP** system. For the torque estimation system illustrated in figure 3 and described in section 5, a tachometer and a torquimeter to compare its indications with estimated values were added.

The torque estimation system was tested with an induction motor. A 2 cv, 220/360 V (Δ/Y), 4 pole, 1725 rpm, and 44 rotor slots. For this motor, the experimental results are presented in table 1.

The first measure was carried out with the continuous current generator working without field current and with this the induction motor worked with very small load. The last measure was carried out at overload condition. Analyzing tables 1 is observed that inside normal band operation of induction motor the error in the torque estimation is very small. The errors were only significant in order on overload and very small load condition. Additionally, at overload condition, the error can be attributed to linear approach made for torque, once the true curve is not a straight line. Therefore, the torque estimation method is efficient inside motors operation band.

The efficiency of the estimation method depends on accuracy of data from manufacturer of the induction motors. The nameplate data have their accuracy standardized, but this does not avoid that any induction motor works outside the nameplate data. Some times, nameplate data and manufactures book data are different. So, part of error for the motor can be attributed

Table 1: Experimental Results for 2 cv Motor.

f_s	n measure (rpm)	n estimated (rpm)	τ measured(Nm)	τ estimated (Nm)	error (%)
59.992	1792	1790	0.82	1.01	23
60.005	1782	1782	2.02	1.94	3.96
59.978	1764	1763	4.03	3.95	1.99
59.978	1744	1744	6.03	6.04	0.17
60.031	1724	1723	8.08	8.28	2.48
60.005	1696	1696	10.05	11.23	11.74
60.024	1667	1666	12.01	14.44	20.23

to accuracy of manufacturer data.

7 CONCLUSION

The estimation methods of torque and speed are sufficiently accurate inside operation nominal band of three-phase induction motors. The use of these methods makes possible the **GP** supervision without the installation of *encoders*, tachometers or torquimeters. This means cost reduction of systems like **SGPA** in **GP** wells.

A next step is the test of the system using frequency inversor and its evaluation on the wells. It is intended also improvement of hardware using a dedicated subsystem. This subsystem must be built with microcontroller and digital signal processor (**DSP**). The complete system will be used in the supervision of approximately 200 oil wells installed in Bahia State, in Brazil.

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REFERENCES

Alegre, L., Morooka, C. K., and Rocha, A. F. (1993). Intelligent diagnosis of rod pumping problems. In *Proceedings of the Annual Technical Conference and Exhibition of the Society of Petroleum Engineers*, pages 97–107, Houston, USA.

Benbouzid, M. E. (2000). A review of induction motors signature analysis as a medium for faults detection. *IEEE Transations on Industrial Electronics*, 47(5):984–993.

Blasco-Gimenez, R., Asher, G. M., Summer, M., and Bradley, K. J. (1996). Performance of FFT-rotor slot harmonic speed detector for sensorless induction motor drives. *IEE-Proceedings on Electronic Power Applied*, 11(1):66–73.

Cerqueira, J. J. F., Corrêa, J. F., Lepkison, H., Bitencourt, A. C., and Schnitman, L. (2002a). Development of an intelligent distribuited manegement system for automated wells. In *Proceedings of the Annual Technical Conference and Exhibition of the Society of Petroleum Engineers*, pages 3053–3058, San Antonio, USA.

Cerqueira, J. J. F., Jesus, A., Dantas, E., Pereira, C. H., Albuquerque, G., Bitencourt, A. C., Pereira, F., Lepkison, H., and Corrêa, J. F. (2002b). An intelligent distributed system applied on automated lift system. In *Proceedings of the WSEAS International Conference on System Science 2002*, pages 1951–1955, Rio de Janeiro, Brazil.

Cerqueira, J. J. F., Jesus, A., Dantas, E., Pereira, C. H., Albuquerque, G., Bitencourt, A. C., Pereira, F., Lepkison, H., and Corrêa, J. F. (2003). An intelligent distributed system applied on automated lift system. *WSEAS Transactions on Systems*, 2(2):482–486.

Cerqueira, J. J. F., Lepkison, H., Corrêa, J. F., Bitencourt, A. C., Reis, A. C., Jesus, A., Fisch, M., Dantas, E., Pereira, C. H., Albuquerque, G., and Pereira, F. (2002c). Sistema de gerenciamento de poos de petróleo automatizados. In *Anais do XIV Congresso Brasileiro de Automática*, pages 3053–3058, Natal-RN, Brazil.

Damasceno, S. M. N. (2002). Uma contribuio a avaliação de rendimento de motores de indução trifásicos. Master's thesis, Escola Politécnica da Universidade Federal da Bahia, Salvador-BA, Brazil.

Damasceno, S. M. N., Cerqueira, J. J. F., Lima, A. C. C., Oliveira, A., and Jesus, R. J. (2002a). Uma proposta para avaliação de rendimento de motores de indução em cho de fbrica. In *Anais do XIV Congresso Brasileiro de Automática*, pages 1136–1141, Natal-RN, Brazil.

Damasceno, S. M. N., Oliveira, A., Cerqueira, J. J. F., Lima, A. C. C., Santos, E. T. F., Cunha, V. J. G., and Jesus, R. J. (2002b). Studies about yhe methodology for the evaluation of energetic efficiency in trifasic induction motors on field. In *Anais do V INDUSCON - Con-*

ferência de Aplicações Industriais do IEEE Brasil, pages 582–586, Salvador-BA, Brazil.

Hosn, N. A., Popa, A. S., and Popa, C. G. (2001). A new realistic approach to pumping unit optimization through the use of intelligent system. In *Proceedings of the Eastern Regional Meeting of the Society of Petroleum Engineers*, pages 1–9, Canton, USA.

Hurst, J. S. and Habetler, T. G. (1996). Sensorless speed measurement using corrent harmonic spectral estimation in induction machine drives. *IEEE Transations on Power Electronics*, 11(1):66–73.

IEEE Standard (1991). IEEE standard test procedure for polyphase induction motors and generators 112-1991.

Nikravesh, M. and Aminzadeh, F. (2001). Mining and fusion of petroleum data with fuzzy logic and neural network agents. *Journal of Petroleum Science and Engineering*, 29(2):221–238.

Santos, E. T. F. (2002). Análise e desenvolvimento de um amplificador lock-in digital. Master's thesis, Escola Politécnica da Universidade Federal da Bahia, Salvador-BA, Brazil.

Santos, E. T. F. and Oliveira, A. (2002). Estimação indireta de velocidade de um motor de indução trifásico utilizando um analisador de espectro lock-in. In *Anais do XIV Congresso Brasileiro de Automática*, pages 304 – 308, Natal-RN, Brazil.