BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LXI No. 3/2009	399 - 406	Seria Tehnică

Power Supply and Cableless Communication in a Smart Well

Alexandru D. Cojan, Constantin G. Popa

Petroleum – Gas University of Ploieşti, 39 Bucureşti Blvd., Ploieşti, ROMÂNIA
e-mail: alexandru.cojan@techemail.com, cgpopa@upg-ploiesti.ro

Abstract

This paper presents the part of optimization of interfacing elements values of equipment with the steel construction of well, for a installation of cableless communication and power supply exclusively from the surface facility, in a smart well. The purpose of the paper is to describe the energy and the associated data transmission to / from surface / bottom hole installation only through the minimal infrastructure of the smart well. An example is provided illustrating the practical application of the algorithm used for the design of the elaborated process.

Key words: *cableless communication, power supply, smart well, coupled resistance, serial data line, electrical load accumulation.*

Introduction

The design of the cableless communication and power supply in a smart well using only the surface installation has to consider the following aspects:

- Evaluation of the effective power of the installation;
- Effective ways to reject the effects created by the uncontrolled contacts between the well tubing and the well casing;
- The design of the alternating data acquisition / transmission manner.

Description of installation

The cableless communication between the surface installation and the bottom hole equipment, as well as the power supply to the bottom hole equipment is made possible only using the production (or injection) tubing. This tubing allows the signal and the energy propagation at Extremely Low Frequencies (ELF).

The down hole equipment is a part of an understructure as a passive receiver, but becoming active to generate signals by the accumulation of energy recovered using the resonance phenomenon. The power supply of blocks for measurement, transmission, reception, servo-control, logical, [2], works intermittently on the accumulation of energy principle, by processing in a switching manner of radiofrequency voltage taken over by a resonant circuit.

The data carrier signals, generated by the bottom hole equipment, as well as those derived from the surface, modulate by negative pulses the frequency current from the tubing. For the information system this is performing the function of a data bus [3]. This ensures a half duplex operation process of a serial data line, connecting the processing computer from the surface central station to the intelligent transducers, controllers, and servo-drivers of the bottom hole equipment [2]. The whole system represents, as shown in figures 1 and 2, an extension of wireless automation system between the surface installation and the smart well bottom hole structure [4].

Evaluation of the effective power of the installation

The bottom hole equipment is electrically coupled, by a special joint element, with the smart well tubing. As represented in figure 1, the joint element is a power series resonant circuit which for the tubing, at working frequency, represents a short-circuit. In parallel with C capacitor is connected a power radiofrequency transistor, controlled by the numeric signal as an „open collector“ element. The pulse created by shunting the capacitor is actively reproduced as a certain disaccord of the whole tubing line, apart from the power oscillator frequency. This is detected at the surface receiver equipment as a change in phase difference among the absorbed current and the generator voltage, after this by comparing the phase values corresponding the two signal logical levels. The pulses are then decoded to find the value of measuring signals. The control signals are transmitted from surface to down hole equipment by current negative pulses in a „bang-bang“ modulation process. To counteract the data carrier currents leakages through the outside well casings, an auxiliary generator heats with electrical potential (bootstrap feed-back) the intermediary well casing by an auxiliary compensation line.

The relatively small energy used by the bottom hole equipment is essential for its resonant circuit. The energy consumption leads to the oscillations damping, therefore the circuits of equipment are globally viewed as a coupled resistance network, (e.g. series), of R, the value of the resonant circuit. In order to maximize the effective power of this ensemble installation, the series resistance shall be flexionless determined by the well structural features values except for R_2 value of the bootstrapping cable of intermediary casing, which could enable the compensation of the effects created by the uncontrolled contacts between the tubing and the well casing.

Regarding the bottom hole equipment, the consumer resistance is restricted by the minimum power ensured by the electrical load accumulation in an intermittent mode of operation, i.e. in a „alternating data acquisition / transmission“ process [1].

As shown in figure 1, the C_1 and C_2 capacitors tune to resonance the tubing and the casing lines on ω_0 frequency. One can see that:

$$-j \cdot X_{C1} + j \cdot X_{L1} + j \cdot X_{L22} = 0, \quad (1)$$

$$-j \cdot X_{C2} + j \cdot X_{L21} = 0. \quad (2)$$

Also, the down hole equipment is tuned on ω_0 frequency of the generators:

$$-j \cdot X_{C} + j \cdot X_{L} = 0. \quad (3)$$

According to figure 2, one can use the notations:

$$j \cdot X_{L1} = j \cdot X_{L11} + j \cdot X_{L12}, \quad (4)$$

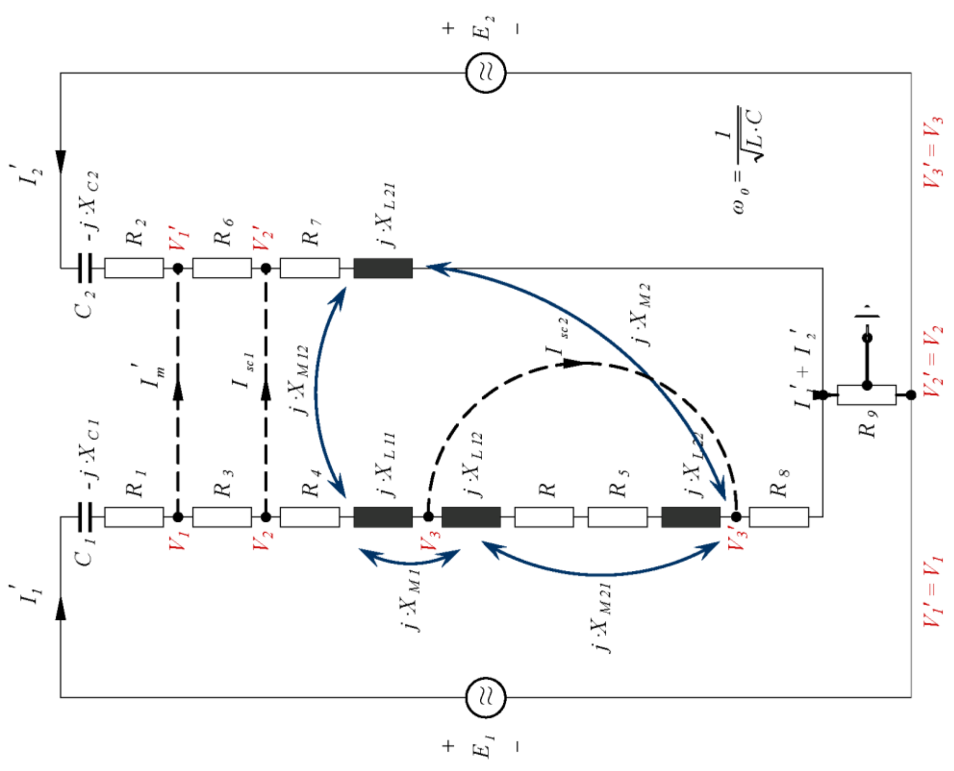

Fig. 2. Universal network equivalent circuit, after the real approximation model of the installation, to resonance conditions.

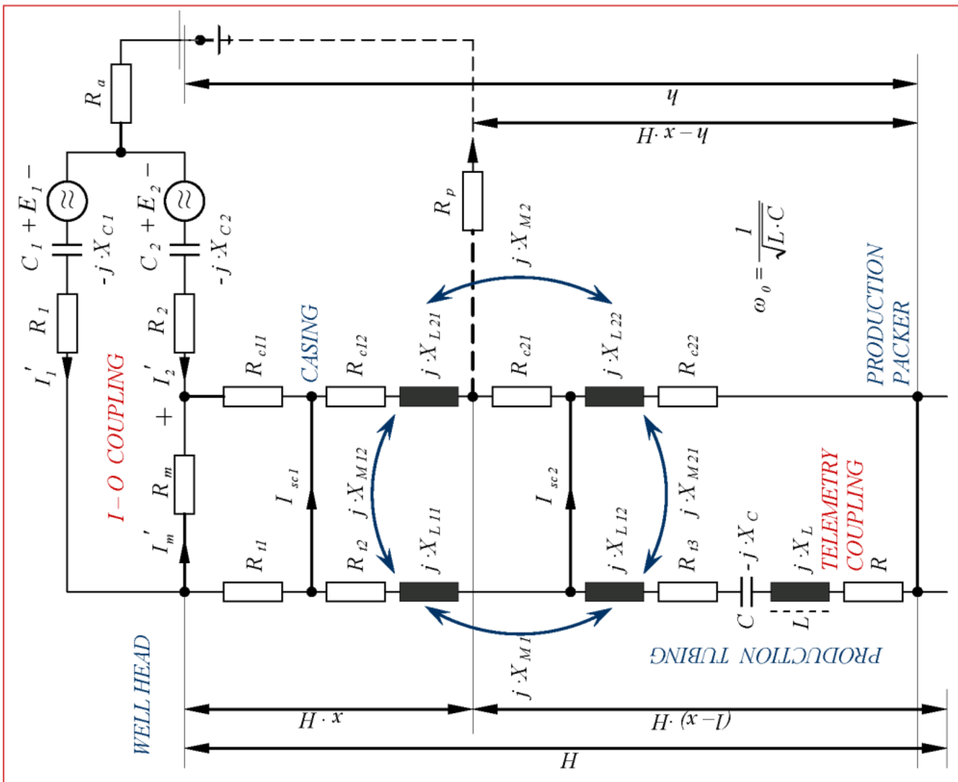

Fig. 1. Simplified electrical model used for dimensioning of the oil field installation elements to create the best conditions of energy propagation on line and recuperation of the down hole data by the measuring of the radio frequency sink current phase.

$$j \cdot X_{L11} \cong j \cdot X_{L21}, \tag{5}$$

$$j \cdot X_{L12} \cong j \cdot X_{L22}, \tag{6}$$

$$R_t = R_{t1} + R_{t2} + R_{t3}, \tag{7}$$

$$R_c = R_{c1} + R_{c2}, \tag{8}$$

$$R_{c1} = R_{c11} + R_{c12}, \quad R_{c2} = R_{c21} + R_{c22}, \tag{9}$$

$$R_{t1} = R_3, \quad R_{t2} = R_4, \quad R_{t3} + R_{c22} = R_5, \tag{10}$$

$$R_{c11} = R_6, \quad R_{c12} = R_7, \quad R_{c21} = R_8, \quad R_a + R_p = R_9. \tag{11}$$

Because the down hole equipment is tuned on ω_0 frequency, one can write:

$$X_C = X_L \quad \text{and} \quad \omega_0 = \frac{1}{\sqrt{L \cdot C}}. \tag{12}$$

This resonance condition will be the restriction to generate the whole set of equations necessary to solve the problem of power supply and cableless communication in the smart well.

In order to create the best conditions for propagation of the energy on the tubing line and the recovery of down hole data, a set of seven equations have been written.

First, for the ideal situation where there are not contacts between the tubing and the well casing, at resonance condition, the voltage equations are:

$$(R_1 + R_3 + R_4 + R + R_5 + R_8) \cdot I_1 + R_9 \cdot (I_1 + I_2) = E_1, \tag{13}$$

$$(R_2 + R_6 + R_7) \cdot I_2 + R_9 \cdot (I_1 + I_2) = E_2. \tag{14}$$

In order to minimize the current loss in the I/O coupling joint (figure 1) from the surface facility, it is necessary that *V1′ =V1*, that is:

$$(R_3 + R_4 + R + R_5 + R_8) \cdot I_1 = (R_6 + R_7) \cdot I_2. \tag{15}$$

In order to get the highest power for the coupled resistance of the bottom hole equipment, namely R , (telemetry coupling joint from figure 1), one can write:

$$I_1 + 2 \cdot R \cdot \frac{d I_1}{d R} = 0. \tag{16}$$

Let consider now the situation where there are two simultaneous contacts between the tubing and the well casing, one superior and the other inferior, the second one being situated under the equivalent midpoint of casing contact with the earth.

According to figure 1, at the first contact, situated at the superior level, it is necessary that *V2′=V2*, and so one can write:

$$(R_1 + R_3 + R_4 + R_8) \cdot I_1' + R_9 \cdot (I_1' + I_2') = E_1, \tag{17}$$

$$(R_2 + R_6 + R_7) \cdot I_2' + R_9 \cdot (I_1' + I_2') = E_2. \tag{18}$$

Finally, in order to minimize the current loss at the second contact between the tubing and the casing, situated under the equivalent point of contact of casing with the earth, it is necessary that *V3′ =V3*, that is:

$$R_3 \cdot I_1' = R_6 \cdot I_2' \, . \tag{19}$$

In the above set of equations, the unknowns are the resistance of the bootstrapping cable R_2, the coupled resistance of the bottom hole equipment, R, the voltage of bootstrapping generator E_2, (those three being the main three unknowns), and the additionally, I_1, I_2 i.e. the current through the tubing and the casing at ideal situation without line contacts, and respectively I_1', I_2', with line contacts.

Combining the above equations, it results:

$$R = R_3 + R_4 + R_5 + R_8 - \frac{R_1}{R_2} \cdot (R_6 + R_7), \tag{20}$$

$$\begin{aligned}
&(R_6+R_7+R_9)\cdot \left[R_3\cdot(R_6+R_7+R_9)+R_9\cdot R_6\right]\cdot R + \\
&+\left[(R_1+R_9)\cdot(R_6+R_7)\cdot R_3 + 2\cdot(R_3+R_4+R_5+R_8)\cdot\left[R_3\cdot(R_6+R_7) - \right.\right.\\
&\left.\left.- R_6\cdot(R_1+R_9+R_3+R_4+R_8)\right]\right]\cdot R_2 + \\
&+R_3\cdot R_9\cdot(R_6+R_7)\cdot(R_6+R_7+R_9+2\cdot R_1) + \\
&+(R_6+R_7+R_9)\cdot(R_3+R_4+R_5+R_8)\cdot\left[R_3\cdot(R_6+R_7+R_9)+R_9\cdot R_6\right] + \\
&+R_6\cdot(R_6+R_7)\cdot\left[(R_1+R_9)\cdot(R_9+2\cdot R_1) + 2\cdot R_1\cdot(R_3+R_4+R_8)\right] = 0
\end{aligned} \tag{21}$$

$$E_2 = \left[\frac{R_2\cdot(R_3+R_4+R+R_5+R_8) - R_1\cdot(R_6+R_7)}{(R_1+R_9)\cdot(R_6+R_7)+(R_3+R_4+R+R_5+R_8)\cdot(R_6+R_7+R_9)} + 1\right]\cdot E_1 \, . \tag{22}$$

The first two equations (20) and (21), first unlinear and the second linear, allows the determination of the R_2 and R unknowns, which can be used in equation (22) to find E_2.

Finally, knowing E_1:

$$I_1 = \frac{(R_6+R_7)\cdot E_1}{(R_1+R_9)\cdot(R_6+R_7)+(R_3+R_4+R+R_5+R_8)\cdot(R_6+R_7+R_9)}, \tag{23}$$

$$I_2 = \frac{E_1}{\dfrac{(R_1+R_9)\cdot(R_6+R_7)}{R_3+R_4+R+R_5+R_8} + R_6 + R_7 + R_9}, \tag{24}$$

$$I_1' = \frac{E_1}{R_1+R_3+R_4+R_8+R_9\cdot\left(1+\dfrac{R_3}{R_6}\right)} \, . \tag{25}$$

				h												f		E_1			P	Δt_2
	h	l_{l1}	l_{l2}	l_{t1}			l_{t2}				l_{t3}		l_a l_p	l_{l12}		kHz		V			W	min
		R_{l1}	R_{l2}		R_{t1}	R_{c11}		R_{t2}	R_{c12}	R_{c21}		R_{t3} R_{c22}	R_a R_p	Neliniar	Liniar	100		130			3.000	0.1
		R_1	R_2		R_3	R_6		R_4	R_7	R_8		R_5	R_9	R	R	I_1	I_2	E_2	I'_1	I'_2	γ	T
	m	Ω	Ω	m	Ω	Ω	m	Ω	Ω	Ω	m	Ω	Ω	Ω	Ω	A	A	V	A	A		min
Well 1	630	1.300	1.300	45	2.250	0.600	360	18.000	0.600	5.400	225	15.150	60.000	39.6000	39.6683	0.03124	2.09289	132.680	0.41673	1.56275	0.01288	7.76392
Well 2	756	1.300	0.860	54	2.700	0.720	432	21.600	0.720	6.480	270	17.400	60.000	46.0033	46.2927	0.03186	2.08409	131.751	0.40999	1.53747	0.01557	6.42274
Well 3	882	1.300	0.600	63	3.150	0.840	504	25.200	0.840	7.560	315	19.650	60.000	51.9200	52.1537	0.03244	2.07541	131.203	0.40346	1.51299	0.01821	5.49054
Well 4	1008	1.300	0.440	72	3.600	0.960	576	28.800	0.960	8.640	360	21.900	60.000	57.2673	58.5039	0.03301	2.06680	130.866	0.39714	1.48928	0.02080	4.80702
Well 5	1134	1.300	0.330	81	4.050	1.080	648	32.400	1.080	9.720	405	24.150	60.000	61.8109	63.2273	0.03365	2.05820	130.635	0.39101	1.46630	0.02332	4.28730
Well 6	1260	1.300	0.250	90	4.500	1.200	720	36.000	1.200	10.800	450	26.400	60.000	65.2200	65.1129	0.03442	2.04952	130.468	0.38507	1.44402	0.02575	3.88328
Well 7	1386	1.200	0.200	99	4.950	1.320	792	39.600	1.320	11.880	495	28.650	60.000	69.2400	70.9931	0.03492	2.04123	130.366	0.37942	1.42282	0.02814	3.55316
Well 8	1512	0.500	0.170	108	5.400	1.440	864	43.200	1.440	12.960	540	30.900	60.000	83.9894	81.6641	0.03322	2.03546	130.329	0.37458	1.40466	0.03090	3.23612
Well 9	1638	0.200	0.150	117	5.850	1.560	936	46.800	1.560	14.040	585	33.150	60.000	95.6800	99.5932	0.03237	2.02869	130.298	0.36943	1.38538	0.03342	2.99185

Table 1. Data provided and the obtained results for the illustrative application.

Time-Rate Parameters

Noting by T the time per cycle, t_2 the time length of data transmission, P_R the power for the coupled resistance of the bottom-hole equipment, and P the transmission power of the bottom hole equipment due to energy accumulation, one can write:

$$P_R = R \cdot I_1^2 , \quad P_R \cdot T = P \cdot \Delta t_2 , \tag{26}$$

$$\gamma = \frac{\Delta t_2}{T} , \quad \gamma = \frac{P_R}{P} = \frac{R \cdot I_1^2}{P} . \tag{27}$$

where γ represents the time rate parameter.

Application

The above algorithm has been applied for the conditions of a smart well from a Romanian oil field. The data used for this application and the obtained results are presented in the table 1. The table is presenting different types of well structure in order to prove the feasibility of the method for different conditions from the oil field.

Supplied frequency of active sections of the ensemble is one placed at upper extremity of audio wave band and below extremity of radio wave band, that's equivalent to 100 kHz.

The bootstrapping generator voltage E_2 tracks the pilot generator voltage E_1, but with a determinated amplitude ratio.

The action mode of the down hole transmission line is the one half duplex, which is controlled by the surface computer, similar a RS 232 interface. Together with the bottom hole equipment, this ensemble constitute an Alternating Data Acquisition / Transmission System, which includes a longish wait time prerequisite of load accumulation, this process being defined in a further application by a parameter named the Time Rate Parameter, γ. It is formulated like the ratio between the real time of transmission, Δt_2, and the periodic time, T.

The obtained results prove that the set of equations used for the design of a such process are consistent and physically realistic. Also, because the energy necessary for a proper work of the down hole equipment, in a time sharing manner, is relatively low, the application of the method in an actual world, has a great chance of success.

Conclusions

The paper presents a novel method of cableless data transmission and power supply in a smart well environment.

It has been also presented a straightforward algorithm for the design of such process.

The example application of the method for an actual smart well from a Romanian oil field proved that the new method is feasible.

The counteraction of the effects created by the uncontrolled contacts between tubing and the well casing, are assured by the bootstrapping feed-back of intermediary casings of the well, and therewith the maintenance in a limited values range of current value from tubing line for various depths of the well.

For the worst situation when the lines are in contacts, the current value in main line increases of over tenfold, therefore the bottom-hole equipment can be power supplied through electromagnetic coupling between line sections, resulting a current of one value close to initial value.

The maintenance of the effective power versus the depth is explained by the descending of the equivalent midpoint of casing contact with the earth.

For a time of transmission of 6 seconds, a bottom-hole equipment with a power of 3W must to wait within 3 - 8 minutes.

The values resulted are very common, and thus the equipment can be designed within standardized elements limits.

References

1. P a r a s c h i v , N . – *Echipamente numerice pentru conducerea proceselor*. Ed. UPG, 1996.
2. * * * – *Industrial Control Equipment. CD 2006/2007*. Rom Devices, www.romdevices.ro.
3. * * * – *Industrial Measurement and Control (CD).* National Instruments, www.ni.com.
4. * * * – *Soluţii pentru instrumentaţie şi automatizări (CD).* MDS Electric, www.mdselectric.ro.

Alimentare şi comunicaţie fără cablu la o sondă inteligentă

Rezumat

Această lucrare prezintă partea de optimizare a valorilor elementelor de adaptare a echipamentului cu structura metalică a sondei, pentru o instalaţie de comunicaţie fără cablu şi alimentare exclusiv de la suprafaţă, într-o sondă inteligentă. Scopul este de a face posibile transmiterea informaţiei şi a energiei de la (/ la) suprafaţă la (/de la) adâncime, numai prin infrastructura minimală a sondei. În *lucrare este prezentat şi un exemplu practic care ilustrează modul de utilizare a algoritmului de proiectare a procesului elaborat.*