A HIGH TEMPERATURE ELECTRONIC SYSTEM FOR MONITORING AND CONTROL OF “INTELLIGENT OIL WELLS”

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Modern complex oil wells with many productive zones operating on a common production tubing may benefit significantly using detailed monitoring and control of the different flows into the well. Ideally the operators want to know and control the individual flows of oil, water and gas from each source within the well. In addition, reservoir parameters like pressure and temperature are always of interest.

For a complex well, seventy primary sensors and seven choke valve control systems may be needed. The equipment will typically operate for extended periods (5-10 years) at an environmental temperature ranging from 150 to 200°C.

SINTEF Electronics & Cybernetics has recently successfully concluded a three year R&D project for the oil industry, with main objective to meet this goal.

A separate paper presents one of the integrated circuits (Σ/Δ-converter) designed as part of the project.

In every joint of the multilateral well, a control module is installed. It will control the liquid flow from each lateral individually, based upon measurements of pressures, temperatures and quality of the liquid flowing from each producing zone into the well. All modules are communicating to topside on the same single conductor wire, encapsulated in stainless steel, supplying power to the downhole equipment at the same time.

System philosophy

To reduce complexity and enhance reliability, the system is based on five specially designed integrated circuits HTASIC®. Two of these take care of the communication to topside, 5km along a downhole cable with a single conductor, which also supplies power to the downhole equipment. One HTASIC® is used to stabilize power individually for each sensor or control circuit. Finally, two circuits are developed to interface the various primary sensor elements used.

The system is digitally time-multiplexed and will transmit control commands downhole when needed, as well as monitor the downhole sensors on a continuous basis. Both power and signals have no DC-component. This enables the use of an inductive coupler to be a part of the downhole cable, simplifying system operation and maintenance. The system is designed for full redundancy of all downhole parts.

A block diagram of the system is shown on the next page.

(HTASIC® is a trademark of SINTEF, Wellbus® is a trademark of Maritime Well Service A/S)
The communication system

Two HTASIC® chips take care of the communication. A “Communication Master” converts the RZ signals used on the Local bus internally in the control modules to a 10V_{pp} bi-phase signal suited for the long transmission to topside. Correspondingly it also receives the messages from topside and converts the configuration data to the simple and efficient RZ format used on the local bus.

The Telemetry Master Module acts as a signal amplifier and transparent code converter between Biphase and Rz code. It also supplies the local-bus and thus all TTC-circuits with a common synch. signal. The Biphase Transmitter (10V_{pp}) is inductively coupled to the downhole cable. Notch filters remove residues of the power frequency.

The TTC chip is the heart of the decentralized communication system. On each sensor board this chip will receive the signals from the transducers, reformat them, and send them to the “Master”, time multiplexed with data from all the other TTC’s connected to the local bus.

All sensors and actuators communicate with topside through a “Tool Telemetry Chip”. It has two input channels, normally intended for the primary signal and a compensation signal. The circuit will detect and recognize messages on the local bus given the right address tag. Messages contain six control bits for external use in addition to internal configuration data for the TTC. These data are used to specify input configuration and speed of communication for this specific TTC.
More details of the TTC chip are shown here. The input signals may have three different formats. Channel 1 is a pulse frequency input but the frequency may be multiplied by 64 to enhance time resolution of low frequency signals. Channel 2 may have voltage input, frequency or binary data.

The time multiplexing scheme is illustrated by the data format used throughout the system. This is shown below.

A data frame consists of 32 bits and contains one bit of data from each of the up to 19 TTC’s, in addition to synchronization bits. A full data word from all sensors consists of 50 such frames and this is sent to topside every 1/8 sec. at lowest transmission rate. The data word from each sensor consists of 24 bits from Channel 1, 16 bits from Channel 2 and a 10 bit delimiter.

**Choke valve control**

A step motor is used to control the choke, and it is stepped forward or backwards a specific number of steps given by a control word from topside. As an adjustment of the choke is a quite important task, a special 3-bit “go” signal in addition is needed to make the motor start.

Three TTC circuits supply a total of 18 control bits needed to specify a move to the next position with a resolution of 0.07mm and generate the safe start signal.

To be completely certain of the choke position, two different methods are in addition used to monitor this parameter. A simple tacho generator is counting the number of revolutions of the motor and a fully independent capacitance position sensor is measuring the position of the choke barrel directly.

A high temperature step motor controller is developed based on HCMOS standard circuits. Slow motion allows high forces (2kN) to be generated at low power consumption (10W).
Sensors
A total of 7 primary sensors are used for the process monitoring at each inflow position. Two absolute pressure transducers (1-1000 bar), one differential pressure transmitter (±1 bar), one capacitance sensor for water/gas-cut, and a differential temperature sensor (±1K). In addition there are a temperature sensor and two different choke position sensors. Several voltages and currents are also monitored.

All primary sensors were designed for this special application, and two different sensor element front-end circuits are used for the primary analog to digital conversion. A capacitance measuring circuit (CMC) is used for differential pressure, watercut and choke position. A Σ/Δ converter with a differential input stage is used for all bridge-type sensors like the temperature sensors (Pt-2000) and the pressure sensors.

A very compact, high performance, absolute pressure sensor is also developed during this project by the Norwegian company Presens A/S. Two units are used to monitor well pressure and zone pressure respectively.

1000 bar pressure sensor from Presens A/S
This is a SOI based strain gauge sensor which has demonstrated good performance during our tests. Pressure rating 1-1000 bar (2000 bar surge pressure) Specified accuracy is 0.1%.
Extreme resolution down to 1ppm, has been observed during system testing by taking mean value of readings over a few seconds.
The sensor is designed to operate in the temperature range 0-200°C. System measurements were done at 100°C and 100 bar system pressure.
Temperature compensation is based on strain gauge bridge resistance, while our Σ/Δ converter measures the bridge output and converts it to frequency.

Watercut by two means
The fraction of water in the oil produced is naturally of prime interest in an oil well. In the IPC system, two different sensor elements are giving data for this measurement.
The first is based on the traditional capacitance concept, measuring the change in the electric field due to saltwater droplets around a concentric system of electrodes. The other is a thermodynamical concept distinguishing water from oil based on the difference in thermal properties. The latter is illustrated below.

A differential temperature gauge is made from two sets of Pt-2000 elements in a full bridge. The voltage across the bridge is a measure of the difference in temperature on the two sides of the choke. The energy lost in the choke will heat the fluid, and the temperature difference will be much higher for oil than for water. Temperature differences as small as a few mK are used.

Testing
The system has been successfully tested for measurement and control functions in a flowloop and training well. All system parts including electronics withstand 200°C, fully operational.

Based on the sensor readings, models for estimation of oil/water and gas flows have been developed. Below some of these results are shown.

Finally, system estimates of oil and water flows are compared with process data from the flow loop. It is important to note that these data were obtained under close to real downhole conditions at Norsk Hydro’s Research lab.

The mixture of oil and water flows measured by the IPC system during flow loop experiments at Norsk Hydro Research:
The green and amber curves show the flow of oil and water measured by Hydro before mixing, while the black and blue lines are our estimates. Note the time difference between corresponding curves. It relates directly to the transit time in the flow loop between the two measurement points.
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