Down-hole switching-mode power supply using a remote CA start up pulse

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Abstract

The hydrocarbon industry leans heavily upon advanced technologies to extract oil and gas from greater depths and in harsher environments. The challenge to electronics manufacturers and designers is to make complex electronics work at the high temperatures, vibration, and extreme pressures encountered in these locations. Among the more critical electronic systems required for high temperature down-hole operations is high efficiency switching mode power supplies (SMPS). The use of high frequency switching permits not only decreasing the size of inductors and capacitors in the circuit design, but also obtaining typical power efficiencies up to 90%. Generally a SMPS is composed of a controller, a converter and silicon carbide (SiC) power switches. High temperature down-hole gauges operate with low voltages either 3.3V or 5.0V; however, wire-line surface power equipment utilizes higher voltages above 250 V CD. Hence, SMPS requires efficient power dissipation circuits to reduce the DC input voltage. This work describes a high temperature SMPS that has a DC input range from 150 V CD to 300 V CD, ± 6 V CD output voltages and 12 W total power. The SMPS design uses a CA start up pulse provided by a programmable surface power supply via a mono-conductor wire-line cable; subsequently, the SMPS sustains its operation by powering itself using one of the voltage outputs. The obtained laboratory tests results of the down-hole SMPS, using changes in temperature from 25 °C – 200 °C, provide a firm basis for testing and evaluating the DC-CD power supply in high temperature gauges in the field.

Introduction

Several industries around the world are demanding for electronics that can operate reliably in harsh environments, which comprises extreme high temperatures. One of these is the down-hole oil and gas industry, with down-hole temperatures regularly reaching 150ºC to 175ºC within the deep shale, and greater depths can reach temperatures as high as 200ºC. While drilling, down-hole instruments are required to acquire data about the surrounding geologic formations, a practice denominated as well logging. During production phases, down-hole measurement tools monitor pressure, temperature, vibration, and multiphase flow [1]. Down-hole measurement tools are located in the bottom-hole assembly (BHA) and provide real-time information to a data acquisition equipment (DAE) located in the surface via a mono-conductor wire-line cable as depicted in figure 1 [2-4].

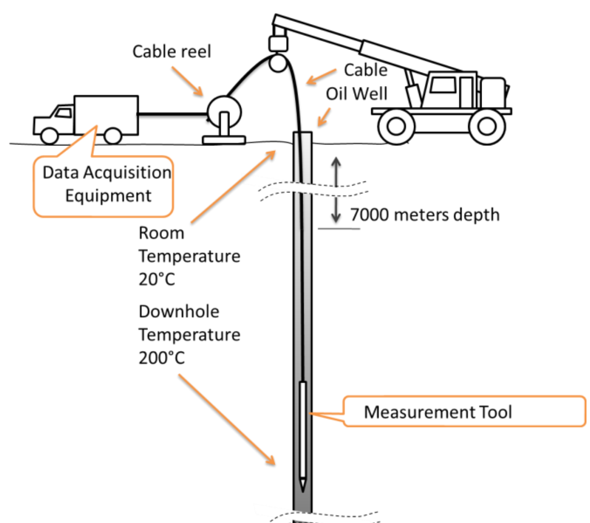

Figure 1. Down-hole gauge located in the BHA and a data acquisition system located in the surface.

The oil and gas industry relies on advanced down-hole electronics instruments designed to work in the harsh environments encountered in these locations. These instruments are continuously challenged and there has been an increase of electronic systems that gradually improve its performance for some of these difficult environments. Among the most basic, however critical, electronic systems needed for extreme temperature operations is the high efficiency switched mode power supply (SMPS) [5].

Usually a SMPS is composed of a controller, a converter and silicon carbide (SiC) power switches. SMPS use high frequency switching in the order of 50 kHz to 1 MHz, which permits decreasing the size of inductors and capacitors in the circuit design, as well as attaining typical power efficiencies up to 90%. These types of power supplies, at high switching frequencies, periodically sample and store energy in an inductor, which converts this energy to charge on a filter capacitor at the desired voltage. Voltage regulation is achieved by using a control loop to vary the duty cycle of the switch that regulates the output voltage.

High temperature down-hole gauges operate with low voltages either 3.3V or 5.0V, generally digital logic and embedded microcontrollers, e.g. high pressure and high temperature (HPHT) measurement tools, gamma ray counters and motor control applications. However, wire-line surface power supplies equipment utilizes higher voltages above 250 V CD. Therefore, SMPS requires wider input voltages and efficient power dissipation circuits to reduce the DC input voltage.

This work describes a high temperature, high voltage SMPS that is planned to be used by an HPHT measurement tool. The SMPS has a DC input range from 150 V to 300 V, symmetric output voltages up to ± 6 V CD and 12 W total power. The SMPS design uses an AC start up pulse provided by a programmable surface power supply via a mono-conductor wire-line cable; subsequently, the SMPS sustains its operation by powering itself using one of the voltage outputs. The obtained laboratory tests results of the down-hole SMPS, using changes in temperature from 25 °C – 200 °C, provide a firm basis for testing and evaluating the SMPS in a proprietary HPHT measurement tool in the field.

High temperature SMPS hardware description

The HPHT measurement system is controlled by a Labview application running in the DAE at surface level. The DAE includes a programmable AC and DC power supply, which is used for remotely powering the down-hole tool thought the logging cable as shown in the block diagram of figure 2.

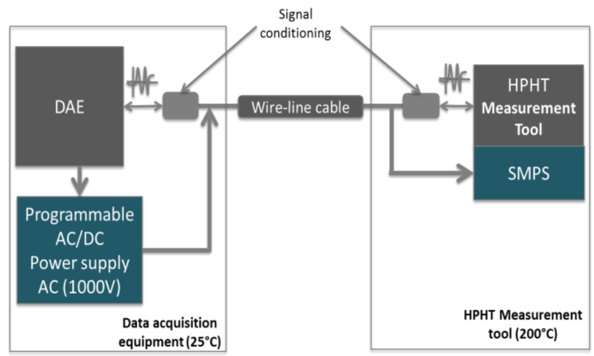

Figure 2. HPHT measurement system and its power supply

The down-hole SMPS is designed using high temperature electronics parts that support an operating temperature up to 200ºC. However, even though the electronics withstand the temperature of the BHA, working electronics produce heat, even when the temperature is already high. This problem becomes more severe as the environment progresses to hotter states.

The power supply in the DAE, used to power the electronics of the HPHT measurement tool via wire-line cable, employs DC voltages. Usually these DC voltages are reduced to match the input voltage range of the down-hole SMPS PWM controller using resistive voltage dividers arrays, which increases the heat produced in the electronics, since it is proportional to the current demanded by the system.

The SMPS is a fly-back architecture made of a high pass filter and rectifier as a front end, a commercial PWM controller and its voltage and current feedbacks, a fly-back transformer, a SiC power switch and two output filters. Figure 3 depicts the block diagram that constitutes the SMPS.

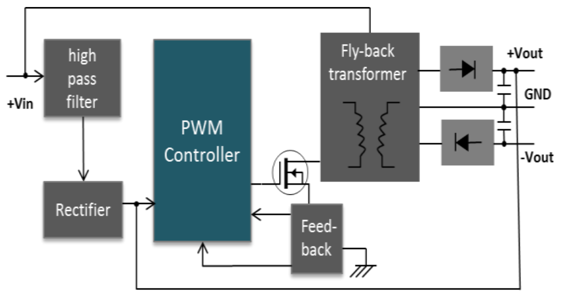

Figure 3. SMPS block diagram

The SMPS has a DC input range from 150 V to 300 V, but the PWM controller has DC input range from 5.5 V to 52 V. With the intention of reducing this high voltage range and exclude voltage dividers, a front end made of a high pass filter and rectifier was implemented as shown in figure 4.

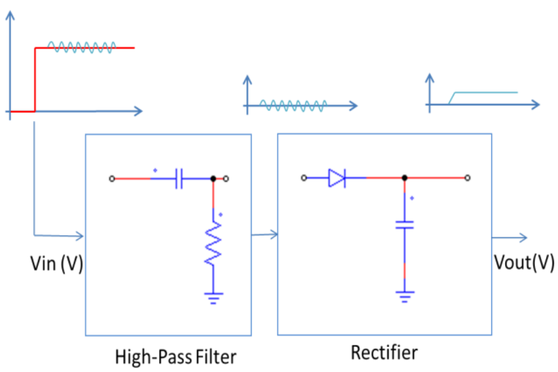

Figure 4. SMPS electronic front-end

In order to turn the SMPS on, a start pulse is required. The programmable power supply controlled by the DAE provides a CA signal superimposed in the DC input voltage range. The CA signal is made of 100 cycles 400 Hz sine wave that uses a voltage range from $10V_{pp}$ to $50V_{pp}$. The high pass filter and the rectifier produced a DC pulse within the input range of the PWM controller. Once the PWM controller is turned on, it keeps operating by powering itself by one of the outputs of the SMPS, as depicted in figure 3. This approach eliminates the use of voltage dividers or pre-regulation stages before the controller, which reduce the temperature in the system.

The SMPS output voltages used synchronous rectification in order to optimize the system efficiency. Voltages regulation in the outputs was attained by means of a voltage feedback towards the PWM controller. The SMPS has a short-circuit protection that was implemented by a current sensing feedback mechanism on the primary side of the fly-back transformer. A threshold was set; above this level, the sensing function disables the gate of the power SiC transistor. Figure 5 depicts an oscillator frequency of 64.5 kHz used in the PWM modulation.

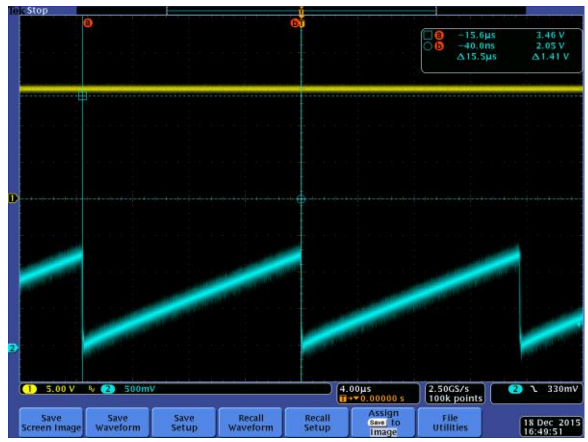

Figure 5. Oscillator frequency of 64.5 kHz used in the PWM modulation.

Figure 6 shows a photograph of the actual SMPS that used a remote CA voltage start pulse.

Figure 6. High temperature high voltage SMPS that used a remote CA voltage start pulse.

Laboratory trials and results

The SMPS was tested in the laboratory using an oven and a 5000m wire-line cable real. During the laboratory trials a DAE provided both the CD voltage input range and CA start pulse. The SMPS was introduced in the oven and the temperature was varied from 25°C to 200 °C. A resistive load was connected to the SMPS in order to withdraw 6 W. The symmetric output voltages were monitored using an oscilloscope as depicted in figure 7.

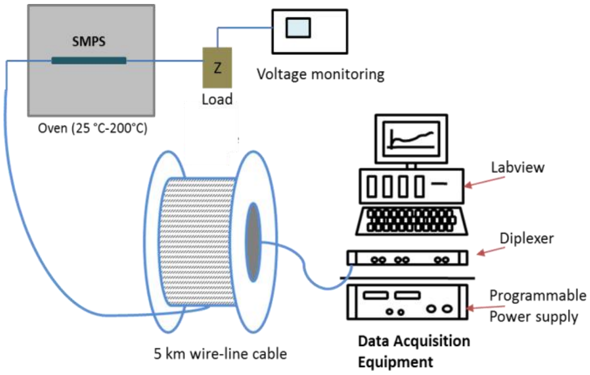

Figure 7 Laboratory setup

Figure 8 shows a SMPS output voltage using a CD input voltage of 150 V, depicted in the yellow trace, and the output voltage of 5.5 V CD, identified as the blue trace.

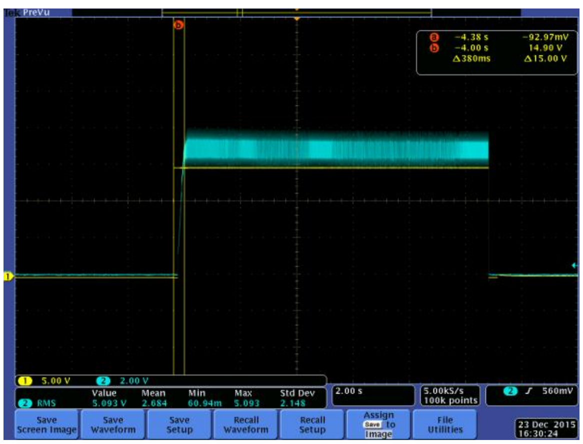

Figure 8. SMPS output voltage using an input voltage of 150 V CD.

The obtained laboratory results were successful in testing the SMPS using a CA start pulse.

Conclusions

A Fly-back architecture SMPS using high temperature parts and a remote CA start pulse is presented. The SMPS design provides isolation capability, and two symmetric outputs while maintaining good regulation. The SMPS has a DC input range from 150 V CD to 300 V CD, ± 6 V CD output voltages and 12 W total power. The SMPS excludes the use of voltage dividers or pre-regulation stages that produce heat by using an electronic front end made of a high pass filter and a rectifier, along with a CA start up pulse supplied by a programmable power supply, located in the surface, via a wire-line cable; subsequently, the SMPS sustains its operation by powering itself using one of the voltage outputs. The attained laboratory tests results of the down-hole SMPS, using changes in temperature from 25 °C – 200 °C and a 5000 m wire-line cable offer a firm basis for testing and evaluating this power supply in a HPHT gauge in the field.

Acknowledgment

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