DIGITAL MEASUREMENT OF THE ELECTRICAL ENERGY

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Abstract: The paper describes the electrical energy measurement techniques based on 8-bit microcontrollers. The advantages of this new method are the precision and a high reliability of the equipment.

Keywords: electrical energy measurement, analog to digital converter, microcontroller, current measurement, tension measurement

1. INTRODUCTION

Today, utilities operate in a competitive environment. Deregulation and soaring global energy demand make increasing revenue while cutting costs the number one concern. To succeed in such a challenging environment, utilities need a more effective energy measurement solution to increase billing accuracy and enable advanced data collection.
As a key component of electronic energy meters, the energy measurement integrated circuit (IC) reliability has a direct effect on the life expectancy of the whole system. IC reliability and its importance for the system are not a new issue for semiconductor manufacturers.
The development of the microelectronics allows at present the specialized devices for single phase or three phase's electrical energy measurement.
Analog Devices manufacture the ADE7761 integrated circuit for single-phase electrical energy measurement.
Figure 1 shows the implementation of a simple, low cost watt-hour meter using the ADE7761. The meter consists of three current transformers, a power supply, mechanical counter, and the various support circuitries's for the ADE7761.
The energy register (kWh) is a simple electromechanical counter that uses a two-phase stepper motor. The ADE7761 provides direct drive capability for this type of counter.
For three phase energy measurement the ADSST-EM-2030 IC from Analog Devices can be used.
ADSST-EM-2030 is a highly accurate and low cost phase energy measurement IC intended to be used in 3-phase, 4-wire systems. When used with an op amp and a multiplexer, the ADSST-EM-2030 surpasses the accuracy requirement of the IEC1036 standard.
ADSST-EM-2030 is a MicroConverter® consisting of a microcontroller, 6-channel, 12-bit ADC, SPI port, program memory and Flash for storage of constants. The only analog circuitry used in ADSST-EM-2030 is the ADC. All other signal processing is carried out in digital domain. This provides superior accuracy over extreme environmental conditions and time.
ADSST-EM-2030 can drive an electromechanical counter or a 2-phase stepper motor counter, or can be interfaced to a microcontroller to build a feature-rich meter with LCD, maximum demand, time of use, and communication.
Figure 2 shows the block diagram for poly phase energy meter using the ADSST-EM-2030.

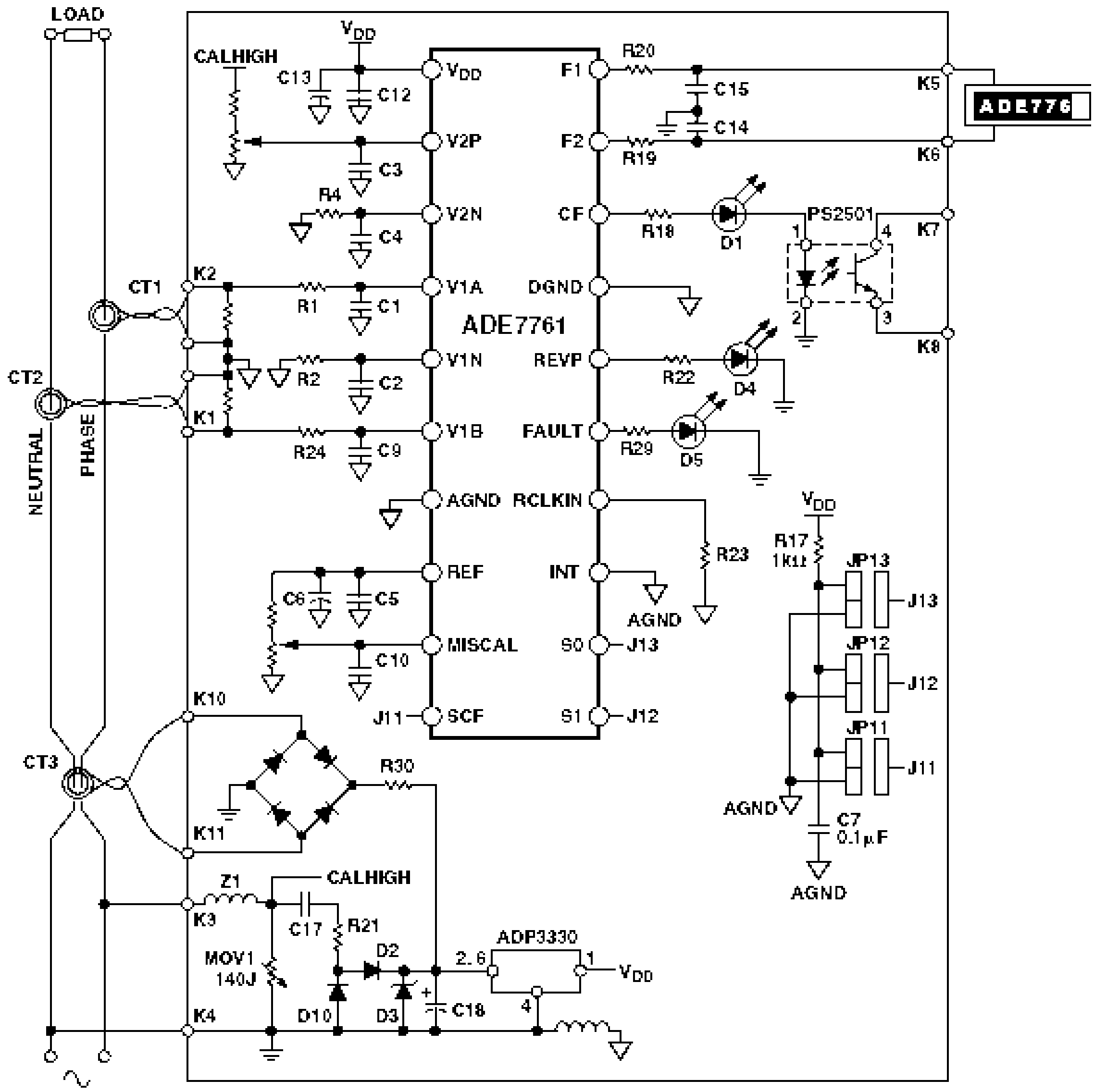

Figure 1. ADE7761 Functional Block Diagram

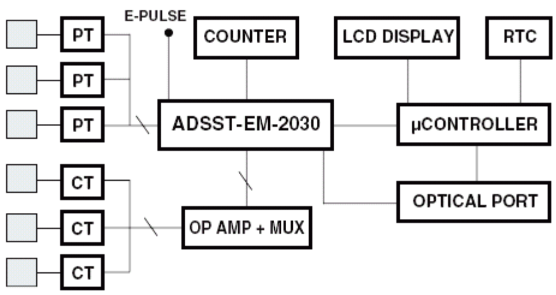

Figure 2. Poly phase energy meter using the ADSST-EM-2030

2. SINGLE-PHASE POWER/ENERGY METER WITH TAMPER DETECTION

This paper describes a single-phase power/energy meter with tamper logic. The design measures active power, voltage, and current in a single-phase distribution environment. It differs from ordinary single-phase meters in that it uses two current transducers to measure active power in both live and neutral wires.
This enables the meter to detect, signal, and continue to measure reliably even when subject to external attempts of tampering.
The heart of the meter is an AVR microcontroller. All measurements are carried out in the digital domain and measurement results are available in the form of frequency-modulated pulse outputs and as plain-text values, accessible over the USART interface. This enables the design to be used in cost-effective applications based on mechanical display counters. Alternatively, the design easily fits more computerized applications with features such as remote reading (AMR), demand recording, multiple tariffs, and other.
The block diagram of the single-phase power/energy meter with microcontroller is sown in Figure 3. The AVR 90S2313 is used.

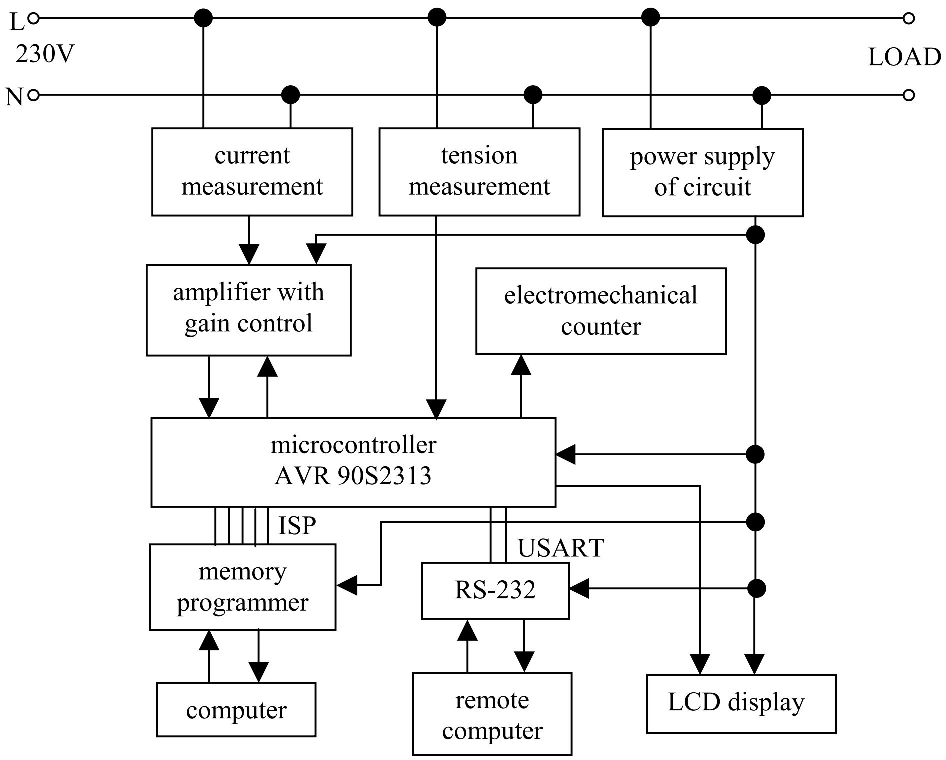

Figure 3. Block diagram of the single-phase power/energy meter

The single-phase electrical energy meter is composed by a tension transducer (resistor ladder), a current transducer with a controlled gain amplifier, an electromechanical counter for the electrical energy measurement, a LCD display for local messages. For the microcontroller programming an on board ISP programmer is used. The serial interface is used for remote communication of the data. The power supply is a very simple transformerless circuitry.

2.1. Capacitor divider supply

The power supply provides power through a high voltage capacitor (C1, Figure 4), that is connected to phase. This capacitor provides the charging current through a diode to a large storage capacitor. A low voltage dropout regulator is used to provide the regulated 5 V supply for the meter.

Figure 4 is the schematic for the power supply. This circuit works as long as a return path for the current is provided through ground. If the meter ground (neutral) is disconnected, there is no current return path for the supply and the capacitor divider circuit shuts down. When the microcontroller determines that there is no zero crossing in the phase signal, the microcontroller goes in to missing neutral mode. The power supply for the capacitor divider supply ceases to operate.
In this supply, capacitor C2 is used to store charge for the voltage regulator. C1 provides the charge through R1. During the positive half-cycle of the line, DZ clamps the voltage on C2 preventing it from exceeding the maximum input voltage to the regulator. On the negative half-cycle, the diodes D1 and D2 are active. D1 blocks the line from C2 preventing it from discharging.
D2 is used to charge C1 during the negative half–cycle through ground.

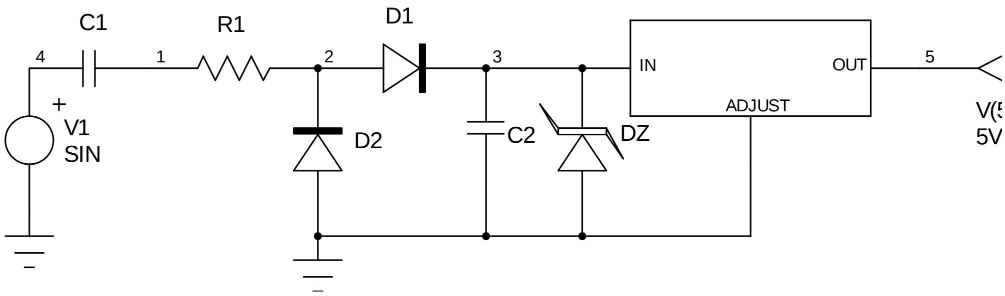

Figure 4. The capacitor divider supply

2.2. Analog front end

The analog front end is the part, which interfaces to the high voltage lines. It conditions high voltages and high currents down to a level where the signals cannot harm the more delicate electronics. It converts high voltages and high currents to voltages sufficiently small to be measured directly by the ADC of the microcontroller.
The nominal line voltage of the meter is 230V and the maximum rated current is 10A, both of which obviously are way too large signals to be fed directly to any microcontroller. The analog front-end converts line voltage and line current to voltages with amplitudes of no more than 1V peak-to-peak. The front end is easy to configure for any other line voltage or current, as described in the following.
Line voltage is first downsized using a resistor ladder, then DC-filtered and finally DC-biased, as illustrated in Figure 5.
The resistor ladder R1-R2 by default produces a 1.1Vpp signal when the line voltage reaches 115% of nominal voltage, as follows:

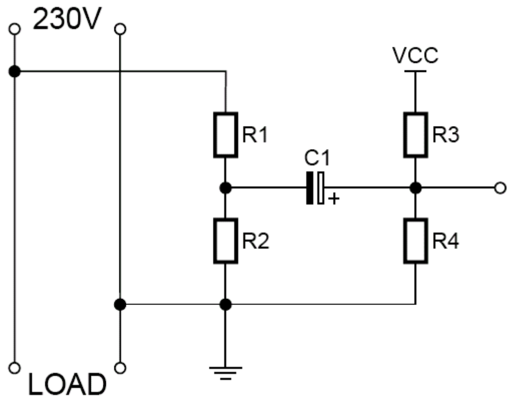

Figure 5. Voltage Front End

$$U_{\max} = U_{nom} \cdot 1.15 \cdot \frac{R_2}{R_1 + R_2} \tag{1}$$

The current front end is a little bit more complex than the voltage front end. This is because line voltage remains constant at, say, 230V but line current varies with the load. Line current typically ranges from some milliamperes to ten amperes, or more. In order to achieve 1% measurement accuracy over such a wide range, the ADC would need to have a resolution of around 16 bits. Since the target device includes only a 10-bit A/D-converter the front end must amplify small-scale signals. The current front end therefore includes a programmable gain stage, which is controlled by the MCU.

The benefits and drawbacks of the different current sensor technologies are presented in Table 1.

Table 1

Sensor	**Benefits**	**Drawbacks**
Low Resistance Shunt	Very low cost, good linearity	Poor high current capability, dc offset, parasitic inductance
Current Transformer	High current performance, low power consumption	Hysteresis/saturation due to dc, phase shift
Hall Effect Sensor	High current performance, wide dynamic range	Hysteresis/saturation, higher cost, temperature drift
Rogowski Coil (Air-Core CT)	Low cost, no saturation limit, low power consumption, immunity to dc offset, wide dynamic range, very low temperature range	Output is derivative of voltage signal - requires an analog (or digital) integrator. EMI sensitivity

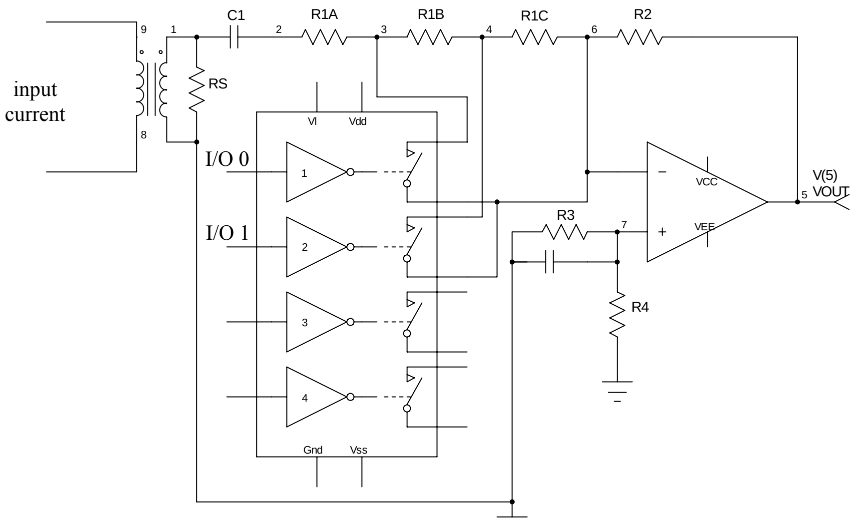

Figure 6. Inverting amplifier with variable gain uses bilateral switches (74HC4066)

The design criteria for the programmable gain stage are not very relaxed; the gain stage must amplify AC signals up to around 100x, but provide little or no DC amplification. This is because the input is a DC-biased AC signal and if the gain stage provides even a small DC amplification the output will saturate. In addition, the gain must be programmable by the MCU and the settling time must be considerably less than a second. Finally, the design must be cost-effective.

A viable solution is found from inverting amplifier topology, although it still requires a rather (but not very) large capacitor to be used. Gain configuration resistors are readily toggled in and out using low-cost switches from 74HC-series logic, as shown in Figure 6. The gain stage shown has a fast switching time and allows high AC gain but a low DC gain.

Gain Of Inverting Amplifier:

$$A = -\frac{R_2}{R_1} \tag{2}$$

Here R1 consists of the series connection of R1A, R1B and R1C. Gain is adjusted by shorting out one of resistors R1B or R1C. This is done using the bilateral switches, which are controlled by two I/O pins of the MCU, shown as I/O0 and I/O1 in the figure.

3. CONCLUSIONS

To make accurate measurements, the input signal must be as clean as possible, especially at low amplitudes. Input signals with low amplitude are amplified before being sampled and processed, which means any noise in the signal will be enlarged, too.
Energy meters are prone to operate in harsh environments; meters are often subject to over-voltages and current spikes. If such disturbances are not properly shielded they may traverse all the way to the MCU and drive it outside operating limits.
For display purposes, this application uses what is sometimes referred to as a stepper motor counter. These types of counters are typically available in a price competitive range and tend to be rather common in designs like this. The counter is driven using a pulse waveform.
The programming interface is required for programming the microcontroller and for calibrating the meter. Using the serial programming interface (SPI) of the AVR, it is possible to access both Flash and EEPROM via the same connector. Complete system programming and calibration can be performed at any time.
The application uses the USART (Universal Synchronous/Asynchronous Receiver/Transmitter) interface of the AVR to send measurement data. Any terminal software can be used for sending commands to the meter and for receiving measurement data. Measurement results, once calibrated, are given in units of watts, volts and amperes.
A tamper condition enters when meter wiring is altered in a pilfering manner, typically with the intention to reduce electricity billing. The firmware detects signals and continues to measure accurately under more than twenty known tamper conditions, including reversal of current and partial or whole earth reroutings.

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