Predictive Maintenance in Smart Meters Using Real-Time Monitoring

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Residential smart meters are used for billing of electricity, gas, water, and heat. The technological advancements in these smart meters are being driven by the demand from utility companies to create a smarter and more efficient grid aimed at reducing non-revenue losses. More sensors are being added to collect more data about the status of the grid including pressure, temperature, etc. There is also a growing trend to incorporate higher precision measurements with newer technologies, such as ultrasonic flow measurements, which often end up adding to the overall complexity, reliability, and power consumption. These meters are also often part of radio-frequency (RF) communication networks that can draw a variable amount of power from the system depending on the required output power of their signal.

Overall, these trends are driving more electronics into these smart meters while still maintaining >15 years of lifetime without required regular maintenance. This is leading to the industry trend of predictive maintenance which allows utility companies to better understand and predict when and where failures will occur similarly to how this is being done in other industries like factory automation. The goal is to maintain a system with minimal interaction over a long period of time with high reliability. Utility companies cannot tolerate a failure in a smart meter because of the financial damage or loss incurred, so a quick or preemptive solution is required.

When designing these next-generation smart meters, it is important to keep several key factors in mind: 1) high reliability, 2) low power consumption, and 3) small size. With higher reliability, utilities spend less on maintaining existing infrastructure and reduce overall operating costs. With lower power, meters are able to operate longer on a single battery. With smaller size, more sensors can be placed in more locations further increasing the intelligence and efficiency of the 'grid' - whether water, gas, heat, or electricity. For instance, with waters meters the addition of information about the pipe pressures will allow for optimization of the pressure injection into the grid and extend the lifetime of the pipes.

More details about how this type of system-level monitoring can be implemented is explained in the Battery and System Health Monitoring of Battery Powered Smart Flow Meters Reference Design.

Autonomous Real-Time Monitoring

The autonomous monitoring capability of a device like the ADS7142 enables higher system reliability by raising an alert when the current consumption goes outside of the known good operating range. This could be caused by aging of the ultrasonic electrodes, changes in urban configuration requiring higher RF transmission time, aging capacitors and inductors, or software malfunction. All of these would cause higher current consumption that would be detected and preemptively addressed before the lifetime of the meter expires. Figure 1 illustrates the concept of using programmable thresholds to monitor a signal and wait for an alert.

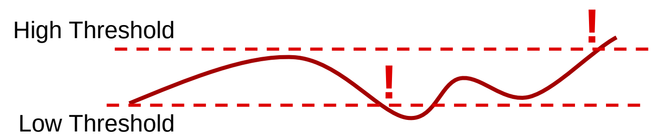

Figure 1. Programmable Thresholds for Monitoring

Early detection of these types of faults is possible by more closely monitoring the normal current consumption profiles before they reach true fault levels. In other words, the system can detect slight changes in current consumption over time instead of waiting for a known fault level thereby enabling earlier detection of faults before they become critical and perhaps allowing the system to simply be repaired instead of replaced. Figure 2 illustrates the concept of detecting a fault before it gets to critical levels.

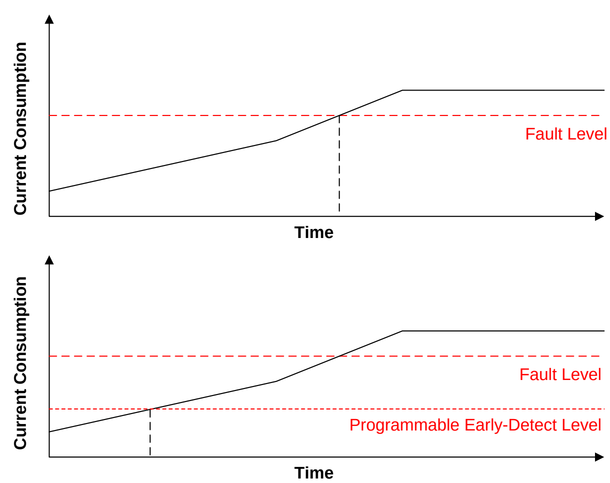

Figure 2. Early Detection of Faults

Low-power Real-Time Monitoring

When implementing a real-time monitoring function, it is important to consider the impact this will have on the lifetime of the battery due to the additional power consumption. The typical current consumption of the ADS7142 in autonomous mode is lower than the leakage current of the primary lithium battery itself. Therefore, this should have a negligible impact on battery life over the lifetime of the system. This point is illustrated by calculating the total used capacity of the battery over 15 years, after deduction of the battery capacity lost due to its self-leakage current.

For this example, assume a self-leakage current of 2 µA and an initial capacity of 3000 mAh. Table 1 shows that 8.8% of the battery capacity is consumed by the battery itself and about 2.2% of the remaining battery capacity is used by the monitoring function. Thereby, 97.8% of the remaining capacity is still available to the rest of the system after implementing the system monitoring function.

Table 1. Battery capacity of ADS7142 system monitor

	Battery Self-Leakage	**ADS7142**
Current Consumption	2 µA	0.45 µA
Annual Battery Capacity Consumption	17.52 mAh/year	3.94 mAh/year
System Lifetime	15 years	15 years
Total Battery Capacity Consumption	262.8 mAh	59.13 mAh
Total Available Battery Capacity	3000 mAh	2737.2 mAh
Total Battery Capacity Consumption %	**8.8%**	**2.2%**

Comparison between ADS7142 and MCU ADCs

The monitoring function can be implemented using the integrated ADC available on most modern microcontrollers (MCU). Two critical points should be taken into account:

1. Operating the integrated ADCs requires running the MCU core.
2. Operating the integrated ADCs requires the use of a voltage reference.

An external ADC like the ADS7142 can be used instead of the integrated ADC on the MCU. The energy consumed per sample can be calculated using Equation 1, and the energy consumption comparison between the external ADS7142 ADC and an internal MCU ADC is summarized in Table 2. Despite the fact that running the ADS7142 at a slower sample rate effectively increases the energy consumed per sample, the table shows that the both reduced current consumption of the external ADC as well as the reduced current consumption of running the MCU in a lower power state helps reduce overall energy consumption of the system.

$$\text{Energy} = \frac{\left[\text{AVDD}_{\text{ADC}} \times \left(\text{IVDD}_{\text{ADC}} + \text{IVREF}_{\text{ADC}}\right) + \left(\text{AVDD}_{\text{MCU}} \times \text{IVDD}_{\text{MCU}}\right)\right]}{\text{Sample Rate}} \tag{1}$$

Table 2. MCU versus ADC power consumption

	ADS7142	**MCU ADC**
AVDD	1.8 V	1.8 V
IVDD	0.45 µA	1000 µA
IVREF	N/A (AVDD is VREF)	400 µA
Sample Rate	600 SPS	1 MSPS
	MCU Core - Standby Mode	**MCU Core - Run Mode (8 MHz)**
AVDD	1.8 V	1.8 V
IVDD	0.9 µA	2000 µA
Total Energy	**4.05 nJ/sample**	**6.12 nJ/sample**

By adding real-time monitoring of the battery current consumption, smart meters can improve their reliability as well as improve the intelligence of the overall smart grid infrastructure. Implementing this real-time monitoring feature with an external nanopower ADC comes at the additional cost of the ADC itself but lowers the overall system power consumption compared to the internal ADC on the MCU thereby increasing the overall lifetime of the smart meter. In addition, it allows for gathering of real-time in-system information and reduces the overall cost of ownership by minimizing complete meter failures in the field.