Energy Autonomous Wireless Water Meter with Integrated Turbine Driven Energy Harvester

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Abstract. Accurate meter reading is the fundamental task of the home water system for the handling of payments. Meters need to be read correctly, to avoid an effect of adding events that increase unnecessary cost and create customer dissatisfaction. This paper presents a fully integrated wireless, energy autonomous water metering system based on the European Standard EN 13757 "Communication systems for meters and remote reading of meters". The system can be used in multiple water metering scenarios. No maintenance will be required and the system will provide precise and secure data transmission as well as timely and accurate recording of the consumption of water. The identification of any leakages will be improved through the analysis of the actual quantity supplied and recorded by the meters. The system is powered by an energy harvester, based on a water driven turbine wheel that is directly coupled to an electromagnetic energy transducer. The power delivered by the generator is dependent of the amount of flowing water and the pressure in the water pipes. Therefor the power is commonly non-continuous, fluctuant and unstable in the voltage amplitude. To be able to report the meter readings at all times, the system needs to be powered not only in times when the energy harvester delivers energy. Therefor an energy buffer, that stores the harvested energy, is installed to compensate the energy requirement between the actual generator output and the energy consumption of the application. Besides a complete system overview, the presentation will focus on the power management and energy aware battery charging circuitry. The design, fabrication, measuring results and the preparations for field tests in rural and urban environment will be presented and discussed.

1. Introduction
Energy efficiency is one of the major issues for wireless metering applications. A connection to the electrical grid can’t be provided in all cases. Therefor the energy consumed by the gas, water and heat meters can be delivered by batteries. As a matter of course the lifetime of the batteries should be as long as the maintenance or calibration cycle of the meter, which typically is between 8 and 12 years and depends on the legal conditions for the specific medium and the specific country. This lifetime is hard to achieve for meters with regular read-out cycles. For these, energy harvesting can be a

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significant advancement to extend the battery’s lifetime. Therefore, the WiMBex project ("Remote Wireless Water Meter Reading Solution Based on the 13757 Standard, Providing High Autonomy, Interoperability and Range") [1] pursues the development of an automatic water meter reading (AWMR) technology. The presented system is based on a cost efficient integrated energy harvesting system powered by the available water flow. Eight companies entered this venture together from December 2011 to November 2013. During a two-year period, the WiMBex consortium aims to develop a remote wireless water meter reading solution, based on the EN13757 Standard, providing high autonomy, interoperability and range. To achieve this goal, the five companies (CAS, JCB, MIB, LBS and MHWS) guide the three research centres (CRIC, HSO and HSG-IMIT) [2]. This paper focuses on the system concept and power management. In addition, the authors present a separate paper which describes the rotational, radial flux energy harvester.

2. System Overview

A system overview of the complete wireless meter device, which is powered by a turbine wheel driven electromagnetic energy harvester is shown in figure 1. The power delivered by the energy harvester is dependent of the amount of flowing water and the pressure in the water pipes. Therefore the power is commonly non-continuous, fluctuant and unstable in the voltage amplitude. Because of this unpredictable nature of the generator an energy buffer is installed, which compensates the energy requirement between the actual generator output and the energy consumption of the application. In addition an efficient rectification-, voltage conversion- and battery charging interface circuit is added to the system. The complete power supply unit is shown in figure 2.

![Figure 1. System overview of the wireless, energy autonomous water metering system (WiMBex).](image)

![Figure 2. Integrated energy harvesting unit with power management PCB.](image)

2.1. Power Supply

A schematic block diagram of the power supply unit is shown in figure 3. The system is completely self-powered and able to work without any pre-charging of the system.

![Figure 3. Block diagram of the energy harvester power unit elements.](image)

The power supply unit can be described by three functional sections: the fluid section, the electromagnetic energy conversion section and the power management section.
2.1.1. Fluid section: The kinetic energy is transferred from the flowing water to the energy harvester by using commercial impeller device housing. Thus the manufacturing cost of the energy harvesting unit can be kept at the lowest possible level. To convert the kinetic energy of the water flow, a new impeller wheel design is implemented to guarantee a better transmission of the energy.

2.1.2. Electromagnetic energy conversion: An electromagnetic energy transducer is used to convert the kinetic energy of the impeller wheel into electrical energy. The transducer consists of three induction coils connected in a star circuit and a two-pole ring-magnet. Thus, a three-phase voltage and current will be induced in the coils. Assuming a fixed load resistance, the power output increases with the rotating speed of the induction magnet, as a function of the water flow rate.

2.1.3. Power management: The power management circuit has to meet different requirements. These requirements are efficient voltage rectification, voltage conversion and stabilization, protection against deep discharge and high voltage peaks, monitoring of the energy balance and efficient charging of the energy storage. *A lithium polymer secondary battery (LiPo) is used as main energy storage of the system.* Figure 4 shows the different parts of the power management pictured in a block diagram.

![Power Management with its different function blocks.](image)

The different function blocks of the power management are designed with regard to low energy consumption. Therefore all of the blocks are able to act in “active” or “sleep” modes. A “safe start” function is implemented to the system to ensure a secure start-up of the system at first-use without any initial energy stored at the energy storage. The converted energy provided by the electromagnetic energy transducer will be stored in ceramic capacitors until a defined start voltage level is reached. After this level is reached the battery charger is connected to the ceramic capacitors and the energy transfer to the storage cell is started. Once the start voltage level is reached, the “safe start” circuit allows the voltage to decline even below the defined start level in order to transfer the complete converted energy to the storage cell.

![“safe start” circuit: A voltage supervisor is used to supervise and control the energy flow to the battery charger.](image)
2.2. Wireless M-Bus
WiMBex exploits the powerful new features of the P- and Q-mode of the Wireless M-Bus standard and in this manner, extend the use and impact of the EN 13757 [4]. By introducing a new network Q-mode protocol which enables precise network time synchronization the high power requirements typically associated with multi hop wireless networks can be significantly reduced by a time division multiple access (TDMA) MAC protocol and an efficient energy aware routing protocol. WiMBex accommodates the new part of the standard, which specifies operation in the newly available 169 MHz band, and which will enable a radio range of 100+ meters (even in the presence of physical barriers). This is a great advantage compared to the vast majority of existing solutions, which operate at 868 MHz or 2.4 GHz. This approach will reduce the need for repeater nodes and their associated technical and commercial disadvantages. WiMBex supports the DLMS standard suite to provide an open, manufacturer independent, interoperable, device and interface specification for electricity, gas, heat and water meters.

3. Measurement results
Measurement results can be seen in figure 6 and 7. The presented graphs show the over-all system balance, since the measurement results include the complete energy consumption of the active electronic circuitries. Figure 6 shows the power measured at the input of the LiPo. The graph reveals the linear behaviour and dependency between the generated power and the applied water flow rate. Figure 6 displays the input voltage, current and power in comparison to the voltage, current and power applied to the rechargeable battery. A maximum power transfer of 310mW with an efficiency of 83% can be achieved.

![Image](figure6.png)

**Figure 6.** Power transfer to Lithium Polymer rechargeable battery in dependency of the water flow rate.

![Image](figure7.png)

**Figure 7.** Charging process. A sweep of the water flow from 0 to 17l per minute is shown. a) Input voltage level and voltage level of the rechargeable LiPo battery. b) Input current und current flow into the LiPo battery. c) Input power and power transferred to the LiPo battery.
4. Conclusion and Future Work
The measurement results show that energy harvesting systems are capable to be applied also in real-life industrial applications. A maximum power transfer of 310mW with an efficiency of 83% was achieved. Real cost advantages are promised, which leads to a good interest from the side of commercial companies. It is expected that especially for the water metering application, energy harvesting approaches will become a new important feature.

At the time of submission of this paper a field test validation takes place in the water distribution network of WiMBex project partner Meath Hill Water Scheme (MHWS). MHWS is a rural water utility located on County Meath (Ireland). The water meters are installed in underground boundary boxes near the road (figure 8). The wireless motes and the 10 energy harvesters will be placed inside the boxes and will be connected to a meter, a Sensus 620, through a pulse sensor wire. First measurement results will be available in December 2013.

![Figure 8. Boundary box and water meter for the field test validation.](image)

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