Faculdade de Engenharia da Universidade do Porto

Railway smart meters

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Thesis Research Plan

Doctoral Programme in Electrical and Computer Engineering

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July 20, 2017

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1 Introduction

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2 Objectives and Contributions

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2.1 Objectives

This work is focused on measuring the energy flows in the railway system The aim of this work is to improve the energy efficiency in the railway transportation system (RTS) and reduce the maintenance cost of RTS power systems. The implementation of smart meters (SM) in RTS promote a better overview of power flow and, based on the information of SM, algorithms focusing on energy efficiency can be implemented. The SM requires sensors such as voltage and current sensors. The level of intrusion as well as the level of electric «valor da grandeza electrica» of such sensors implies considerable costs of the sensors. Therefore, the implementation of complex processing on smart meters is of added value. This complex processing can be the implementation of fault monitoring algorithms in SM based on the energy measurements. Framed in the shif2rail, the work is focused on the implementation of a smart meter demonstrator for the RTS. To embrace the entire railway system, the power flow should consider the energy flux from and to the catenary. Therefore, the key point should be the measurement of the energy in the traction substations and in the train power transformer Based on this thesis proposal, the objectives are the following:

1. Research on high-voltage and high-current measurement systems
2. Research of train power transformer and implementation of a simulation model of a train power transformer.
3. Development and implementation of a measuring system with high acquisition and processing capabilities.
4. Research on communication systems and development of a network model in a simulation environment.
5. Research, development and implementation of a fault monitoring system.
6. Research, development and implementation of an energy flow monitoring system.
7. Implementation and validation of SM in a pilot project through real tests.

2.2 Contributions

1. Increase of energy flow information of RTS

2. Reduction of transmission costs of information (no need of LTE, the data are concentrated and transmitted from trains to stations, during passenger exchange, with a high throughput link)

3. Decrease of the Life Cycle Cost (LCC) of

3 Literature Review

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3.1 Section 1: Smart metering

In this section, special attention is given to smart metering. The smart grid framework is presented to justify the need for smart meters and then, an overview on metering systems is presented.

1. Smart grids and the need for smart meters
2. Metering systems – overview
3. Metering systems in railways
4. Wireless sensor networks – overview
5. Smart metering with WSN in Railway Transportation System (RTS)

3.1.1 Smart grids and the need for smart meters

Smart Grids improves the functionality and concept of traditional electrical grids by obtaining the grid component's data using Information and Communication Technology (ICT). Such grids benefit the reliability and the efficiency of the system with the usage of the acquired data, Mohassel et al. (2014).

Although the smart meters does not have an effective definition, those devices are composed by an electronic box and a communication link, Seppo and Elektraflex (2012). A smart meter is responsible for measuring the energy-related parameters and the user consumption with a given time interval. All those measurements are then transmitted upon a communication network to the utility or to other player with the responsibility of using the meter data. The information obtained from the data is shared with consumer-side devices, to inform the end-users on their related costs and energy usage, Siano (2014).

Smart meters implement a bidirectional communication on top of AMR. They are inherent to smart grid systems.

Similarly to the evolution of electricity meters, the utility grid has evolved from a centralized production and control perspective to a distributed one. The conventional electrical grid is a network with a transmission link connecting power producers and end-user consumers. The control and distribution of electrical power is made in a centralized way. With the increase of power demand, increase of complexity and having more and more decentralized power generation, a migration to the smart grid framework is required, Reddy et al. (2014).

3.1.2 Features of Smart Meters and metering systems

A smart metering system combines several controlling devices, a extensive number of sensors for measuring the parameters and devices responsible for the transferring of the data and the commands. The detection of unauthorized consumption due to electrical energy theft and the improvement of the energy in the distribution are other advantages of smart meters. These devices acts as a gateway by having a communication interface protocol to the database stored by the utility company, Reddy et al. (2014).

The design of an ideal smart grid has to focus on prediction, adaptability and reliability points. Moreover, it requires to cover the demand adjustment, the load handling, flexibility and sustainability and it should incorporate advanced services. In advance, an end to end control capability has to be ensured as well as finding the optimal cost and asses, increase the quality of energy and quality of service. Another features of smart grids are the automatic restoration ans self-healing, being all the previously presented features of the smart grids highly dependent of the role of the smart meters, Mohassel et al. (2014).

Smart-meter types are also distinguished based on features like data-storage, communication type and connection with the energy supplier. The data storage capability allows data to be stored in the meter, being transferred after a few days or weeks to the Meter Data Management System (MDMS) of the utility. Compensations for some power quality deficiencies can be also considered; therefore the future meters should be also capable of register certain basic power quality characteristics. In advance, the design of rate and tariffs of electricity providers determine the requirements such as the period of meter intervals or the temporal resolution (commonly ranging from 15 min to 1 h). During those intervals, the production and consumption of active and reactive power is mandatory to be separately measured, Siano (2014).

3.1.3 Metering systems in railways

3.1.4 Wireless sensor networks – overview

3.1.5 Smart metering with WSN in Railway Transportation System (RTS)

3.2 Section 2: Wireless networks

In this section, communication networks are presented, with special attention to wireless technologies. An historic overview is presented

1. Network technologies – historic overview
2. Current technologies and standards:
3. Emerging technologies and standards
4. Network Simulators and Network Emulators

3.2.1 Network technologies – historic overview

3.2.2 Current Wireless technologies and standards

The following sections will cover the wireless communications in smart metering systems, starting with the low-rate and low-power communications applied around the smart meters and ending with the high-rate communications (and consequently higher costs and power than low rate communications). With the increasing on demand for higher bandwidth, broadband technologies such as mobile WiMAX, IEEE 802.16e and broadband PLC are expected to be considered and used in newer installations, Mohassel et al. (2014).

3.2.2.1 IEEE 802.11 (Wireless LAN (WLAN) or Wi-Fi)

IEEE 802.11 is the standard for the information exchange between systems and for the telecommunications. The coverage area of this technology is on local and metropolitan area networks (LANs and MANs). The specific requirements are on the Medium Access Control and on Physical Layer. The most popular versions of this standard is the IEEE 802.11b and IEEE 802.11g, that differs in the modulation technique (Direct Sequence Spread Spectrum (DSSS) technique versus Orthogonal Frequency Division Multiplexing (OFDM) modulation technique). The data rates are, respectively, 11 Mbps and 54 Mbps, Usman and Shami (2013); IEEE (2016).

3.2.2.2 IEEE 802.15.4 (ZigBee)

The standard IEEE 802.15.4 imposes conditions in the physical layer and media access control focusing on low-rate (up to 300 kHz) wireless personal area networks. Developed by the Zigbee Alliance and covering the specifications of the IEEE 802.15.4 on the physical layer and the medium access control, Zigbee is a commonly used for low power wireless communication technology. It operates on the ISM bands of 868 MHz, 915 MHz and 2.4 GHz adopting direct sequence spread spectrum (DSSS), Usman and Shami (2013).

3.2.2.3 DASH7

On the low-rate field of research, an alternative to Zigbee is the DASH7. Using the ISO/IEC 18000-7 standard to support this wireless sensor network technology, DASH7 is developed to reach active Radio Frequency Identification Devices (RFIDs) and operates at 433MHz band. The advantage is the typical range of 250m (could achieve 5 km) and has a typical and maximum data rates of 28 kbps and 200 kbps, being in this specifically designed for Smart Grid and for applications in Smart Energy.

3.2.2.4 6LoWPAN

IEEE 802.15.3: IEEE 802.15.3 [46] is a physical and MAC layer standard for high data rate WPAN. It is designed to support real-time multi-media streaming of video and music. IEEE 802.15.3 operates on a 2.4 GHz radio and has data rates starting from 11 Mbps to 55 Mbps

3.2.2.5 Wibree

Wibree [47] is a wireless communication technology designed for low power consumption, short-range communication, and low cost devices. Wibree allows the communication between small battery-powered devices and Bluetooth devices. Small battery powered devices include watches, wireless keyboard, and sports sensors which connect to host devices such as personal computer or cellular phones. Wibree operates on 2.4 GHz and has a data rate of 1 Mbps. The linking distance between the devices is 5–10 m. Wibree is designed to work with Bluetooth. Bluetooth with Wibree makes the devices smaller and more energy-efficient. Bluetooth–Wibree utilizes the existing Bluetooth RF and enables ultra-low power consumption. Wibree was released publicly in October 2006.

3.2.2.6 Industrial Wireless Communications: WirelessHART and ISA100.11a

Launched by HART Communication Foundation in September of 2007, WirelessHART is an open wireless communication standard designated specifically for the process measurement and control applications, Song et al. (2008). This standard is specifically designed to comply with industrial requirements, such as stricter timing requirement, higher security concern, immunity to harsher interferences and obstacles and enough scalability to be used in large process control systems.

Similarly, ISA100.11a aims to provide secure and reliable wireless communication for non-critical monitoring and control applications, Petersen and Carlsen (2011).

3.2.2.7 IEEE 802.16 (WiMAX)

On the field of the broadband wireless communication there is the Worldwide Interoperability for Microwave Access (WiMAX) under the IEEE 802.16 standard. It is specifically developed aiming the point-to-multipoint communications being applied in fixed and mobile applications and it has data rates up to 70 Mbps over a distance of 50 km. Framed into the smart grid systems, this communication technology is considered as a solution for high data rate communication link to be applied at the backbone of the utilities, Usman and Shami (2013).

3.2.2.8 Broadband communications: GSM/GPRS and LTE/LTE-Advanced

Operating at 900 MHz and 1800 MHz, the Global System for Mobile communications (GSM) is the most used cellular network all over the world. The modulation technique is the Gaussian Minimum Shift Keying (GMSK) and it achieves transfer rates up to 270 kbps. Its architecture consists of four components: the Operation Support Substation, the Network Switching Substation, the Base Station Subsystem and the Mobile handset. Due to its level of development around the world being present in remote locations, this advantage makes this an interesting technology to be applied in Smart Grid applications, Usman and Shami (2013).

Long Term Evolution (LTE) is a recent standard for wireless technology that allows high data rates with high capacity and low latency and with a good Quality of Service (QoS). The improved version of this technology, the LTE-Advanced, admit higher capacity with expanded peak data rate of 1 Gbps for the downlink and 500 Mbps for the uplink, obtained on the increase of the spectral efficiency, higher number of active subscribers connected at the same time, and better performance at cell edges, Mohassel et al. (2014). This technology, for the Smart Metering environment where the high bandwidth and good QoS are mandatory at some communication points.

3.2.3 Emerging technologies and standards

3.2.4 Network Simulators and Network Emulators

3.3 Section 3: Energy sensors

1. Sensor overview – historic perspective 2. Current transducers and voltage transducers a. Commonly used technologies and principles b. New breakthroughs 3. High power measurement challenges in RTS 4. Energy measurement technologies in RTS

3.4 Section 4: Power system of RTS

1. Overview of existing worldwide power systems 2. Overview in the perspective of production-distribution-consumption a. Traction substation (Production) b. Catenary (Distribution line) c. Rolling stock (Consumption/load) 3. Traction substation transformer overview 4. Catenary (?) 5. Train power transformer 6. Train motor and power converter 7. Auxiliary loads

3.5 Section 5: Decision Support Systems (DSS)

1. Overview/definition 2. Eco-driving – driving assistant 3. Timetable scheduling 4. Maintenance support

3.6 Section 6: Outlier detection in RTS energy measurement

1. Definition of outlier detection in RTS energy measurement perspective 2. Literature review of Outlier detection in WSN a. Motivation b. Research areas c. Challenges 3. Taxonomy of outlier detection techniques a. Classification based b. Statistical based c. NN-based d. Clustering based e. Spectral decomposition-based

4 Methodology and Work Plan

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Note: not in chronological order

4.1 RTS wireless network

1. Purpose: model and simulate a WSN for energy measurement of RTS rolling stock, with an advanced network infrastructure (englobing both train WSN and station AP's)

2. Contribution: An energy measurement system in rolling stock does not require a broadband real-time/continuous communication (such as LTE), being possible to collect and store data in train data concentrator and, while the train is waiting at station for passenger exchange (which lasts for less than one minute), the data is transferred between train and station AP (and then to a remote server). Therefore, the contribution will be the cost reduction of information transmission of energy sensor network data

3. Methodology: a. Modeling of energy sensor network of rolling stock: sensor nodes and data concentrator b. Modeling of infrastructure: train concentrators, station AP, station data "buffer" and station internet connection c. Implementation in simulation environment of such models, using NS3 simulator or similar d. Definition of "sensor data rate" as function of the line length-between-stations ()

4.2 Non-intrusive self-powered sensor node

1. Purpose: In the scope of Shift2Rail, is expected to develop a smart meter for railways. The purpose is to model, simulate and implement a series of sensor nodes for current measurement in the transformer´s secondary windings. Assuming that the railway environment requires non-intrusive measurement devices and, if possible, self-powered, a set of requirements is then identified for the sensor node: a. Electrically non-intrusive (using hall-effect, rogowsky or current transformer principles; without the need for mechanically changing the windings) b. Self powered, if the current transformer has sufficient power capabilities c. With high processing capabilities, high acquisition frequency and sufficient amount of memory i. Variable acquisition in

tens of samples per second (according to the power quality standard of 15kHz <?>) ii. Frequency analysis capability iii. Capable of implement outlier detection algorithms

2. Contribution: new advanced sensor node for high current measurement 3. Other Contribution: given the measurement characteristics, a self powered wireless sensor node can implement features of high processing. 4. Methodology to be defined

4.3 Rolling stock traction transformer model

1. Purpose: model the train transformer with two perspectives: a. Efficiency estimation based on secondary measurements b. Evaluation of transformer operation towards fault detection 2. Possible contribution: an accurate model for train transformer, capable of efficient estimation of energy consumption based on secondary windings current measurements 3. Possible contribution: assuming that the influence of transformer in the power life cycle cost is relevant (see note), the contribution will be the operation monitoring towards maintenance cost reduction. 4. Methodology: a. Study failure rates of trains/transformers b. Model in a simulation environment the power transformer c. Identify and model transformer failures d. Implement in sensor nodes an energy estimation mechanism based on the loss model of the transformer and sensor nodes measurements e. Implement in sensor nodes a frequency analysis towards operation monitoring f. Prepare and implement results in field operation

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