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Considerations for packet delivery reliability over polling-based wireless networks in smart grids ☆

Atef Abdrabou *, A.M. Gaouda

Electrical Engineering Dept., UAE University, Abu Dhabi, Al Ain 15551, United Arab Emirates

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ABSTRACT

Supervisory control and data acquisition (SCADA) systems currently use the polling technique for monitoring electric utility networks. Unfortunately, conventional SCADA systems do not suit the needs of smart grids in terms of the required data rate. Polling-based wireless networks can extend the capabilities of SCADA systems as they provide low cost transceivers and bounded packet delay. However, the harsh environment of power stations negatively impacts the performance of wireless links. This paper introduces a field measurement-based study that focuses on the effect of power system noise and transients on packet delivery reliability of Zigbee and WiFi polling-based wireless networks. Extensive experiments show that the electromagnetic interference emitted from high voltage substations, during normal operation conditions, do not significantly affect wireless communication in the gigahertz range. Moreover, we analytically and experimentally demonstrate that abnormal operation conditions of power systems may negatively impact the reliability of packet delivery in polling-based wireless networks. Furthermore, we show that this negative impact can be mitigated by following some proposed technical considerations regarding the wireless standard, the operating frequency, the location, and the number of wireless transceivers used.

1. Introduction

Smart grids represent the future of power grids as they provide the opportunity and a multitude of solutions for power utility companies to efficiently manage energy generation. Smart grids also integrate renewable energy resources into the classical power network, which changes its radial power flow nature. Therefore, power grid automation represents one of the highest priority objectives for the successful implementation of smart grids.

In the era of smart grids, the definition of power grid maintenance is broadened to include the *self-healing* activities, i.e., automated activities that preserve the function of an asset in the power network [1]. In other words, the full-fledged realization of self-healing in smart grids makes the power network capable of detecting system abnormal conditions, isolating system faults, and restoring system power without human intervention.

In fact, real-time monitoring and fast response during abnormal power system operation are important for fault detection, isolation, and system restoration procedures. Currently, SCADA systems are widely used to monitor/control conventional power grids. Admittedly, most of the current deployments of SCADA systems use the polling technique in order to

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* Corresponding author.
E-mail addresses: atef.abdrabou@uaeu.ac.ae (A. Abdrabou), agaouda@uaeu.ac.ae (A.M. Gaouda).

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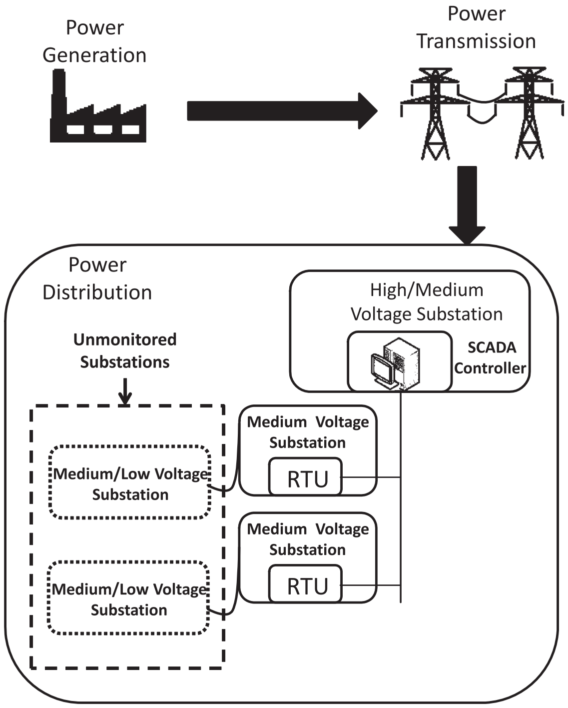

Fig. 1. A widely-used SCADA architecture for power distribution networks.

send data to or from end devices or remote terminal units (RTUs) via low data rate multidrop communication links (e.g., 9.6 kb/s or lower) [2,3]. Fig. 1 outlines the there basic phases of electric power supply (i.e., generation, transmission, and distribution) with a focus on the typical SCADA architecture for power distribution networks. Fig. 1 shows a SCADA master controller (usually located at a high/medium voltage substation[1]) monitors/controls medium voltage substations by communicating with their RTUs via a multidrop communication link using the polling technique [2]. In this technique, the SCADA master controller sends a request message to every RTU, one by one, asking for the availability of any system alarms or updated information. Each RTU replies back, if it has data to send. The request and the reply constitute a polling transaction. However, the current capacity of communication links in SCADA systems provides a delayed status of the monitored components with 3–5 s information reporting latency [3]. In addition, most medium/low-voltage distribution substations (e.g., 11/0.24 kV) are not covered by SCADA systems (i.e., no monitoring is available) [3].

Fortunately, the availability of low-cost easy-to-deploy miniature wireless transceivers makes it possible to transfer data representing fast changing physical phenomena in electric power systems with a high data rate. Therefore, wireless technologies can extend SCADA systems in medium/low-voltage distribution networks by combining high data rate with low data transfer latency, which are required to enable the realization of self-healing in these networks [2]. Consequently, the scope of this work addresses monitoring medium/low voltage substations. This is performed by using a single-hop polling-based wireless network in order to collect data from various sensors, which are distributed inside a substation, then sending it to a network controller (or coordinator) located also inside the substation. The infrastructure of the communication between the network coordinator and other SCADA system entities is out of the scope of this work.

Generally, power systems generate significant amount of electromagnetic interference that may negatively impact the operation of wireless communication links and their electronic circuits. This electromagnetic interference can cause erroneous packet reception, if it has sufficient power within the operating bandwidth of these wireless links. Therefore, our focus in this paper is on the reliability of packet delivery using polling-based wireless mechanisms provided by Zigbee (IEEE 802.15.4), WiFi-2.4 GHz (IEEE 802.11g), and WiFi-5 GHz (IEEE 802.11a) standards while operating inside medium/low voltage distribution substations. In fact, some polling-based schemes, which are introduced in IEEE 802.15.4 and IEEE 802.11 standards, trade off packet delivery reliability for fast data transfer. For instance, in IEEE 802.15.4, a coordinator does not have to acknowledge the data packets successfully received from end devices. This implies that no packet retransmission is performed. However, timely wireless transfer of sensed data without packet loss, specially during power system abnormal conditions, is crucial. The lost packets may contain very important sensed data. These abnormal conditions are usually related to fault conditions, which do not frequently occur [4,5], and hence they do not have any tangible effect on the

[1] Distribution substations contain step down transformers, where the first voltage level (e.g., high) refers to the voltage level of the primary side of the transformer and the second voltage level (e.g., medium) refers to the voltage level at the secondary side.