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Comparison of Software Defined Radio Techniques and Smart Metering Devices for Predictive Maintenance Applications

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Abstract

The paper compares two approaches for generating input data for Predictive Maintenance systems. Smart meters are commonly used in industrial applications and could also be used for adopting Predictive Maintenance. The second approach uses Software Defined Radios outside of their traditional application field, because of their high flexibility. The existing Software Defined Radio tool chains for signal processing can be easily adopted to generate and process input data for Predictive Maintenance algorithms. Besides the theoretical comparison and discussion of these two approaches, a concept for the practical evaluation is presented.

1 Introduction

Software Defined Radio (SDR) is an universal hardware and software approach, which is normally used for radio communication systems. Due to its huge flexibility, it can be used in a wide range of applications. Examples are universal receivers which can receive analogue television as well as Digital Video Broadcasting Terrestrial (DVB-T). Also concepts for SDR based radar systems which can be implemented with the same hardware have been presented [1]. Therefore, one might also think of applying SDR techniques to other application fields which also require a high sample rate and accuracy but are not related to radio transmissions. One of said applications is Predictive Maintenance (PM) which aims to reduce maintenance times and costs by predicting defects. This is done by analyzing data from various sensors. It's the authors' belief that a SDR system can be adopted to record the necessary signals and perform the required processing steps in order to enable PM applications. The high flexibility and the possibility for easy modifications, which SDR systems offer, may prove to be highly valuable especially for research applications. On the other hand, off the shelf smart metering devices may also be a feasible approach for generating the data necessary for PM, as they also sample their input signals at a high rate and with great accuracy. In contrast to SDR these systems are mostly black boxes, which allow the user only minor modifications. In this paper a concept for the comparison of these two approaches (SDR and smart meters) in terms of their viability for Predictive Maintenance is proposed. The goal is to show whether they are viable for PM at all and also where the advantages of either approach are.

2 Related Work

Concepts for predictive maintenance based on mechanical analysis are well established [2]. The next logical step is to use electrical signals for this process. Bonaldi et al. show an approach for fault recognition using information from current sensors (and some additional sensors like an accelerometer) [3]. For signal analysis and classification, feature engineering and wavelet transformation must be done [3]. Bravo-Imaz et al. shows another approach using only the motor current for signature analysis [2]. Furthermore artificial intelligence is used for diagnostics [2]. The usage of current and voltage signature analysis can be seen as a kind of indirect sensing, since the parameter which decides whether a defect occurred is not monitored directly. Forth gives a formal approach for indirect sensing [4]. Kleen and Nienhaus show that a motor can be used as sensor indirectly [5]. The Fraunhofer Society shows the possibility to recognize devices in the power grid using device signature generated by a special smart meter. Therefore, only voltage and current need to be measured [6].

3 Evaluation Concept

3.1 Architecture

Figure 1 shows a simplified assembly enabling the comparison of the SDR approach and a smart meter for analyzing grid signals.

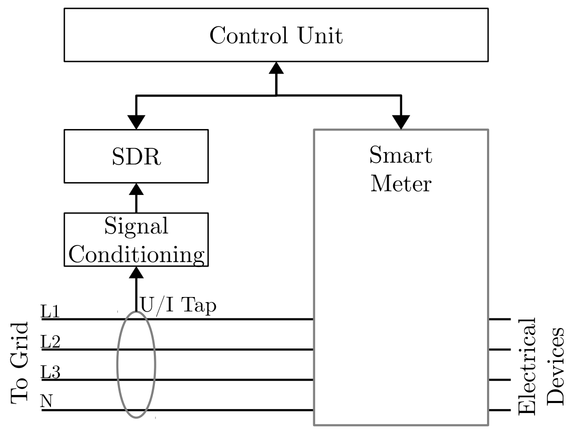

Figure 1. Architecture for proof of concept

The grid signals are fed to the SDR through a chain of components. The first is a tap, which can be divided into a voltage and a current tap. The current tap can be realized with a current transformer which should have a high frequency bandwidth. Both signals have to be matched to the input of the SDR. This is achieved through a signal conditioning circuit which may consist of filters, amplifiers, attenuators and impedance matching circuitry. The SDR is directly connected to a computer which controls the SDR and processes the incoming data. The SDR provides high flexibility, as the user can set almost every parameter as desired. On the other hand, the smart meter which is also connected to the grid lines can be seen as a black box. In most cases, signal conditioning and processing is not accessible from the outside. Only the measurement results can be read via a digital interface (e.g. infrared). Both acquisition systems are connected to the same computer to get synchronized datasets, which are comparable later on.

3.2 Test Setup

In order to get defined input signals for the comparison of the two approaches, a programmable pattern generator in combination with a signal divider is connected to the inputs of each Device Under Test (DUT) instead of the power grid. This test bench setup is illustrated in Figure 2.

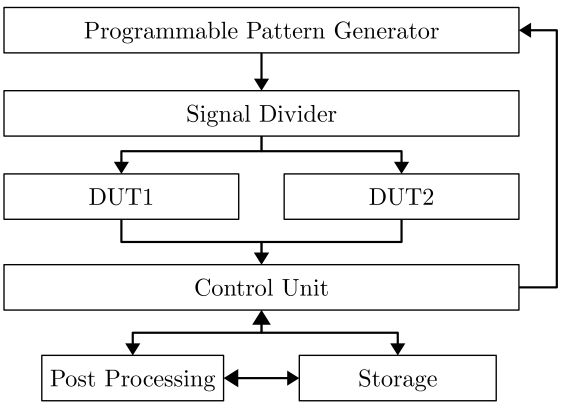

Figure 2. Test setup

The output of both DUTs is connected to a control unit, which is a normal workstation computer. A set of different test patterns is generated and applied to the inputs of the DUTs. The data, provided by each device, is stored on the workstation's hard drive. Each test is executed for a defined period of time. Afterwards the data is read from the storage and post processed using different methods and algorithms, which are described later on.

3.3 Test Pattern

Dynamic Tests The first step of the proposed comparison is to find the dynamic limits of either DUT. It is important to know, how fast the input signal may change, so that the DUT can still measure and process it properly. The dynamic behavior is especially important for device recognition, which is required when the PM measurements are taken at a central point in the grid and not taken for each device individually. Additionally, short time changes in the signal (e.g. impulses) can be indicators for pending defects. The used test pattern must have fast changing characteristics, which are controllable by the programmable pattern generator. A potential test pattern for this case is a frequency sweep which changes the frequency of a sine wave. The sweep time is then reduced incrementally to the point, where the DUTs can't process the signal properly. Another possible test pattern may be a pulsed input signal, where the pulse width is reduced step by step. The dynamic behavior of smart meters is often not known precisely. Hence, a special focus of the dynamic test is to determine the limits of the used smart meters. The SDR based approach, on the other hand, is in all likelihood able to generate data that is accurate enough for typical PM algorithms. Here the focus is more on finding feasible parameter sets for the SDR.

Simulation of typical PM effects The second type of test pattern is used to simulate aging effects that develop over a long period of time. The detection of such effects is usually the basis for PM analysis and defect predictions. In real life these effects occur over a timespan of months or even years. For the purpose of this evaluation, the test patterns are condensed to a time span of a few hours. Possible examples for such test patterns include, but aren't limited to:

- Frequency and Amplitude variations: Over the course of the test the frequency and/or amplitude of the signal is slightly shifted.
- Increasing jitter: Jitter of the signal is slightly increased during the test.
- Time-variable filters: A filter is applied to the input signal, which allows to pass more (or less) harmonics. The filter characteristics are changed over time.

The goal hereby is to generate data sets with the same setup as previously described and then use different analysis methods to determine whether the simulated effects can be detected. This is done with the raw data from either DUT as basis.

3.4 Post-processing Methods and Algorithms

Smart meters The output data of smart meters typically contains information on the active power or the amount of energy that is consumed or generated respectively. However, depending on the used system a variety of other information may be presented to the user. For example, the Atmel ATM90E36A smart metering integrated circuit provides the following information amongst others [7]:

- Power (active, apparent, reactive)
- Root mean square (RMS) values of voltage and current per phase
- Harmonic / fundamental power per phase
- 2nd - 32nd harmonic component (voltage and current) of each phase
- Phase angle
- Power factor

These information can be used directly for post-processing and analysis, without the need for further feature engineering. The output data of the smart meters can be used to perform supervised or unsupervised anomaly detection for PM using typical machine learning methods like k-nearest neighbor, neural networks or support vector machines.

Software Defined Radio In contrast to smart meters, SDR systems generate a raw stream of In-phase and Quadrature (I/Q) data. With the right feature engineering, SDR systems can provide same information as smart meters. Therefore, the same PM techniques can be applied in this case. Additionally, the application of machine learning algorithms on the I/Q data is a possibility. Also, a wide variety of arbitrary features can be generated from the I/Q data (e.g. power spectrum, etc.), which can then be fed to PM algorithms. A great advantage hereby is, the availability of signal processing tools for Software Defined Radio systems, such as GNU Radio or LabVIEW. Each step of signal processing also can be parameterized to the user's liking, whereas smart meters offer no or very limited possibilities.

4 Conclusion

Both approaches seem promising for generating a viable data base for PM algorithms. Smart meters are a relatively inexpensive solution. Since smart meters are already in use at potential application areas, the addition of PM may be easily implemented in existing machinery environments, without the need for further feature engineering. Their possibility to process fast changing signals has to be evaluated further, though.

Existing SDR solutions are comparable expensive and the necessary infrastructure is nonexistent in established facilities. To enable the widespread use of SDR for this application, specialized systems will be necessary. They may be based on SDR techniques but otherwise have to be scaled down in order to be economical. Nevertheless, existing SDR systems are very well suited for research applications. The high flexibility and modularity allow the user to easily process the raw data to their liking. On top of that, modifications are easily implemented, thus allowing to test and evaluate different parameter sets or approaches.

5 Future Work

While both approaches seem to be promising and feasible for PM applications in theory, a definitive statement can only be made once the proposed test setup is fully implemented and evaluated. All DUTs will be evaluated using the presented setup (see Figure 2). Once these experiments using test patterns yield promising results, a measurement setup as shown in Figure 1 can be implemented. To achieve reproducible test results within a reasonable time span, accelerated aging techniques can be used on the connected electrical devices.

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