2008년도 대한전기학회 하계학술대회 논문집 2008. 7. 16 - 18

전력 설비 진단을 위한 무선 센서의 응용

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Application of Wireless Sensor for Diagnostics of Electric Equipments

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Abstract - The concept is based on distributed wireless sensors that are attached to the incoming and outgoing power lines of secondary substations. A sensor measures only phase current characteristics of the wire it is attached to, is not synchronized to other sensors and does not need configuration of triggering levels. The main novelty of the concept is in detecting and locating faults by combining power distribution network characteristics on system level with low power sampling methods for individual sensors. This concept enables the sensor design to be simple, energy efficient and thus applicable in new installations and for retrofit purposes in both overhead and underground electrical distribution systems.

1. Introduction

In networks with an ungrounded neutral, the fault current is basically composed of the currents flowing through the earth capacitances of the sound phases. In a 20 kV overhead network with zero fault resistance, the fault current is approximately 0.07 A/km [1]. Some systems have a compensated neutral. The aim with the compensation is to cancel the system earth capacitance by connecting an equal inductance to the neutral [1]. Hence, the earth fault current decreases correspondingly. In the case that the inductance is tuned to exactly match the system capacitance, the fault current will contain only a small resistive component. In practice, however, the network is slightly under- or overcompensated, at 95% or 105%. This type of earthing is common in Continental Europe. Solidly earthed distribution networks are used in the United States, for instance. In these, the single phase to earth fault current varies with the fault location and the fault resistance.

The properties of detecting and locating earth faults depend basically on the type of earthing and on the network topology. The location is generally determined by the characteristics of the zero sequence current I_0, the neutral voltage U_0, and the phase shift between I_0 and U_0. Wireless sensors that participate in activities to detect and locate earth faults should, therefore, have capabilities to concurrently measure current and voltage of the three phases in one location, so that the sum current in that network point can be determined.

Some prior art wireless sensor solutions have solved these issues by using specific hardware design [2], by constantly measuring and reporting phase current and voltage [3], or by synchronizing sensors using the Global Positioning System, GPS.

There are a number of disadvantages with these solutions. Continuous monitoring and reporting draws a great amount of energy. This energy may not be available and the activity of a sensor should be tuned accordingly. GPS provides very accurate time synchronization, but is expensive and has high energy dissipation compared to other standard components used in wireless sensors of today. Using specific hardware is an error prone alternative that is sensitive to installation and calibration precision.

Arranging reliable voltage measurements is also problematic in a number of ways. The most feasible means seems to be a voltage divider based on a capacitive principle involving the phase wire and the earth capacitance. This solution has a number of drawbacks. A cable network can not be retrofitted with the voltage sensors as it is prohibited to put any items on the sleeve of cable terminations or joints. The capacitor will have to hang in the air on a distance from the cable. The other two parallel phases and the ground capacitance will then greatly affect the reliability and sensitivity of the measurement, even if the phenomenon is computationally compensated for. The same is recognized in overhead power line systems as well, especially when the phase angle should be determined.

In this paper, methods and analysis of a simple wireless sensor concept for detecting and locating faults as well as for load monitoring are presented. The concept is based on distributed wireless sensors that are attached to the incoming and outgoing power lines of secondary substations. A sensor measures only phase current characteristics of the wire it is attached to, is not synchronized to other sensors and does not need configuration of triggering levels. The main novelty of the concept is in detecting and locating faults by combining power distribution network characteristics on system level with low power sampling methods for individual sensors. Different sampling methods are assessed in the concept framework and test results with a prototype implementation are discussed.

2. Experiment

The system architecture being considered is illustrated in Fig. 1, where PS stands for the primary substation, SA and SB for secondary substations and NCC for the network control center. A secondary substation has wireless sensors attached to incoming and outgoing medium voltage power conductors. The dark gray circles on every power line phase illustrate this.

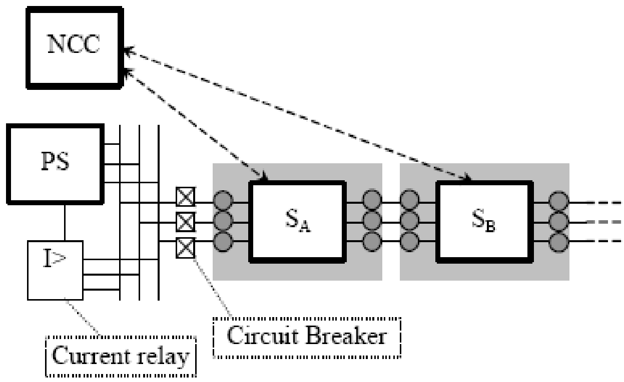

Fig. 1. A view of the system hierarchy. *PS* stands for the primary substation, *SA* and *SB* for secondary substations and *NCC* for the network control center.

The gray boxes surrounding a secondary substation show to which substation different sensors belong. Secondary substations are assumed to have communication capabilities so that they can either communicate with each other, with the primary substation or with the network control center.

Load tapping occurs only at substations. Load monitoring has briefly been described in the previous section. From the viewpoint of the system concept it is rather trivial to implement, thus it is not further discussed here. Detecting and locating faults by using distributed sensors that are unsynchronized and only measure phase current, is however challenging. The required system level methods needed for detecting and locating short circuits and single phase to earth faults are therefore addressed next.

3. Result and Discussion

Fig. 2 shows the average current consumption of a sensor during tests of different tasks and different periods between the tasks. The Fourier algorithm that utilized only 6 samples consumed, despite the low number of samples, significantly more current than the simpler peak sampling methods. With the peak sampling methods, the sleep current dominated the current consumption when the period between measurements was longer than 60 ms. With the Fourier algorithm, the average current consumption was still 30 μA with a period of 100 ms (the longest feasible period between measurements as discussed above). Considering the fact that 6 samples is a minimum realistic number of samples with the Fourier algorithm, a microcontroller with lower operating current dissipation should be used in the implementation of the algorithm. This feature becomes especially important when considering that 16 samples or more are needed to effectively remove harmonics and imaging frequencies of a signal that first has passed a low order analogue filter.

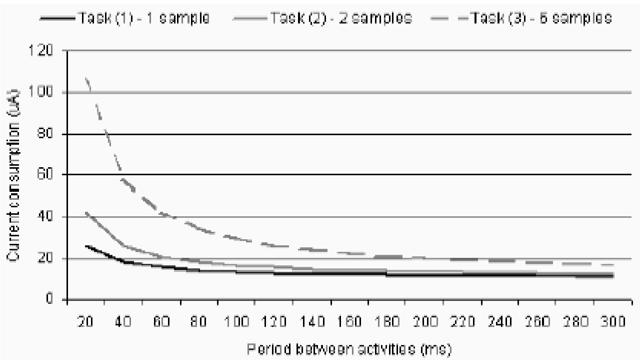

Fig. 2. Average current consumption of a prototype sensor with different sampling behavior and measurement periods.

The accuracy of the sampling methods was evaluated in a total of 9 tests. A test lasted 6 hours and the sensors (one per phase) sampled the current with a measurement period Tper of 80 ms. The measured current was averaged for every minute of a test and compared to the average minute current measured by a LEM Topas 1000 power quality analyzer. The experimental system had a load current of approximately 2.4 A and the total harmonic distortion was 8% with the third harmonic at 5% and the fifth at 6%.

Because the accurate physical characteristics of the Rogowski coils were not known and the sensors were not precisely calibrated, a difference between the current measured by a sensor and by the analyzer was recorded. This is illustrated in Fig. 3 (sampling according to Task (1)) where also some disturbances in the sensor reading can be noted after 5 hours, and in Fig. 5, where sampling is done according to Task (3). The average difference for Task (1) and Task (2) was approximately 2 - 3%, and with the Fourier algorithm 1%. The better performance by Fourier is explained by less impact of harmonics , and also the quantization error.

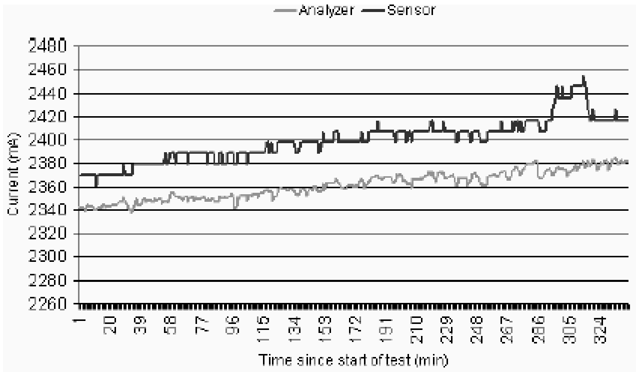

Fig. 3. Per minute current measured by a sensor (Sensor 0) and the analyzer during the test run of Task (1) at 10.10.2003.

4. Conclusion

A wireless sensor concept for load monitoring and fault management of electrical distribution networks has been presented. The concept is based on distributed wireless sensors that are attached to incoming and outgoing power lines of secondary substations. A sensor measures only phase current characteristics of the wire it is attached to, is not synchronized to other sensors and does not need configuration of triggering levels. However, current measurements made by these sensors are shown to be useful in fault management.

[Acknowledgement]

This work was finally supported by MOCIE program (I-2006-0-092-01).

[References]

[1] R. Fernandes, and R. Sieron, "Transmission line sensor apparatus," European patent application 0223507, May 27, 1987.

[2] R. Fernandes, "Electrical power line parameter measurement apparatus and systems, including compact, line-mounted modules," European patent application 0314850, May 10, 1989.

[3] R. Fernandes, "Electrical power line and substation monitoring apparatus and systems," European patent application 0314849, May 10, 1989.