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Impact of electrical environment on wireless sensor communication

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In order to ensure security and reliability of Internet of Things, electromagnetic disturbance issue in electrical environment is studied, where a wireless sensor is applied. Research on characteristics of electromagnetic disturbance in substations of different voltage levels and of different insulation types is carried out through field measurements. Simulation and field experiment of electromagnetic disturbance and communication obstruction produced by electrical equipment is performed to reveal impact on communication quality of wireless sensor.

Keywords: Wireless sensor, Electromagnetic disturbance, Communication obstruction, Electrical environment

INTRODUCTION

State Grid Co., Ltd. proposes an “Internet of Things” program which is featured by “Sense, Transmission, Awareness” in order to increase the management level in Smart Grid. Smart monitoring system using the Internet of Things in electrical environment is a vital part of Smart Grid and secures grid electrical operation [1].

Through field experiment in a 400kV GIS substation carried out by the British power system Co., Ltd, original data with electromagnetic disturbance which contain impulse signal were acquired [2, 3]. Impulse signal was produced by switch operation, partial discharge and periodic process of power electronics. Research also illustrates that SF6 gap breakdown and vacuum gap breakdown result in negative impact on wireless communications [4, 5]. Research indicates that rise time of current impulse produced by partial discharge in strong dielectrics such as SF6 reaches to 50ps, which means that the impulse includes frequency components up to 3GHz and may generate electromagnetic disturbance to impact communication quality of wireless sensors [6, 7, 3]. Scotland power system Co., Ltd. in UK studied the impact to wireless sensors produced by electromagnetic disturbance of partial discharge and obtained some results [4, 8].

This paper mainly focuses on the impact on communication of a wireless sensor in electrical environment. Wireless sensors employ ZigBee techniques and communicate in the band of 2.4GHz~2.5GHz, which is easy to be impacted by electromagnetic disturbance [9, 10]. When electromagnetic disturbance is severe, the wireless sensor may lose information packet or even stop working. This paper studies the characteristics of electromagnetic disturbance by field measurement, which may impact on the communication of a wireless sensor. Electromagnetic disturbance was generated by electrical field and magnetic field at power frequency, corona discharge, partial discharge and gap breakdown in substations of different voltage levels and of different insulation types. Measurement data of electromagnetic disturbance in complex electrical environment were acquired by wide-band antenna, digital oscilloscope and receiver. Simulation was performed to reveal the impact on communication of a wireless sensor under electromagnetic disturbance and obstruction of electrical equipment [11].

MEASUREMENT AND STATISTICAL ANALYSIS OF ELECTROMAGNETIC DISTURBANCE

Electromagnetic disturbance on a wireless sensor caused by a complex electromagnetic disturbance cannot be negligible, with wide application of the Internet of Things in electrical environment. Through field measurement, the electromagnetic disturbance characteristics in substations of different voltage levels and different insulation types were obtained. Statistic properties of electromagnetic disturbance were analyzed.

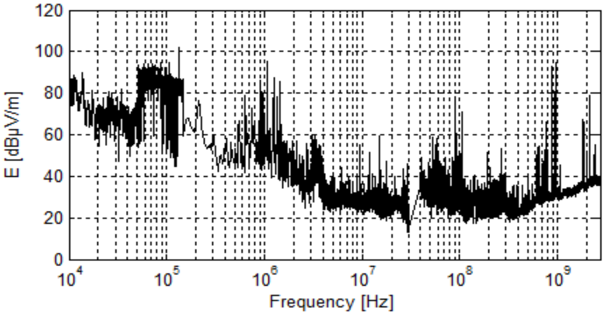

Fig. 1. Spectrum of electromagnetic disturbance around a circuit breaker in a 500kV GIS substation

The spectrum of electromagnetic disturbance around a circuit breaker in a 500kV GIS substation measured by a receiver is shown in Fig. 1. The dominant frequencies are around 100kHz, 1MHz,

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3MHz, 110MHz, 936MHz, 1.84GHz and 2.43GHz, which cover the communication frequency band of a wireless sensor, i.e. 2.4GHz. In this GIS substation, packet loss rate of wireless sensor was about 5.6% in a performance test.

Since the disturbance spectrum of each single measurement is different, data of a single measurement are not representative for the overall level of disturbance. Fig. 2 shows spectrum envelope diagrams of 100%, 80% and 50% measured at 4 measurement points in 500kV open air and GIS substations. The 100% spectrum envelope diagram denotes the maximum value at each frequency in the spectra of all measurement data. The 80% spectrum envelope diagram means 80% of the maximum value at each frequency in the spectra of all measurement data. The 50% spectrum envelope diagram represents half of the maximum value at each frequency in the spectra of all measurement data. The dominant frequencies are around 0.1MHz, 1MHz, 110MHz, 960MHz, and 2GHz, which may impact communication quality of a wireless sensor [12].

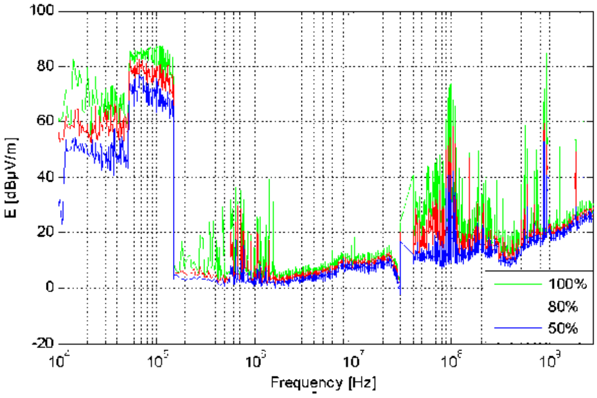


Fig. 2. Spectrum envelope diagrams of 100%, 80% and 50% at 4 measurement points in open air and GIS substations at the voltage level of 500kV

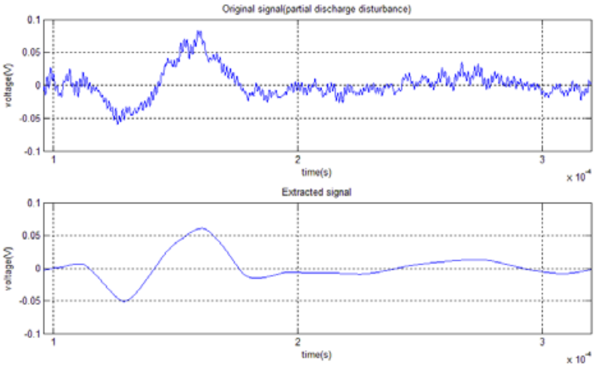


Fig. 3. Impulsive signal extraction

Electromagnetic disturbance in substations of different voltage levels and different insulation types was acquired by field measurement. Statistic features of electromagnetic disturbance were obtained. Using wavelet packet transform as demonstrated in Fig. 3, impulsive signal was extracted from these electromagnetic disturbance data. In order to acquire approximate and detail coefficients, symlet-6 wavelet was employed for 12-layer wavelet transformation. By applying Stein's unbiased risk estimate (SURE), the best tree was obtained. According to these coefficients of each layer, the impulsive signal was reconstructed.

Pulse characteristic parameters such as peak to peak value, duration, etc., were collected from the extracted impulsive signal and distribution fitting of these parameters was statistically analyzed. Probability density function (PDF) was calculated for the extracted impulsive signal features. According to numerous mathematical probability distribution functions, best fitting distribution of pulse characteristic parameters was acquired [13]. PDF of peak to peak value, which obeys normal distribution, is shown in Fig. 4. PDF of duration that obeys log-logistic distribution is illustrated in Fig. 5.

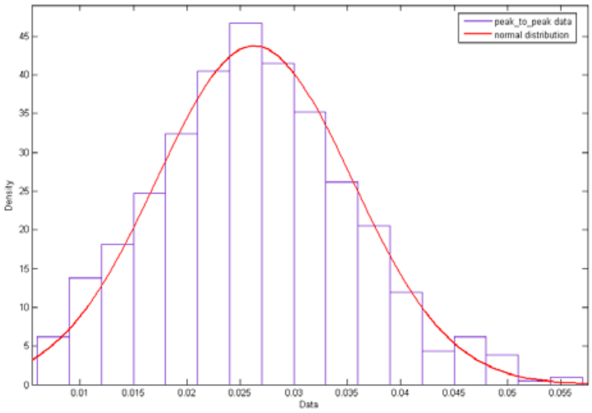


Fig. 4. PDF of peak to peak value

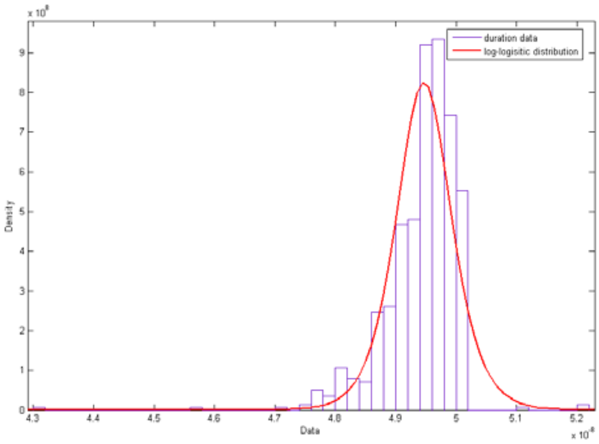


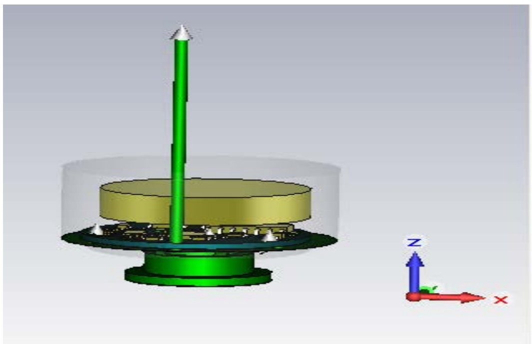
Fig. 5. PDF of duration

SIMULATION AND EXPERIMENT

Simulation and Experiment of Electromagnetic Disturbance to Wireless Sensor

The electromagnetic disturbance from the electrical equipment was studied in order to reveal the immunity of the wireless sensor, when the latter is applied in electrical environment. Field measurement and experiment indicated that the communication quality of the wireless sensor is impacted by electromagnetic disturbance. Analysis of the measurement data indicated that the frequency range of electromagnetic disturbance includes the communication frequency of the wireless sensor, i.e. 2.4GHz. The model of the wireless sensor was established in order to reveal the distribution of induced voltage inside the wireless sensor.

(a) A photo of a wireless sensor



(b) Model of a wireless sensor

Fig. 6. Photo and model of a wireless sensor

The photo and model of the wireless sensor are shown in Fig. 6 (a) and (b), respectively. Set plane wave as an excitation source and assign electrical field strength 10V/m according to the IEC Standard 61000-4-3 definition for the third class test level. A disturbance signal in simulation, taking a partial discharge signal as an example, was set as an excitation source, shown in Fig. 3. Fig. 7 shows the spectrum of induced voltage on the antenna, the dominant frequencies of which are 1.2GHz and 2.3GHz. The maximum value of induced voltage is 1.04V, which is high enough to lead to communication packet loss of the wireless sensor. After all, the 1.2GHz signal component can easily generate 2.4GHz signal by frequency multiplication, which is the communication band of the wireless sensor, and leads to the same frequency interference. The 2.3GHz signal component causes neighboring interference. The frequency components at 1.2GHz and 2.3GHz impact on the communication quality of the wireless sensor.

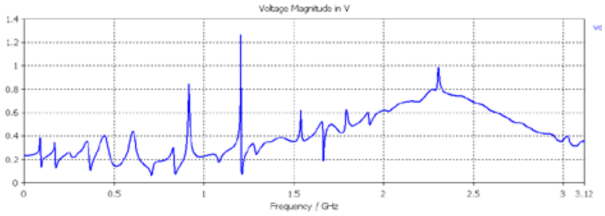


Fig. 7. Spectrum of induced voltage signal on the antenna

Field experiment testified that electromagnetic disturbance of electrical equipment influences the communication quality of the wireless sensor. The representative photo of the field experiment is shown in Fig. 8.

Fig. 8. A photo of the field experiment on the electromagnetic disturbance of a wireless sensor

Immunity test on the wireless sensor was performed at an open area test site, as shown in Fig. 9, in order to obtain communication performance of the wireless sensor under electromagnetic disturbance and to indicate the variation in work state with variation of electrical field strength of the electromagnetic disturbance. A wireless sensor acts as a transmitter and receiver under electromagnetic disturbance generated by signal generator, power amplifier and transmitting antenna.

Fig. 9. Photo of immunity test on the wireless sensor performed at an open area test site

Electromagnetic disturbance varies in the frequency band range of 100MHz to 2.5GHz. Critical electrical field strength of normal-operation/packet-loss work state and of packet-loss/halt work state was acquired by test at a frequency around 2.4GHz and 1.2GHz, which is the most sensitive frequency, as shown in Figs. 10 and 11.

“Critical electrical field strength of normal-operation/packet-loss work state” means that during communication under this electrical field strength, the work state of the wireless sensor changes from normal operation to packet loss. “Critical electrical field strength of packet-loss/halt work state” means that during communication under this electrical field strength, the work state of wireless sensor changes from packet loss to halt [14].

At electrical field strength of 0.80V/m that is almost at the noise level at the frequency of 2.405GHz that is the current communication frequency of the wireless sensor, the latter stops working, as illustrated in Fig. 10. At frequencies that are lower or higher than 2.405GHz in the frequency range of 2.4GHz~2.409GHz, the critical electrical field strength is higher than 0.80V/m. The same frequency interference area is around 2.405GHz, and the impact of electromagnetic disturbance at this frequency is outstanding. Taking as an example the frequency of 2.409GHz, the electrical field strength that makes the wireless sensor start losing packet during communication is 9.6V/m and the wireless sensor stops working when it rises to 11.6V/m. With the increase in electrical field strength at each frequency, the wireless sensor experiences a process from normal operation to packet loss, and then to halt, its packet loss rate rising from 0 to 100% during communication, as illustrated in Fig. 12 at the frequency of 2.409GHz.

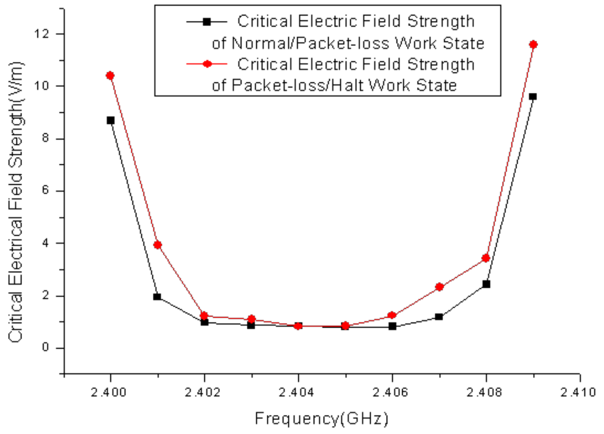


Fig. 10. Critical electric field strength at 2.4GHz

There is also a distinguished sensitive area as shown in Fig. 11 in the frequency range from 1.2GHz to 1.2035GHz. The most sensitive frequency in this range is 1.203GHz that is about half of the communication frequency of a wireless sensor, i.e., 2.405GHz. However, the whole electrical field strength level is much higher than that in the frequency range of 2.4GHz. Wireless sensor halted working at 1.203GHz at an electrical field strength of 2.45V/m, but changed the work state from normal operation directly to halt at electrical field strength of 36.93V/m at 1.2035GHz, while it did not halt working at 1.2GHz even at the maximum value of electrical field strength during communication in this open field test site.

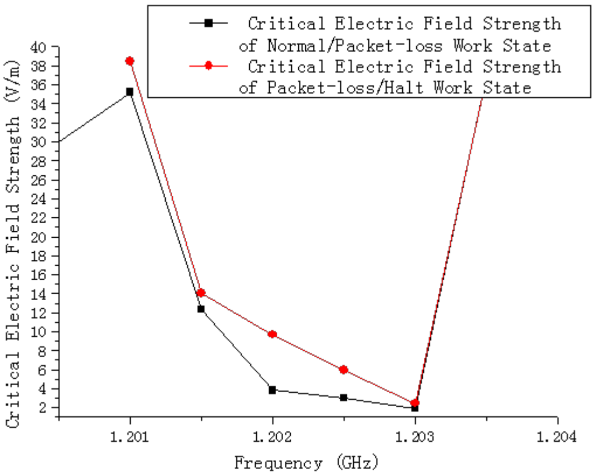


Fig. 11. Critical electric field strength at 1.2GHz

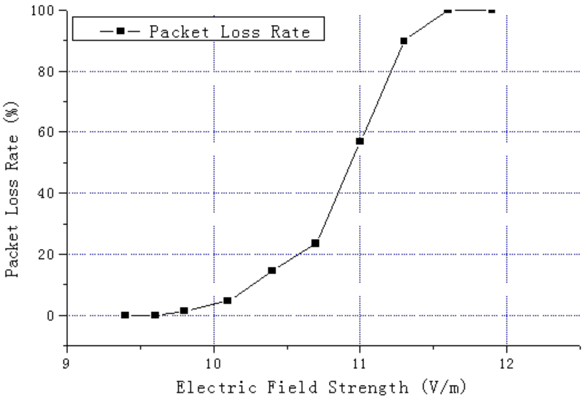


Fig. 12. Packet loss rate variation at the frequency of 2.409GHz

The immunity test indicates that the wireless sensor may be impacted and lose packet at 2.4GHz and 1.2GHz during communication. Detailed curves in Figs. 10, 11 and 12 illustrate the communication sensitivity of the wireless sensor at specific frequency and electrical field strength of disturbance.

Simulation and Experiment of Communication Obstruction of a Wireless Sensor in Electrical Environment

Simulation model which employs the uniform theory of diffraction at a high frequency range (i.e. 2.4GHz) to solve large size problem, was studied to obtain the magnitude of electrical field when electromagnetic disturbance exists in the electrical environment. Different placement locations of the wireless sensor resulted in different effects of electromagnetic disturbance, because of the distance of disturbance source and obstruction layout.

A transformer model was established in order to reveal the communication obstruction of wireless sensors, as demonstrated in Fig. 13. Through simulation, it was illustrated that when a wireless sensor modeled as a dipole transmitting antenna, is placed around the transformer, the wireless sensor at different locations produces different electrical field distributions, due to distance and obstruction. According to the electrical field distribution, the induced voltage inside the receiving wireless sensor and the effective wireless sensor communication range was estimated and thus, wireless sensor communication obstruction of electrical equipment was evaluated [15].

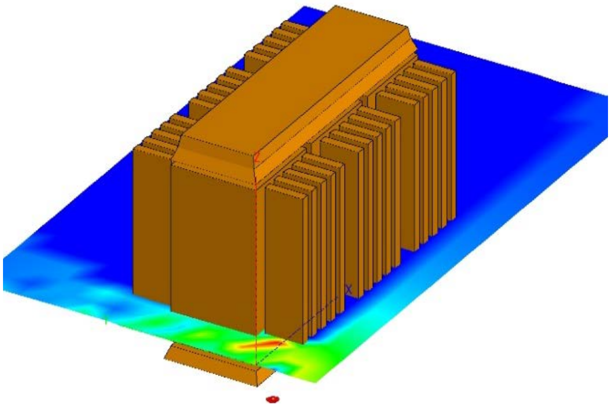


Fig. 13. A transformer model

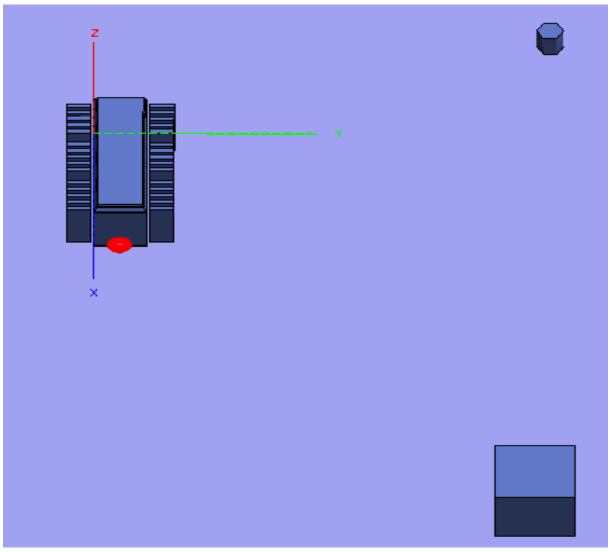


Fig. 14. Location of electrical equipment

Protection room and capacitor were located at the right side of the transformer as demonstrated in Figure 14. When the wireless sensor is placed on the left of transformer at a height of 1 m, 2 m and 3 m, the electrical field distribution is illustrated in Fig. 15 (a), (b) and (c), respectively. The red part in this figure denotes the maximum value of the electrical field strength (i.e. 3.6V/m), while the blue part represents the minimum value. This simulation shows that the transformer obstructs the communication of wireless sensors, since the electrical field distribution is obviously impacted by the transformer. Different placement heights of the wireless sensor, as demonstrated in Fig. 15, result in different electrical field distribution, and therefore lead to different communication ranges of the wireless sensor in the same electrical environment. The communication quality is impacted by the height of wireless sensor around the electrical equipment.

When the wireless sensor is placed on the right of the transformer at a height of 1 m, 2 m and 3 m, the electrical field distribution is demonstrated in Fig. 16 (a), (b) and (c). Obviously, the electrical field distribution is mostly focused in the area of the transformer, capacitor and protection room. Different placement heights of the wireless sensor, as shown in Fig. 16, produce different electrical field distribution and different communication range of wireless sensor.

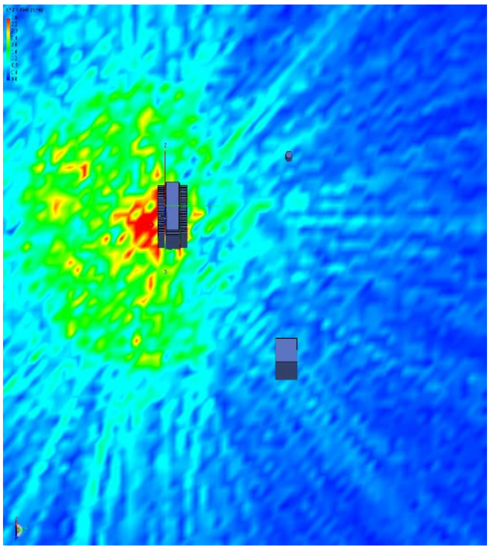
Fig. 17 (a), (b), (c) and (d) shows that the electrical field distribution is distinctively different when the wireless sensor is placed at a height of 0 m above, below, on the left and on the right of the transformer. This simulation presents that a different placement of the wireless sensor around the transformer at the same height yields different electrical field distribution, because the large-size electrical equipment, i.e., the transformer, blocks the communication of the wireless sensor. The communication quality of the wireless sensor at the same height around the electrical equipment varies when wireless sensor changes position.

By simulation, it was illustrated that the communication obstruction of the wireless sensor produced by electrical equipment is a vital factor having an impact on the communication quality. Different positions and different heights of the wireless sensors result in different communication ranges around the transformer, protection room and capacitor. Therefore, the communication quality of the wireless sensor is impacted by obstruction of electrical equipment.

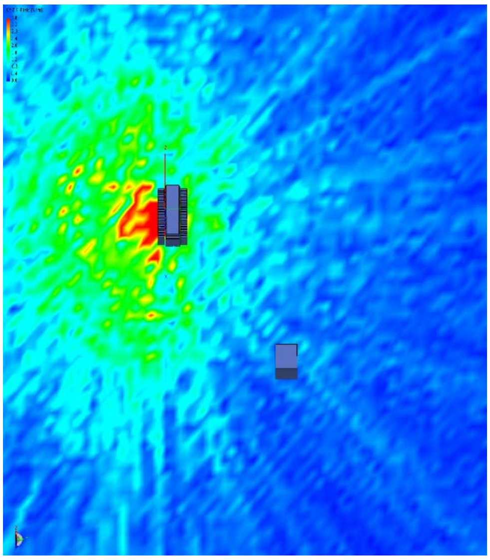
Field experiment verified this conclusion and Fig. 18 is a representative photo.

CONCLUSION

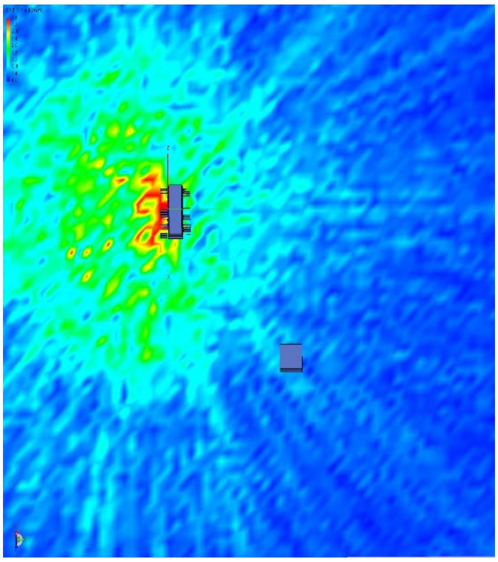
The measurement data in substations of different voltage levels and of different insulation types were studied and statistically analyzed. Experiment and simulation indicated that the communication quality of the wireless sensor is impacted by electromagnetic disturbance and the location of electrical equipment, such as transformer, protection room and capacitor in the electrical environment. Communication obstruction produced by the electrical equipment influences the communication quality of the wireless sensor at different locations.



(a) Wireless sensor at the height of 1m

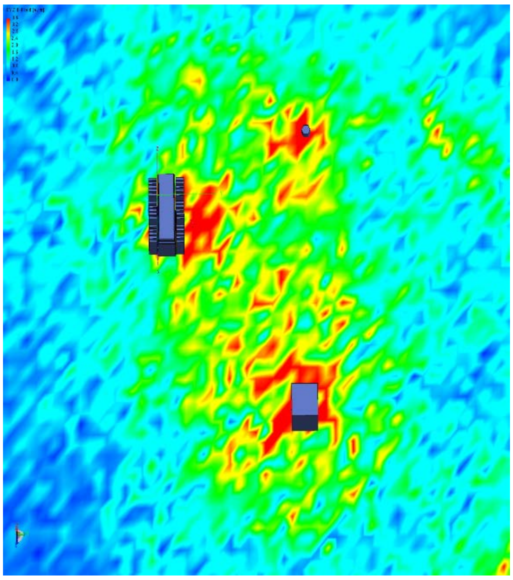


(b) Wireless sensor at the height of 2m

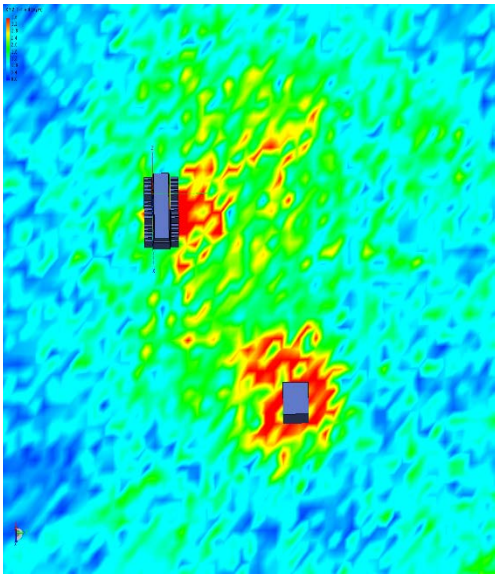


(c) Wireless sensor at the height of 3m

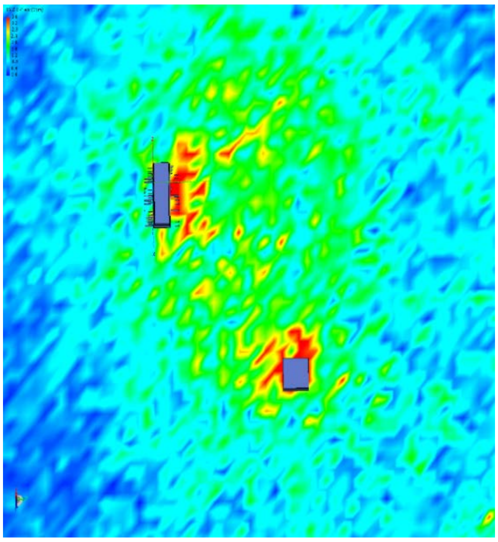
Fig. 15. Electrical field distribution when the wireless sensor is placed at a height of 1m, 2m and 3m on the left of the transformer



(a) Wireless sensor at the height of 1m

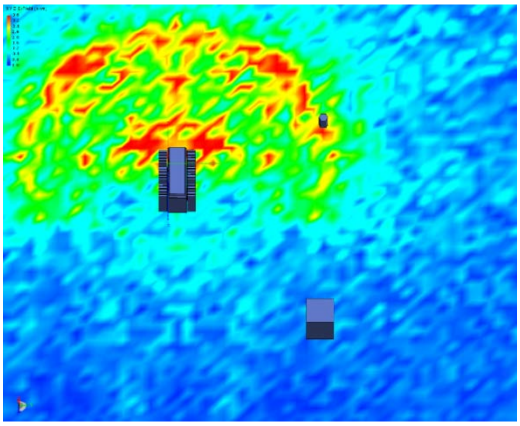


(b) Wireless sensor at the height of 2m

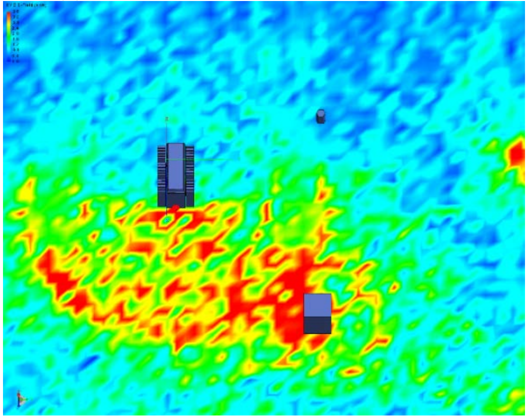


(c) Wireless sensor at the height of 3m

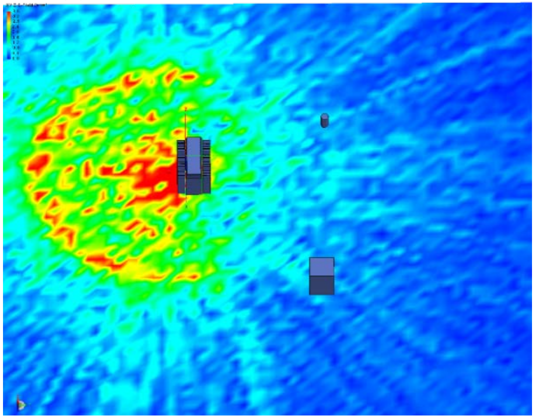
Fig. 16. Electrical field distribution when wireless sensor is placed at the height of 1m, 2m and 3m on the right of the transformer



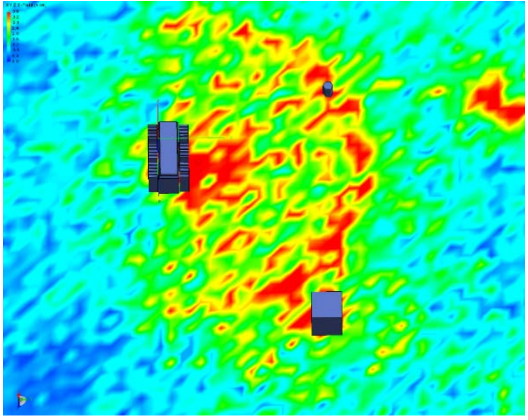
(a) Wireless sensor above the transformer



(b) Wireless sensor below the transformer



(c) Wireless sensor on the left of the transformer



(d) Wireless sensor on the right of the transformer

Fig. 17. Electrical field distribution when the wireless sensor is placed at the height of 0 m around the transformer

Fig. 18. A photo of the field experiment on communication obstruction of a wireless sensor

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