DETECTION OF ULTRA-WIDE-BAND IMPULSIVE NOISE IN A 400 KV AIR INSULATED ELECTRICITY SUBSTATION

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ABSTRACT

A measurement campaign has been carried out in 400kV air insulated electricity substation to characterise and model radio frequency impulsive noise with a view to assessing its impact on wireless network technologies. The relatively recent availability of new technologies such as WiFi, Bluetooth and Zigbee means that particular emphasis has been put on higher frequency bands (e.g. 2.4, 5 GHz) than have previously been investigated. A detection system to measure wideband noise over a spectrum extending up to 5.1 GHz has been designed, implemented and deployed in a large electricity substation in central Scotland. Results based on a preliminary analysis of the recorded data are reported.

INTRODUCTION

A large amount of instrumentation and control equipment is scattered throughout the compounds and control rooms of electricity substations. Information and control signals for both normal and abnormal operation are traditionally connected, using cables or optical fibres, to a SCADA (Supervision, Control and Data Acquisition) system [1] and/or its successor UCA (Utilities Communication Architecture) system [2]. Ethernet local area network (LAN) implementations of such UCA/SCADA systems, which simplify the addition/reconfiguration of instrumentation and the coordination of protection systems, have been proposed and are already being evaluated [3]. Significant flexibility and cost advantages over a wired LAN infrastructure would be gained, however, if signals could be routed around electricity substation compounds wirelessly. Furthermore, wireless communication technologies hold out the prospect of 'hot-line', sensors that can be deployed on energized high-voltage (HV) equipment without the inconvenience and costs associated with bridging the system's primary insulation [4, 5]. Wireless LAN and Wireless Personal Area Network (PAN) technologies represent obvious opportunities to realize these advantages. Whilst the naturally occurring noise environment is relatively benign at Wireless LAN (2.4, 5 GHz) and Wireless PAN (2.4 GHz) frequencies [6], the man-made noise environment within a substation compound is complex and hostile due to (i) partial discharge (PD) arising from imperfect insulation and (ii) sferic radiation arising from switching and fault transients (The term sferic usually relates to radiation from a lightening event but is used here as a shorthand for similar radiation arising from any large current transient). An investigation into the vulnerability of WLAN and WPAN technologies to impulsive noise in electricity transmission substations is currently in progress [7]. One of the primary objectives is the detection and investigation of PD in the microwave bands used by WLAN and WPAN technologies such as IEEE 802.11a/b/g, IEEE 802.15.4 and IEEE802.15.3. This requires investigation of the frequency spectrum up to 5 GHz.

PD is an electrical discharge that fails to fully bridge the space between a pair of electrodes. It can occur around an electrode in a gas (corona), within gas bubbles in a liquid or within the space created by voids in a solid. HV plant (transformers, switchgear, cables etc) is especially prone to PD if its insulation is damaged and/or as its insulation ages. If remedial action is not taken the insulation can be seriously compromised leading, ultimately, to catastrophic failure. Energy from PD processes can be radiated whenever spectral components arising from current pulse edges extend into the radio frequency (RF) region [8]. Although the character of PD appears to have some dependence on the size and geometry of plant components (e.g. insulating spacers, L-shaped buses, T-branch buses) damping typically appears to become significant somewhere between 100 MHz and 300 MHz and increases with increasing frequency above this [9]. PD energy in the frequency range 0.5 - 1.2 GHz, however, is readily radiated from apertures formed, for example, by insulating spacers or bushings [13]. PD current pulses in strong insulators (e.g. SF_6) can have rise-times as short as 50 ps and may contain significant energy at frequencies up to 3 GHz [10].

Several methods and systems for detection of very-high-frequency (VHF, up to 300 MHz) and ultra-high-frequency (UHF, up to 3 GHz) PD in GIS have been investigated [10-12]. These are intrusive techniques, however, in which VHF or UHF couplers are mounted directly onto items of plant. A non-intrusive PD measurement system based on RF technology has been shown capable of detecting energy at frequencies up to 1.2 GHz [13]. The authors are not aware, however, of any non-intrusive measurements of PD at frequencies up to 5 GHz.

In this paper we describe a system to monitor impulsive noise in the general electricity substation environment and present preliminary measurement results.

MEASUREMENT SYSTEM

An impulsive noise detection system has been developed. The system consists of a low-band (LB) TEM half-horn antenna, a high-band (HB) TEM half-horn antenna, a disk-cone antenna, a WLAN dual-band (2.4/5 GHz) antenna, a high-bandwidth (6 GHz) digital storage oscilloscope (DSO) and a 1 TB external hard drive disk (HDD). A block diagram of the measurement system is shown in Fig. 1. The system is shown deployed in a 400 kV substation control room in Fig. 2.

The TEM half-horn was selected as the principal antenna type for the collection of data because of its excellent impulse response characteristics. Details of the TEM half-horn design are reported in [14] but a summary is repeated here.

The LB horn is constructed from a triangular aluminum plate and a 122cm×122cm aluminum ‘ground’ plane. The width (*w*) of the triangular plate at the aperture is 65.1cm, its length (*L*) is 84cm and its aperture height measured from the ground plane (*h*) is 20.1cm. The antenna feed is a 50Ω SMA connector with its flange in electrical contact with the ground plane and its centre-conductor connected to the triangular plate apex. The amplitude response, measured with network analyzer, shows the -3dB bandwidth of a pair of identical horns (transmit and receive) to be 1.264 GHz covering the frequency range 716 MHz - 1.98 GHz. The peak value of the amplitude response occurs at 1.068 GHz.

The HB horn triangular flange is constructed from a PCB. The flange width (*w*) at the aperture is 21.7cm and its length (*L*) is 28cm. The aperture height (*h*) is 6.7cm. The feed structure and ground plane are identical to those of the LB horn. The -3dB bandwidth of a cascaded pair (transmit and receive) is 3.195 GHz (1.905 to 5.1 GHz) and the amplitude response peak value occurs at 2.13 GHz.

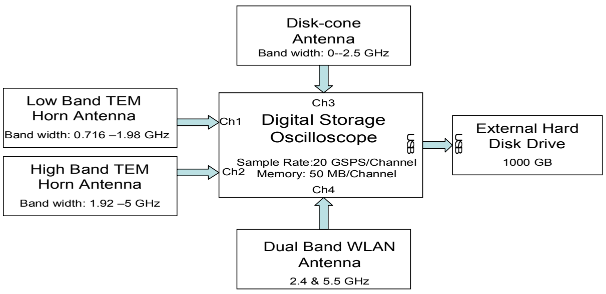

Fig. 1 Impulsive noise detection and recording system

The disk-cone antenna covers the frequency range below 710 MHz which corresponds to the frequency range conventionally assumed to be important for PD. The details of this antenna design are reported in [13] but are, again, summarized below.

The disk-cone antenna consists of an inverted right circular cone over a circular ‘ground’ plane. The ground plane is 171cm in diameter and is constructed from aluminum plate. The cone was machined from solid aluminum. It has a base diameter of 13.3cm and a height of 5.4cm. A non-inverted cone with equal base diameter sits on top of the inverted cone. The antenna is vertically polarized and has approximately flat frequency response in the range 0 - 2.5 GHz with approximately constant (50 Ω) impedance.

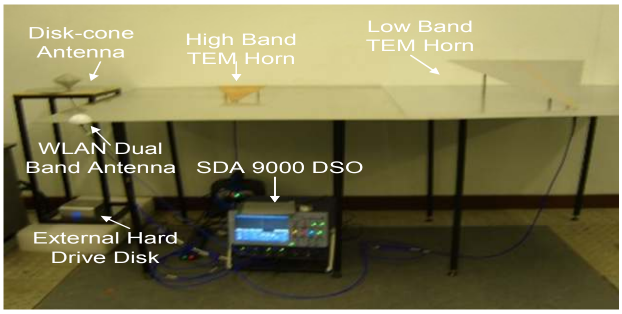

Fig. 2 Impulsive noise detection and recording system deployed in substation control room

A commercial dual-band WLAN antenna is also deployed. It has two passbands sufficiently wide to accommodate WLAN signals at 2.4 and 5 GHz.

The DSO is a LeCroy SDA 9000 with four simultaneous sampling channels. Each channel has a sampling rate of 20 GS/s and 50 MS of RAM. The analogue bandwidth is 6 GHz, and the input impedance 50 Ω.

The antennas are connected (directly) to the DSO. Direct sampling is used since previous studies, e.g. [15], have shown this to be advantageous in terms of minimising signal distortion. Interconnection is achieved via the use of 18 GHz, 50 Ω, coaxial cables. Time series are recorded using conventional amplitude triggering. Each recorded time series is 2.5 ms in length which is the longest possible using the available RAM. The recorded signals are saved to the external HDD which is connected with the DSO via a USB interface.

MEASUREMENTS

The measurement site is Strathaven air insulated substation in the UK, owned by Scottish Power Ltd. Fig. 3 is shows a composite image of the 400 kV compound. The site also contains 275 kV (out of shot behind the camera) and 132

Fig. 3 Strathaven substation – 400 kV compound

kV compounds (out of shot to the left). The 400 kV control building, in which the measurement system was deployed, is shown on the left in Fig. 3.
An example measured time-series instance obtained using the LB horn during the measurement campaign is shown in Fig. 4. The recorded signal has been divided into to five contiguous data segments (a) - (e). In each segment the abscissa is time in µs and the ordinate is signal magnitude in mV.

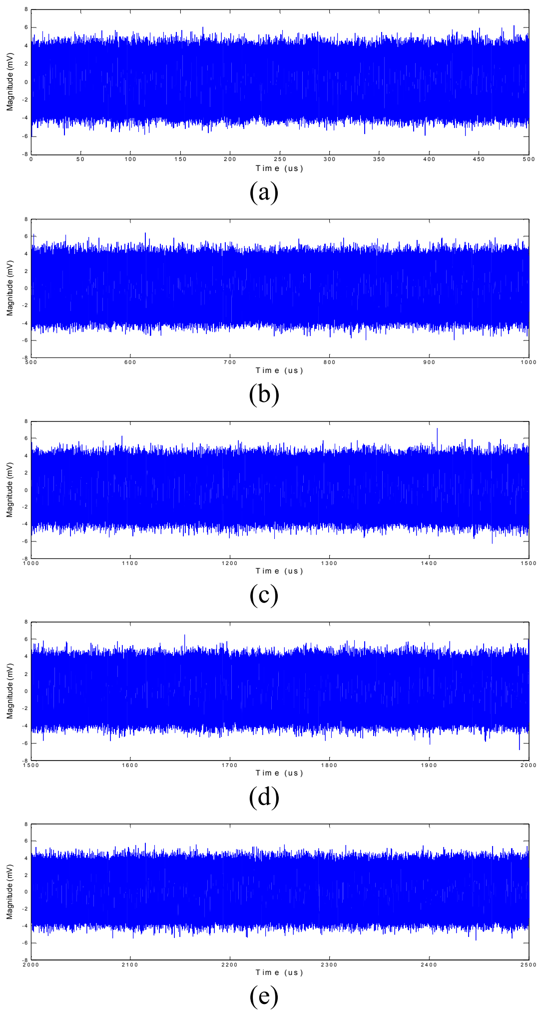

Fig.4. Original signal measured in power substation

INTERFERENCE

A spectral analysis of the measured data has been carried out, Fig. 5. Discrete spectral lines representing broadcast, radar, mobile communications and other radio signals are clearly visible in the frequency rang 0.5 MH to 5 GHz. All these lines have been identified using, in part, OFCOM's radio frequency allocation table [16]. The most significant components are in the bands 0.5 - 1.2 MHz, 90 – 108 MHz, 177 – 285 MHz, 500 MHz, 600 – 750 MHz, and at 833 MHz, 1.25 GHz, 1.666 GHz, 1.76 GHz, 2.1 GHz, 2.917 GHz, 3.333 GHz, 3.75 GHz and 5 GHz. 0.5 - 1.2 MHz represents the MW AM broadcasting band. 90 -108 MHz is the FM radio band. 177 - 285 MHz contains Public Access Mobile Radio (PAMR). The 500 MHz, 600 -750 MHz and 833 MHz are TV broadcasting bands. 1.25 GHz is the civil airport radar band. 1.76 GHz and 2.1 GHz are the GSM 1800 and the 3G bands, respectively. 2.917 GHz contains civil maritime, air traffic control and range safety radars. 3.333 GHz is a maritime mobile band. 3.75 GHz is C-Band

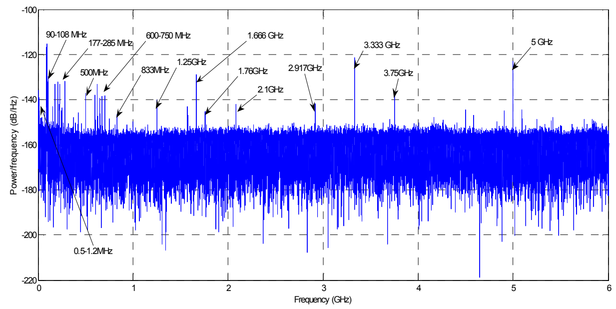

Fig.5. The spectrum of the measurement from 400 kV power substation

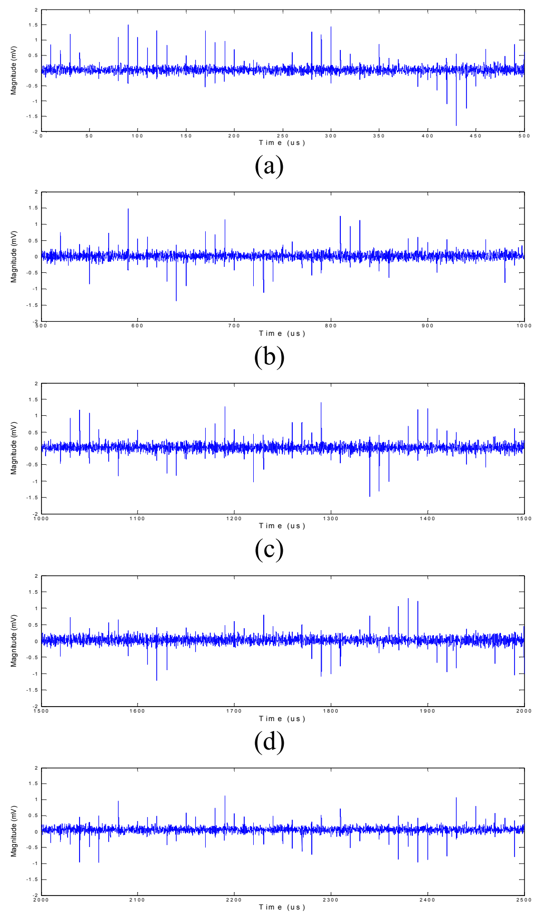

Fig.6. Impulsive noise

satellite TV and 5 GHz contains civil landing system signals. These broadcast, radar and communications signals obscure the impulsive noise processes that are the subject of this study. This is why there is no obvious sign of impulsive noise in Fig. 4.

EXTRACTION OF IMPULSIVE PROCESS

Since the impulsive noise is buried in coherent interference, the measured data are 'de-noised' using a wavelet transform based pre-processing techniques. The de-noising algorithm is described in [17]. Fig. 6(a) – (e) show the time series segments after pre-processing. The abscissa is time in µs and the ordinate is de-noised signal amplitude in mV. An impulsive noise process is now clearly visible.

CONCLUSION

A measurement campaign to detect, and record, impulsive noise in an electricity substation in frequency bands hitherto ignored has been presented. The impulsive noise is weak due to the distance between the source and the measurement equipment and the impulsive process is thus obscured by strong, coherent, interference. The impulsive noise has been extracted using signal processing and its preliminary statistics obtained.

ACKNOWLEDGMENTS

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