Detecting partial discharge with ultrasonic measurement

Ultrasonic measure to detect partial discharge corona, arcing and tracking has become a viable means used for electrical equipment. Author Lee Wai Meng discusses the considerations in this new method.

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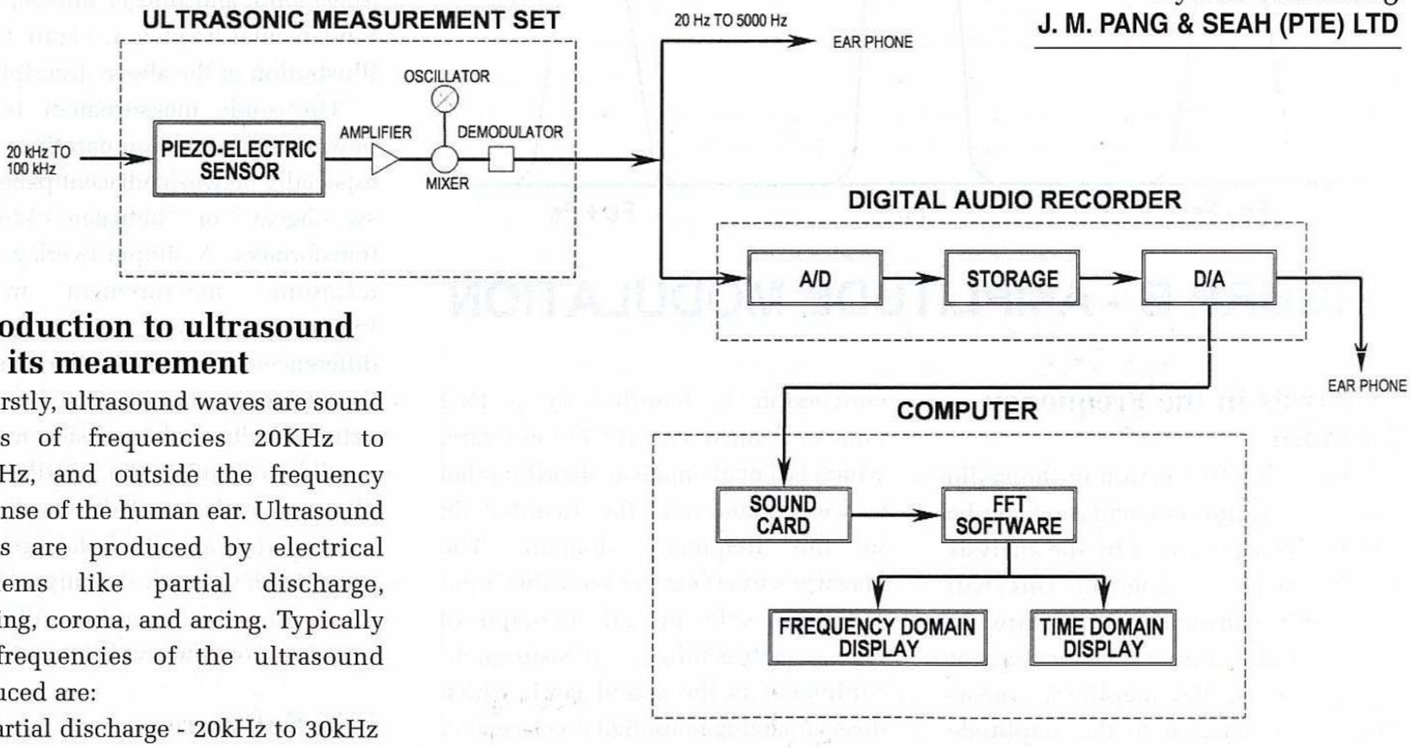

FIGURE A - BLOCK DIAGRAM

Introduction to ultrasound and its meaurement

Firstly, ultrasound waves are sound waves of frequencies 20KHz to 100KHz, and outside the frequency response of the human ear. Ultrasound waves are produced by electrical problems like partial discharge, tracking, corona, and arcing. Typically the frequencies of the ultrasound produced are:

- Partial discharge - 20kHz to 30kHz
- Corona, arcing, tracking - 40kHz

Ultrasound waves are able to penetrate small openings, seals, door seams and air vents. The ultrasound is perceived as crackling sound by the human ear. The ultrasonic measurement used is on-line and non-intrusive. Therefore measurements can be done on energised electrical equipment without the need to remove protective covers. By maintaining the insulation integrity of the electrical equipment being tested, this method has already been employed in common applications such as cable terminations, switchgears, busbars and transformers.

Ultrasonic Measurement Equipment

Figure A is the basic block diagram for ultrasonic measurement. The ultrasound is detected by the piezoelectric sensor, which converts pressure energy from the ultrasound striking the sensor into electrical energy. Quartz is a common material for such piezoelectric sensors. Typically, the electrical signal is very small and will have to be amplified. The resulting electrical signal is in high frequency and thereafter, this high frequency electrical signal is shifted down to the audio frequency range by amplitude modulation. This is done by mixing the electrical signal with a carrier frequency from a local oscillator.

If we assign the electrical signal be Fs, and the carrier frequency be Fc. The three output signals from the amplitude modulation will have frequencies Fc, (Fc + Fs) and (Fc - Fs). Refer to Figure B.

Only the output signal with frequency (Fc - Fs) will fall into the audio range of the human ear. The demodulator extracts the signal and a connection to a loudspeaker or earphone will produce the crackling sound should the measured electrical equipment have partial discharge, corona, tracking or arcing.

One major disadvantage of using the human ear to hear the crackling sound is the difference in perception and sensitivity of various people.

An obviously crackling sound to one person may not be obvious to another person. Hence to solely rely on the audio analysis of the measured ultrasonic emission will not be accurate.

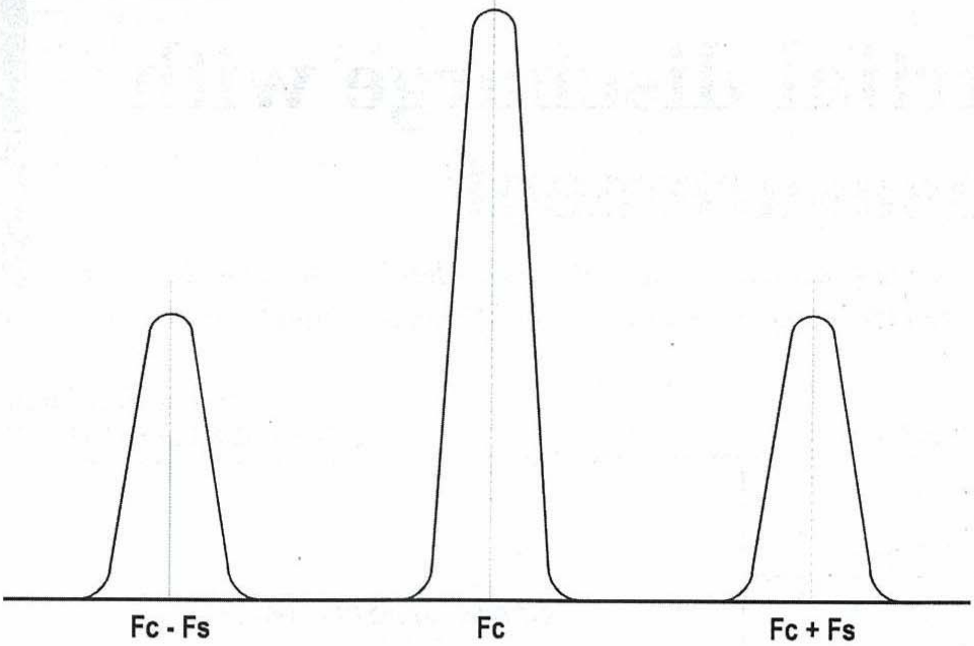

FIGURE B - AMPLITUDE MODULATION

Analysis in the Frequency Domain

The subjective nature of the audio analysis of ultrasonic emission can be significantly improved by the analysis in the frequency domain. This will require the conversion of the output of the ultrasonic measurement equipment in the amplitude versus time representation to the amplitude versus frequency representation. This conversion is handled by a Fast Fourier Transform (FFT) software, which is a mathematical algorithm that converts signal from the time domain to the frequency domain. The hardware interface between the input of the FFT software and the output of the ultrasonic measurement equipment is the sound card, which does an analogue to digital conversion of the audio signal. The 16 bit sound card commonly used on personal computer will work well with audio frequency analysis using FFT.

Partial discharge, corona and arcing in electrical equipment have signature characteristics when viewed in the frequency domain. Invariably, amplitude spikes will appear at the fundamental frequency of the electrical supply (50 hertz in Singapore), and integer number of the fundamental frequency. Figure C is an illustration of the above description.

Ultrasonic measurement is most powerful on a comparative basis, especially between adjacent panels of a switchgear or between identical transformers. A simple overlay of the ultrasonic measurement in the frequency domain will show up differences and indicate the source of the ultrasonic emission. The directional nature of ultrasonic emission makes it possible to confirm the location of the ultrasonic emission. This is easily done by removing a bolt of the protective panel to the electrical equipment and measuring the escaping ultrasonic emission from the created opening.

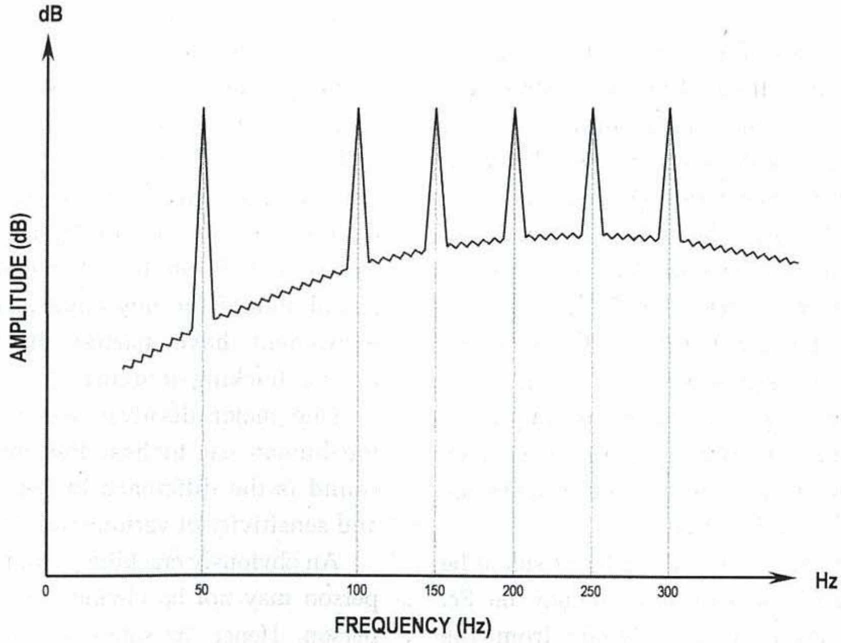

FIGURE C - SIGNATURE OF ELECTRICAL PROBLEMS

FFT Software

Any commercially available FFT software will work well with the output electrical signal of the ultrasonic measurement set. This is because the output electrical signal is in the audio frequency range and both the hardware and software requirement are not stringent, unlike high frequency measurements, storage, processing and analysis. In using a FFT software, the following are the very important parameters;

- Sampling rate
- FFT size

Sampling Rate

The sampling rate determines the number of times a second the analogue input signal is digitized by the sound card. The larger the sampling rate the more accurate the representation of the analogue signal in the digital form. An important concept in digital signal processing is the Nyquist sampling rule, which states that if the measured analogue signal is 8,000Hz, the sampling rate must be greater than twice of 8,000 Hz. Otherwise, unwanted signal will appear in the subsequent digital to analogue conversion to obtain the original analogue signal.

FFT Size

The FFT size determines the resolution of the frequency spectra. The number of frequency spectra lines is half the FFT size. Hence, a 1024 FFT size will produce 512 output frequency spectral lines. The frequency resolution of each frequency spectra lines is equal to the sampling rate divided by the FFT size. For example, a sampling rate of 8192 hertz will have a 8 hertz separation between consecutive frequency spectral lines. Larger FFT size will produce higher resolution of the frequency spectral lines, but will require longer time to compute.

When buying the digital audio recorder, the low limit of the frequency response must be as low as 10 hertz, otherwise important spectral information at the low frequency will be lost. The present setup used by the author consists of:

- Ultrasonic measurement set - model ultraprobe 9000 from UE systems of USA
- Digital audio recorder - Sony mini disc
- FFT software - Spectra Plus of USA

Practical set-up for Ultrasonic Measurement

We have tried various components and configurations for the ultrasonic measurement. The most accurate configuration is a direct connection from the output of the ultrasonic measurement equipment to the sound card of the PC with the FFT software. However, this has practical problems at site because it is cumbersome carrying the PC during the ultrasonic measurement. The practical configuration will need a digital audio recorder as depicted in Figure A. The input stage of the recorder is an analogue to digital converter, which stores the audio signal in the digital form. The output stage of the recorder is a digital to analogue converter for connection to the sound card of the PC.

Conclusion

As the ultrasonic measurement does not require the de-energisation of the electrical circuit nor the removal of protective cover, it is a convenient and powerful tool for preventive maintenance.

However, one must not solely rely on ultrasonic measurement. The use of equipment with different measurement techniques will significantly increase the reliability of correct detection of partial discharge, corona, arcing and tracking in electrical equipment.

CASE HISTORY

For 22kV Cable Termination at Switchgears

A petrochemical plant in Jurong Island experienced a flashover at one of the 22kV cable termination at the power receiving switchgear to PowerGrid. The back cover to the switchgear was completely blown off. Investigation of the cable revealed a puncture at the interface between the semi-conducting tape and the XLPE insulation. The extensive damage to the cable made it impossible for any root fault analysis.

The plant was concerned that a similar flashover may occur at the 22kV cable termination of the other power receiving switchgears. An ultrasonic measurement was conducted and very obvious crackling sound was detected by a earphone. The circuit was subsequently de-energized and investigation revealed the followings:

- The stress control tube was NOT a single continuous length, but consisted of two overlapping sections. This effectively meant the stress control tube was good for 11kV, but is not safe for the 22kV operating voltage and

- At the interfere of the XLPE insulation and semi conducting tape, the XLPE insulation was badly pitted and turning to a powder form.

For 22kV Cable Termination at Transfomers

The author was commissioned to do ultrasonic measurements for 9 numbers of 22kV/400 Volts transformers at a petrochemical plant in Jurong Island. The measurements at the 22kV cable box showed large spikes at 50 hertz and integer numbers of 50 hertz.

In a subsequent shutdown maintenance, the 22kV cable termination was stripped for inspection. It was found that the stress control tube was too short and made worse by incorrect positioning. The result was a severe brown discolouration of the normally white XLPE insulation, an indication of overheating of the XLPE insulation beneath the stress control tube.