Chromatic monitoring in radio frequency active high voltage environments

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Abstract—This paper considers the problem of monitoring high voltage equipment in the presence of radio frequency emissions at high voltage power transmission/distribution substations. Examples of monitoring approaches using the radio frequency signals themselves and ones which are immune to the radio frequencies are given. It is shown how chromatic techniques can be used with both types of monitoring and how this has the potential for providing an overall condition assessment of equipment by combining both sets of data.

I. INTRODUCTION

Monitoring High Voltage equipment in the presence of radio frequency emissions can have both positive and negative attributes. The radio frequency signals themselves can provide information about the condition of the high voltage system whilst conversely they can interfere with electronic instruments measuring other parameters.

This contribution presents examples of both cases in monitoring high voltage power distribution and transmission substations. It shows how chromatic techniques can be deployed to extract information from radio frequency signals in the first case and from radio frequency immune systems in the second case. The potential of the chromatic approach is indicated for correlating the radio frequency quantified information with that of the radio frequency immune data to provide a more complete assessment of the condition of the high voltage equipment.

II. ELECTROMAGNETIC EMISSIONS IN HIGH VOLTAGE SUBSTATIONS

Two sources of electromagnetic emissions in high voltage substations are:

a) Switching of 50 Hz power system currents
b) Degradation of electrical insulation by high voltages in cables and transformers via Partial Discharges.

Fig. 1(a) shows an example of radio frequency emissions produced during switching operations with a high voltage circuit breaker [1]. Figure 1(b) shows some typical radiofrequency signals produced by Partial Discharges under laboratory conditions [2].

III. MONITORING BASED UPON RADIO FREQUENCY EMISSIONS

A. Partial Discharges in Electrical Insulating Materials

Signals of the form shown on Fig. 1(c) may be addressed to distinguish between different kinds of Partial Discharges so that incipient faulty elements may be identified. The progression towards full electrical breakdown can also be tracked so that remedial action can be planned at an early stage.

One technique for extracting such information is the use of the chromatic approach [3]. For this particular application, time domain chromaticity is deployed which involves addressing the time varying radio frequency signal with three
non orthogonal processors whose responses vary in the time domain. Examples of three such processors (R, G, B) deployed on a signal is shown on Fig. 2.

![Chromatic Transforms and Maps](image)

The outputs from these processors may be transformed into chromatic parameters to form chromatic maps. There are several transforms possible leading to two particularly useful chromatic maps - the x, y, z Cartesian map and the H, L, S polar map (Fig. 2(c)). The algorithms for transforming R, G, B into x, y, z and H, L, S and the physical meaning of each chromatic parameter is given by Jones et al [3]. For example, H represents a dominant time within the signal envelope, S is the effective signal spread etc.

Fig. 3(a) shows a Cartesian chromatic map (z1: y1) for various Partial Discharges and which indicates the dominant phase angle for each radio frequency signal within the first quarter cycle of the 50 Hz power frequency.

The different Partial Discharges include discharges within the bulk of an insulator, on the surface of a dielectric insulator, in insulating oil etc. The values of the dominant phase angle follow various loci as the 50 Hz alternating peak voltage to which each is exposed was increased.

![Time domain Cartesian chromatic map of various Partial Discharges](image)

As the insulation progresses towards full breakdown, the loci of the various data sets converge towards the full breakdown point 0.33, 0.33 which corresponds to the signal extending across the full quarter cycle. Fig. 3(b) shows the variation of another chromatic parameter (L*/(1 – S*)) with z1 which represents a notional amplitude of the signal. The final progression towards full breakdown is indicated by an increase in the value of L*/(1 – S*).

An advantage of the chromatic approach is that unlike many alternate techniques (e.g. Neural Networks) it offers transparency for relating the output data to the physical reason for the result.

### B. Arcing Duration in High Voltage Switchgear

When a 50 Hz high voltage circuit current is switched, an electric arc is formed between the two contacts of the switch. This process produces some radio frequency emissions which offer the possibility for monitoring the arc duration, which leads to the wear of the switch contacts and the need for
servicing. By monitoring the radio frequency emissions it may be possible in principle to determine the duration of arcing from a series of switch operations and so predict when the switch requires servicing [1].

Fig. 4 shows a typical radio frequency signal obtained from such a switching procedure.

Also shown on the figure is the voltage across the switch contacts and the increasing gap between the contacts during the operation. The radio frequency emissions are most pronounced during the arcing period as verified by the form of the arc voltage variation so enabling the arc duration to be determined.

IV. RADIO FREQUENCY IMMUNE MONITORING

The signals from Partial Discharges and arcing shown on figures 1(b) and 4 are representative of those obtained under ideal conditions. However, in real substations, such signals may be affected by interference from each other and other sources [1], [4] such as reflection of emissions from substation walls, switching of three phases of 50 Hz power networks, multiple circuit breaker arcing gaps etc..

Fig. 5(a) shows an example of the radio frequency emissions from a high voltage circuit breaker due to arcing on each of its three phases with separation of contacts on each phase occurring at different times (tcsA, tcsC, tcsB) [1]. (The strong interference following current interruption is caused by arcing in an auxiliary circuit breaker.)

Fig. 5(b) shows an example of radio frequency emissions from a high voltage transformer [4]. Emission from a Partial Discharge within the transformer is embedded within the overall emission.

These examples illustrate the difficulty of obtaining trustworthy and traceable information under such operating conditions. Possible approaches for overcoming the difficulties are –

(a) the use of more sophisticated signal discrimination approaches
(b) the use of radio frequency immune monitoring.

An example of more sophisticated discrimination is with time and frequency domain chromatic analysis for identifying Partial Discharge signals from test records of the kind shown on Fig. 5(b). Such analysis for a series of transformer test records suggests that the PD signals may be identifiable as lying within specific ranges of values of the chromatic parameters H, L, S (Fig. 5(c)) using both time and frequency domain chromaticity [4]. However further investigations are needed regarding the approach.

An example of radio frequency immune monitoring is with an acoustic optical fibre mechanical vibration sensor monitoring tap changer switches in high voltage transformers [5]. Fig. 6 shows a schematic diagram of such an optical fibre based monitor which can be conveniently retrofitted outside the transformer housing.
This shows how the switching signals can be identified from other vibration signals and with the potential for identifying the sources of these other characteristic signals.

V. CONCLUSIONS AND FUTURE PERSPECTIVES

Both positive and negative aspects of radio frequency emissions for monitoring in high voltage transmission / distribution systems have been discussed. It has been shown how chromatic techniques can be deployed both with radio frequency signals and with radio frequency immune sensing systems. Chromatic techniques appear to offer a means for discriminating Partial Discharge signals from others [4] although further verification is needed.

The versatility of the chromatic approach provides a possibility for its deployment in additional ways. It should be possible to use

(a) space domain chromaticity for resolving complex spatial distributions of radio frequency emissions which can occur in high voltage substations. This has already been demonstrated in the optical domain [3]

(b) discrete domain chromaticity to enable data from radio frequency and radio frequency immune monitors to be combined to provide an overall equipment signature for more trustworthy condition assessment. Such potential has already been demonstrated for combining off line monitoring of dissolved gases and thermal, electrical, optical degradation of High Voltage transformer oils [5].

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REFERENCES


