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Model Based-Testing of Spatial and Time Domain Artificial Intelligence Smart Antenna for Ultra-High Frequency Electric Discharge Detection in Digital Power Substations

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Abstract—This paper presents a fifth-generation (5G) wireless smart antenna for performing both power substation communication (in space domain beam-steering) and electrostatic discharge (in time domain Ultra-high Frequency "UHF" impulse) detection. The same smart antenna used to communicate with other wireless antennas in the switchyard, as well as with the control room, is utilized to cyclically gather data from power apparatus, busbars, and switches where electrostatic discharge (ESD) may occur. The ESD poses a major threat to electrical safety and lifetime of the apparatus as well as the stability of the power system. The same smart antenna on which beam rotation in space-domain is designed by implementing an artificial neural network (ANN) is also trained in time-domain to identify any of the received signals matching the ultra-high frequency band electrostatic discharge pulses that may be superimposed on the power frequency electric current. The proposed system of electrostatic discharge detection is tested for electrostatic pulses empirically simulated and represented in a trigonometric form for the training of the Perceptron Neural model. The working of the system is demonstrated for electrostatic discharge pulses with rising times of the order of one nanosecond. The artificial intelligence system driving the 5G smart antenna performs the dual roles of beam steering for 5G wireless communication (operating in the space domain) and for picking up any ESD generated UHF pulses from any one of the apparatus or nearby lightning leaders (operating in the time domain).

1. INTRODUCTION

The substations carry out crucial tasks in power generation, transmission, and distribution. Therefore, to maintain the performance and reliability of the system, substation fault monitoring must be done speedily, accurately, and effectively. Over the past years, many researchers have successfully examined methods to improve the fault monitoring system for conventional substations. However, there is still room for improvement as many of the conventional substations are converted into digital substations using smart antennas for switchyard communication and control. Going digital means that the protection, measurement, and control units are digitized.

1.1. Motivation

The digital power substation [1] and the use of smart antennas [2–5] inside the substation open new techniques to be used for the detecting and identifying the location of ESD inside and close to the substation [6–12]. One of the two commonly used techniques used to detect and locate the ESD has

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been the Time Difference of Arrival Techniques (TDOA) where a minimum of three antennas are used to obtain the arrival of the UHF signals to three antennas. Then using the distance as the time of arrival divided by the velocity of light, circles are drawn around each antenna to get the intersection point, the point of ESD origin. The second method is the well-known Angle of Arrival (AoA) technique. The AoA with a single antenna requires distance measurement technique to get the accurate location of the source of ESD. Otherwise, the AoA may need a minimum of two antennas for detection and location [6, 11].

Smart antennas may be used to survey the substation cyclically using narrow steerable antenna beams and are ideal for the location of ESD in a substation switchyard power apparatus such as power transformers, switches, or busbars, as well as approaching lightning leader or lightning flash. With smart antennas, using just one adaptive array antenna and the ability to rotate the beam around the substation, it is possible to locate the ESD location accurately [9]. Smart antennas are part of the wireless communication systems inside the substation, and without extra cost, may be used for ESD diagnostics. One major reason for not using ESD detection and localization systems inside the substation is the extra cost involved [8]. However, in this method, we are proposing the communication system using ESD detection without any extra hardware required. It only involves a scanning algorithm that goes over the UHF signals captured by the smart antenna. This additional algorithm searches for the presence of ESD electromagnetic pulses (ESD_EMP) at UHF, in the 5G communication band.

Figure 1 shows the three levels of digital substation. The the protection data exchange system is between the protection and bay level, including data on the switchyard power apparatus ESD_EMP, which is picked up by the smart antenna in the switchyard. The exchange of instantaneous data from the electronic current transformer and electronic voltage transformers is between the bay and process level. Control data exchange takes place between the control room and bay level, as well as the process and bay levels. Through the wireless system, the data are exchanged using the smart antenna installed at each point of data acquisition for eventual transmission to the control room. The size of the process level switchyard may be 100 m × 100 m, within which the placement of wireless antennas enables communication within the switchyard, as well between the switchyard and the substation control room. The control room is within a distance of 25 m from the switchyard. The control room will have its wireless, smart antenna receiving data from the switchyard antennas. The smart antennas used for 5G communication between the switchyard and the bay level are also used to pick up ESD_EMP, thus playing the dual roles of communication and ESD detection for preventive action data acquisition [13].

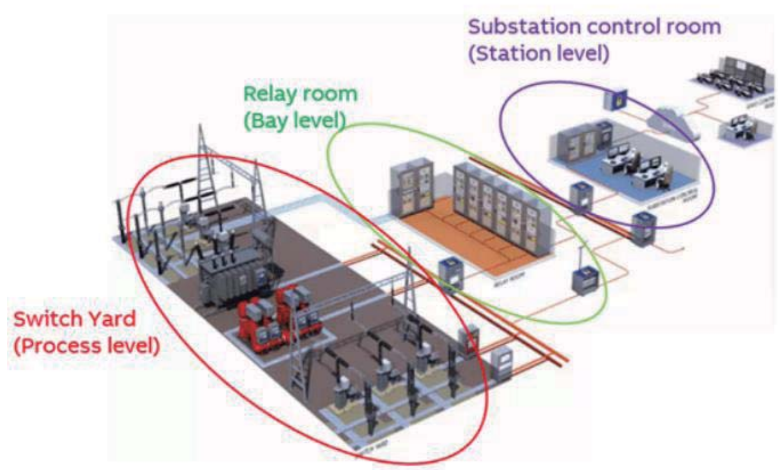

Figure 1. Layout of digital substation [1].

Modern digital electronic sensors, replacing the conventional sensors, use direct digital communication to process switchyard electrical state and to initiate control and protective actions. The use of copper wires connected point-to-point to the Current Transformers (CTs) or Potential Transformers (PTs) is replaced by electronic voltage/current transformers (EVT and ECT), fibre optics