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Analysis and Simulation of Partial Discharge Effect on Resonance Circuit of Wireless Pressure Sensor

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ABSTRACT
In Gas insulated circuit breaker especially, the Sulphur Hexafluoride (SF_6) circuit breaker (CB). The performance of the SF_6-CB depends on the pressure of SF_6 gas inside it. Hence the pressure test is one of crucial parameter to be measured and monitored for proper operation of CB. To measure the pressure inside the CB is done using the wireless pressure sensor in the present technology. These pressure sensors should have immune to the partial discharge (PD) frequency, which is produced during the operation of CB. The wireless pressure sensor is consisting of LC resonance circuit and are widely used in the intelligent circuit breaker system due to its reliable remote measurement and control. The existence of partial discharge during the operation of CB leads to high frequency interference radiated signal and affect the performance of the basic sensor resonance circuit. The analysis of PD effect and its suppression plays very important role in the design of sensor system. The inconsistent measurement of pressure from the sensor during the PD of the circuit breaker. This paper focus on the effect of PD on the resonance capacitor value of the pressure sensor and deviation of the pressure measurement. The analysis and simulation are carried out using python programming language.

KEYWORDS: *Partial Discharge (PD), Resonance frequency, Dielectric constant.*

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I. INTRODUCTION

The main optimum testing of the SF_6-CB are: (a) Timing test (b) Contact resistance test (c) Pressure test and (d) Gas leakage test and (e) High voltage test[1] apart from these test the Partial Discharge(PD) is also the important to know the performance of the circuit breaker. The PD has two types (a) Internal PD and (b) External PD as per IEC 60270 standard. The PD will exist in the gas filled chamber and affects the insulation of the high voltage equipment. Partial Discharge(PD is defined as the electrical discharge between the two components which incompletes the improper spacing between two conducting electrodes[2].The energy emitted by the PD are Electromagnetic waves, Acoustic waves and gases of Ozone, Nitrous Oxides and Nitric Acid along with water[2]. During the partial discharge , the emission frequency of the magnitude may vary up to 500MHz frequency[3].

The wireless pressure sensor which is connected to the circuit breaker will be functioning in the harsh environment. Hence the efficient cavity LC resonant wireless pressure sensor with high temperature co-fired ceramic (HTCC) technology-based pressure sensor is designed[4]. The operating resonance frequency of the HTCC based sensor is nearly about 18MHz[4].The operation of this sensor during the period of Partial Discharge can undergo the frequency deviation. This frequency deviation lead to the inaccurate measurement of pressure. Hence the analysis of resonance circuit under Partial Discharge is crucial while designing the pressure sensor for Gas Insulated (GI) circuit breakers.

The resonance frequency is mainly depending on the dielectric area and the relative dielectric constant and these are inversely preoperational to resonance frequency[5]. The sensor itself produces the noise and also from other interconnected circuits. These noises or the unwanted frequency signal can enter through the stray capacitor or through conductive or inductive path[6]. The variation of dielectric constant and its capacitance is mainly depends on the frequency of signal it operates[7]. Hence the performance analysis of pressure sensor resonance circuit is essential when it operated under the PD period, before designing any sensor for the GI Substations application. The approach is carried out in 4 sections.

1.1 The HTCC Wireless pressure sensor resonance circuit and Mathematical Model:

The pressure sensor parameters are inductor coupling, reader antenna, capacitor and the internal resistance. The equivalent electrical circuit of readout LC passive pressure sensor is as shown in figure-1. The

'L1' and 'L2' are coupled inductors, 'C1' is the capacitance of antenna, 'C2' is pressure dependent capacitance, 'R1'and 'R2' act as internal resistance of reader antenna and 'L2C2' resonance circuit respectively. As 'L1' and 'L2' are coupled inductors which exhibits the mutual inductance 'M' between them[4].

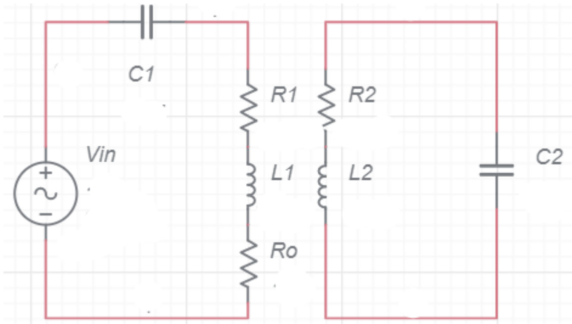

Figure-1 Pressure sensor resonance equivalent circuit.

Mathematical Model:

$$\begin{bmatrix} (R1 + j\omega L1 + \frac{1}{j\omega C1} + Ro) & j\omega M \\ j\omega M & (R1 + j\omega L2 + \frac{1}{j\omega C2}) \end{bmatrix} \times \begin{bmatrix} I1 \\ I2 \end{bmatrix} = \begin{bmatrix} Vin \\ 0 \end{bmatrix} \text{--------(1)}$$

From the above equation voltage across 'Ro' can be obtained as

$$Vo = \frac{Ro \times Vin}{\left[\left(R1 + j\omega L1 + \frac{1}{j\omega C1} + Ro\right) \times \left(R1 + j\omega L2 + \frac{1}{j\omega C2}\right)\right] - (j\omega M)^2} \text{ ---------(2)}$$

From equation (2) it is evident that as pressure varies, capacitance 'C2' also varies and the pressure sensor gives the pressure values in terms of voltage 'Vo' across 'Ro'. Therefore, the output voltage function of pressure depends on resonance capacitance 'C2'.

1.2 Resonance Circuit Simulation using PYHTON:

The resonance circuit parameters are considered as per the[4] for the simulation and same has been compared with[4]. At zero pressure i.e., at resonance the capacitance 'C2' will be 20pF and voltage is nearly equal to zero or minimum. From figure-2, it can be observed that the at 'C2=20pF' the voltage of the sensor is minimum (0.047V). As the pressure is the function of capacitance'C2' the output voltage varies according to variation in the 'C2' value.

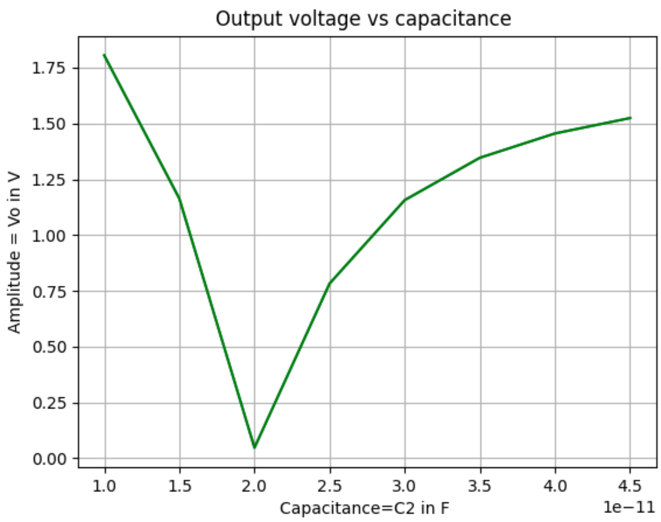

Figure-2 Change in Output Voltage with respect to Capacitance.

1.3 Mathematical Model for Dielectric and Capacitance under the variation of frequency:

The Dielectric and Capacitance with respect to the frequency is given by[8].

The permittivity in complex form is

$\varepsilon^c = \varepsilon_{hf} + \frac{\varepsilon_{lf}-\varepsilon_{hf}}{1+j\omega\tau}$ -------------(3)

Where ε_{hf} = Permittivity at higher frequency

ε_{lf} = Permittivity at lower frequency.

$\omega =$ Angular frequency

$\tau =$ Relaxation time.

The Real and Imaginary part can be written as

$\varepsilon^R = \varepsilon_{hf} + \frac{\varepsilon_{lf}-\varepsilon_{hf}}{1+\omega^2\tau^2}$ --------(4)

$\varepsilon^i = \left(\frac{\varepsilon_{lf}-\varepsilon_{hf}}{1+\omega^2\tau^2}\right) * \omega\tau$ -------(5)

The dynamics of the Dielectric constant will give rise to the effect of internal field and the alternating current external field[8]. The frequency dependent of dielectric constant can be expressed in the form of capacitance equation. The dielectric constant and its losses are expressed as[8].

$\varepsilon^R = \frac{Cd}{\varepsilon_{oA}}$ and $\varepsilon^i = \varepsilon^R(tan\delta)$ --------(6)

C= $C_n + \frac{g\tau}{1+\omega^2\tau^2}$ ---------------------------(7),

where g= conductance and C_n = Geometrical capacitance.

From the equation (7) it is evident that the change in interference frequency certainly change the actual resonance frequency and its response when it is operating under partial discharge mechanism of the circuit breaker.

1.4 Simulation of pressure sensor resonance circuit model in the presence of Partial Discharge frequency:

The effect of partial discharge on the capacitance value and hence the voltage reference values of resonance circuit of the pressure sensor output is simulated according to the mathematical model discussed in the previous section. It can be observed that there is a change in the actual output voltage as shown in the figure-3. The resonance capacitor value and output voltage are changed due the partial discharge frequency and in turn the deviation in the actual pressure measurement. As the voltage is electrical signal in terms of pressure, which leads in the error in actual measurement of pressure under the partial discharge.

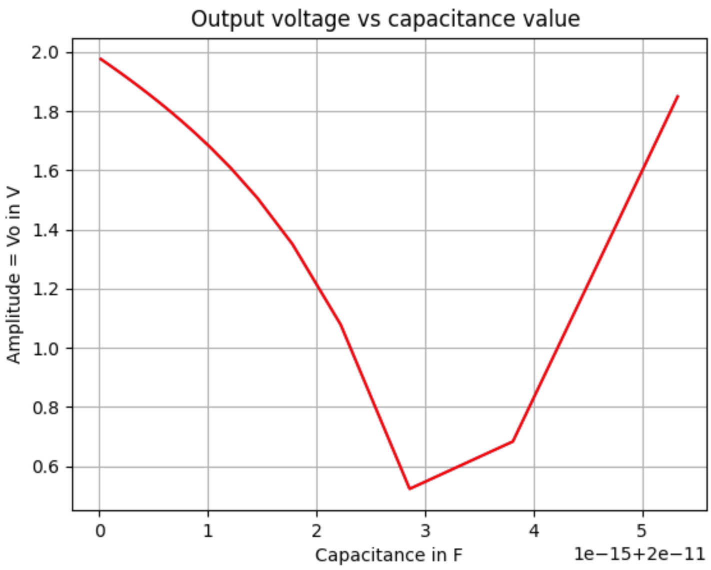

Figure-3 Performance of the resonance circuit of wireless pressure under Partial Discharge frequency.

II. CONCLUSION

The PYHTON simulation is carried out using linear mathematical approach for resonance circuit of the HTCC Wireless pressure sensor under the effect of partial discharge frequency. The selection of passive components and the integration of analog circuits in the design of wireless pressure sensor plays very important role when it is used for Gas Insulated substations under Partial Discharge condition.

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