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RF Pressure Sensor Filter Design for Gas Insulated SF_6 Circuit Breakers

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Abstract:
The stability of smart grid system depends on the data monitoring of medium and high voltage switchgear system from smart sensors or electronic devices. In medium and high voltage switchgear system the main protective device is gas insulated (GI) circuit breaker particularly Sulphur hexafluoride (SF_6) circuit breaker (CB). The mechanical properties like pressure, temperature and velocity are to be monitored dynamically for reliable operation of SF_6-CB. The fluctuation of voltage level in circuit breaker are mainly due to the variations of pressure in arc. Hence the pressure is the major physical parameter to be measured in the SF_6 circuit breaker. The smart grid system uses the many wireless devices for the data transmission and data management and these devices exhibits the electromagnetic radiation interferences. The Radio frequency (RF) pressure sensor which is used to monitor the pressure, pressure density of the circuit breaker certainly undergoes with interference effect and works improperly under electromagnetic interference (EMI) environment. In this paper, the work is carried out to design and simulate the microstrip low pass filter using Ansys High frequency structure simulator (HFSS) to attenuate the interference signal which is above the operating frequency of the RF sensor.

Key Words: *Sulphur hexafluoride (SF_6) circuit breaker, RF pressure sensor, EMI, Microstrip filter.*

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I. Introduction:

The Sulphur hexafluoride(SF_6) gas mainly used in extensively used in devices like Medium and high voltage circuit breaker, switches, ring main units, contactors as well as in all gas insulated substations because of its good dielectric property[1]. The density of the SF_6 is commonly monitored by temperature compensated pressure density monitor system with pressure sensor[2].The voltage drops in circuit breakers are mainly due to the fluctuations of pressure in arcs[3] .The main parameter dynamically to be monitored in the CB is pressure. There the use of RF pressure sensor and its performance is a crucial, when it is operating in the grid system. The pressure sensor many times degrades when it is working under the electromagnetic environment. In the electromagnetic environment there is conducted and radiated interference signal, these signals will interfere during the operation of senor and degrades its performance drastically. Hence any sensor should be immune when it is working under electromagnetic environment[4].

The attenuate of interference signal can be done by integrating the filter along with RF sensor unit. Many commercially available RF pressure sensor comes with Electromagnetic compatibility (EMC) standards. Nevertheless, there is still research is going on to set the standard for EMC when the RF sensor is working under complex wireless environment. The commonly available low-cost RF pressure sensor with RF transmission and sensitivity frequency nearly about 0.9GHz[5],[6]. The efficient way of attenuating the EMI signal for MEMS or smart RF sensor is the microstrip filter. In this paper, the analysis and design of microstrip filter to attenuate the EMI signal above 0.9GHz for RF pressure sensor is demonstrated. The work is demonstrated in two stages, 1. Mathematical modelling of microstrip low pass filter and 2. Simulation design using Ansys High frequency structure simulator (HFSS).

II. Mathematical Modelling:

The prototype low pass filter components normally have the source impedance g_o =1 and cut-off frequency Ω_c = 1 with transformed inductor and capacitor for specified cut-off frequency and source impedance usually 50Ω[7].

The evaluation of prototype elements values is done using following equations[7]

$g_m = 2sin\left\{\frac{(2m-1)\pi}{2N}\right\}$ -----------------(1)

$Li = \frac{Z_O}{g_O} \times \frac{\Omega_C}{2\pi f_C} \times g_i$ ---------------(2)

$Ci = \frac{g_O}{Z_O} \times \frac{\Omega_C}{2\pi f_C} \times g_i$ ---------------(3)

Where the Li and Ci are the inductance of microstrip ladder network.

The evaluation of length and width of microstrip structure is done using low and high characteristic impedances[7].

For inductor

$\frac{W}{h} = \frac{8e^A}{e^{2A}-2}$ ------------------------------(4)

Where, $A = \frac{Z_{OL}}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left[0.23 + \frac{0.11}{\varepsilon_r}\right]$ --------- (5)

For Capacitor

$\frac{W}{h} = \frac{2}{\pi}\left\{B - 1 - \ln(2B-1) + \frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\}$ --------- (6)

Where, $B = \frac{377\pi}{2Z_{OC}\sqrt{\varepsilon_r}}$ ------------- (7)

Based on the $\frac{h}{W}$, the effective dielectric constant of microstrip filter is calculated using the following equation and in turn the effective wave length.

$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\frac{h}{W}}}\right]$ ------------(8)

And wavelength $\lambda = \frac{c}{f\sqrt{\varepsilon_{eff}}}$ -----------(8)

Where c= Speed of light $=3 \times 10^8$ m/s.

Sl.No	Parameter Specification	Parameters Values
1	Order of the filter (N)	11
2	Cut-off frequency (f_O)	0.9 GHz
3	Dielectric constant (ε_r)	4.4
4	Substrate thickness (h)	0.5mm
5	Characteristic impedance (Z_O)	50 Ω
6	Highest line impedance (Z_{OL})	184 Ω
7	Lowest line impedance (Z_{OC})	24 Ω
8	Normalized frequency (Ω_C)	1

Table-1 Parameter Specification and Values.

Sl.No	Prototype element value	"L" and "C" values
1	0.2846	2.2647 nH
2	0.8308	2.6445 pF
3	1.3097	10.4223 nH
4	1.6825	5.3556 pF
5	1.9189	15.2701nH
6	2	6.3662 pF
7	1.9189	15.2701nH
8	1.6825	5.3556 pF

9	1.3097	10.4223 nH
10	0.8308	2.6445 pF
11	0.2846	2.2647 nH

Table-2 Calculated values of lumped elements (L and C).

Sl.No	Impedance (Ω)	Length (mm)	Width (mm)
1	50	10	0.9559
2	184	2.2077	0.02207
3	24	10.2457	2.7577
4	184	10.3771	0.2207
5	24	23.4814	2.7577
6	184	15.6436	0.2207
7	24	32.1469	2.7577
8	184	15.6436	0.2207
9	24	23.4814	2.7577
10	184	10.3771	0.2207
11	24	10.2457	2.7577
12	184	2.2077	0.2207
13	50	10	0.9559

Table-3 Dimensions of Stepped impedance microstrip low pass filter

1. Simulation design using Ansys High frequency structure simulator (HFSS).

The simulation design is carried out using HFSS for the proposed microstrip low pass filter with cut-off frequency 0.9GHz. The following simulation results consists of different views of microstrip low pass filter, frequency response and gain of the filter are shown in figure-5, figure-6, figure7 and figure8 respectively.

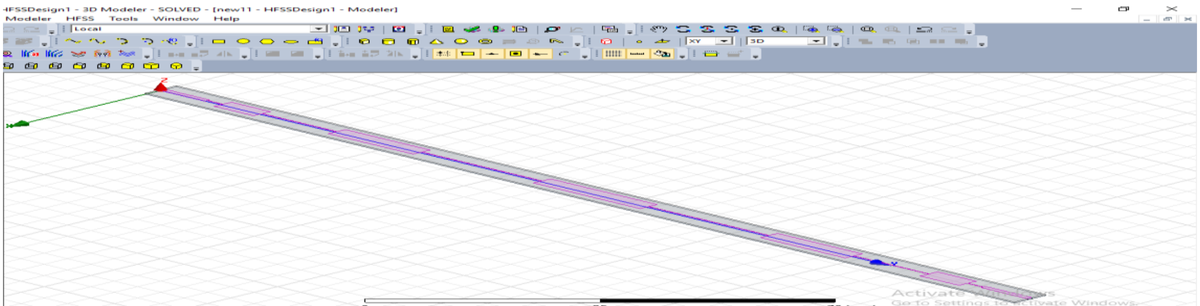

Figure-5 Top view of proposed Stepped impedance 11^{th} order microstrip low pass filter.

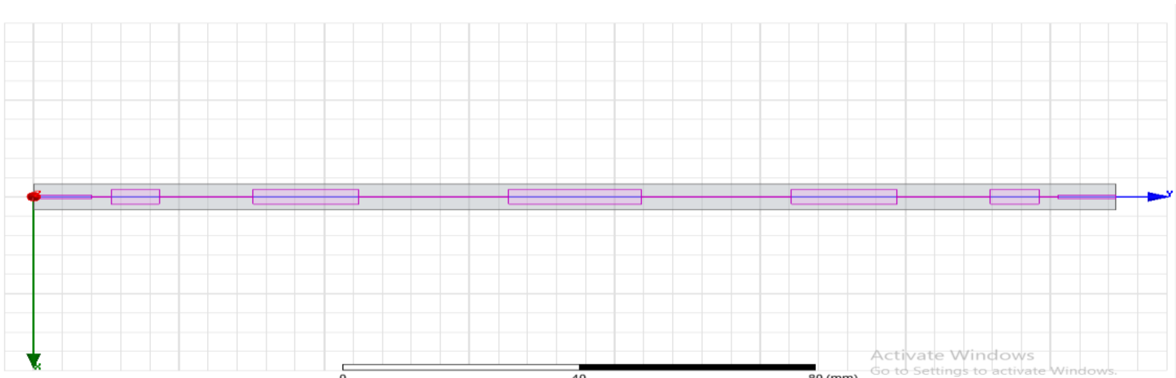

Figure-6 Front view of proposed Stepped impedance 11th order microstrip low pass filter.

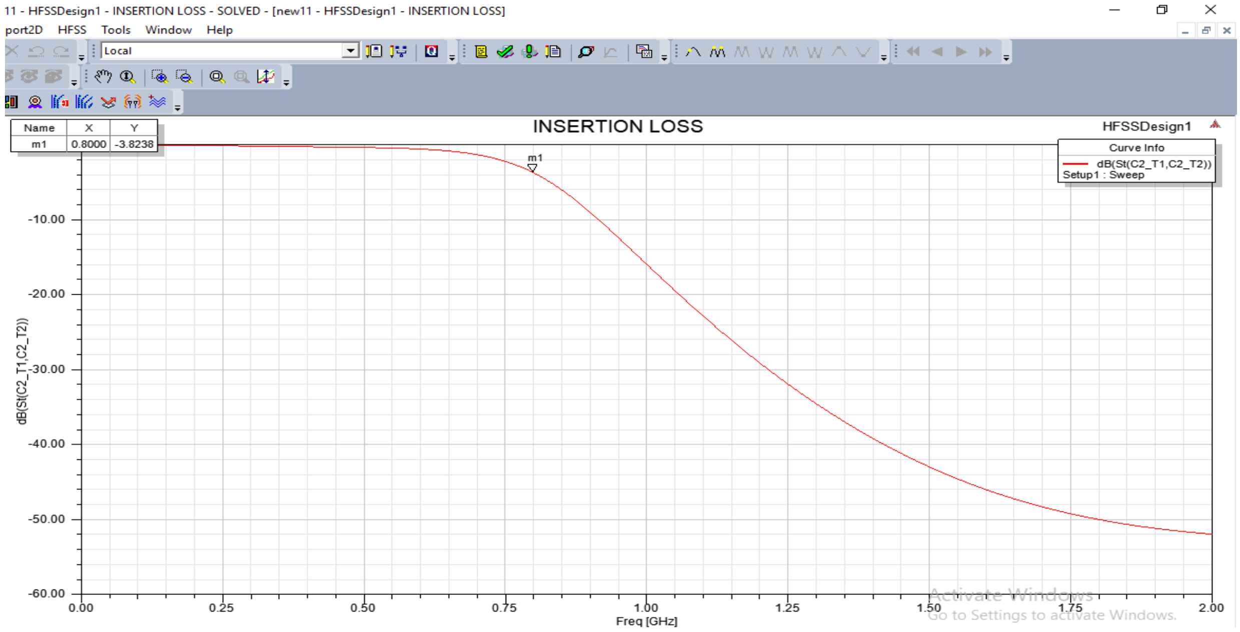

Figure-7 Frequency response of proposed Stepped impedance 11th order microstrip low pass filter

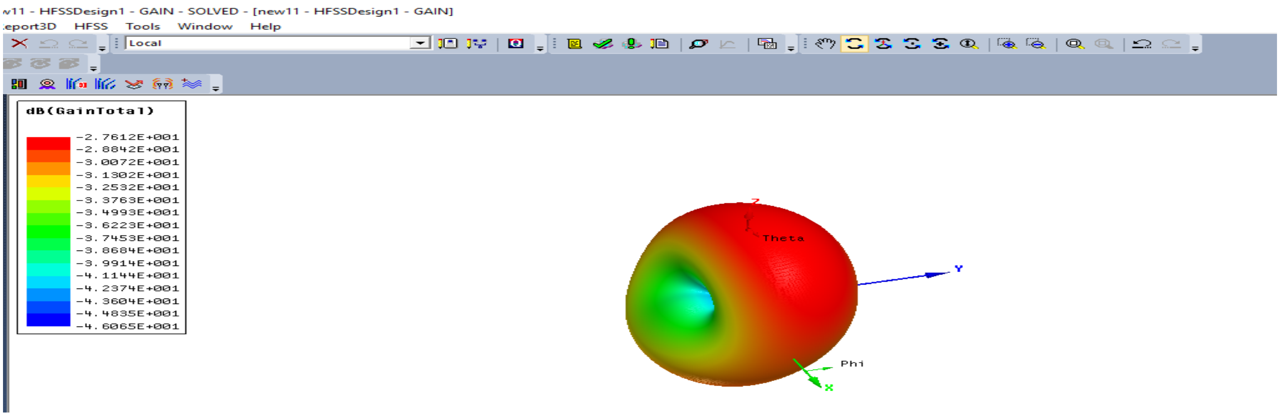

Figure-8 Gain of proposed Stepped impedance 11th order microstrip low pass filter.

From the simulation results It is observed the cut-off frequency is 0.8GHz and the response of the filter is reaching closer as the order the filter increase. The comparison has been made with designed value and simulated value which is shown in table-4

Location	Design values	Simulated values
3dB	0.9GHz	0.8GHz
40dB	1.62GHz	1.325GHz.

Table-4 Comparison between Designed and Simulated values.

III. Conclusion and Future Scope:

The microstrip low pass filter to attenuate the Electromagnetic interference (EMI) signal on RF pressure sensor used in SF_6 circuit breaker is demonstrated in this paper, using the simulation software HFSS. It is very much essential analyse the simulation design before implementing the real scenario, as the simulation design save the time and cost and to improve the sensitivity of the filter before fabrication process. The design of microstrip low pass filter also coast effective and time saving during fabrication process. The analysis and design for different types of microstrip filter can be achieved based on the working frequency range of the device and EMI strength and its frequency range.

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