Development of EMC Filter in the High Powered Breaker

Eun-Mi Kim[1] · Mi-Hwa Jeon[1] · Dong Il Kim[1] · Young-Sup Ahn[2]

Abstract

Remarkable developments in the electric and electronic industry have given people's daily life much more convenience and abundance. However, in electrical communication, or electric and electronic fields, making electrical and electronic devices more functional, more integrated, and faster have put electromagnetic interference(EMI) into more complex forms, and lots of problems such as interruption, malfunction, or interference by noise between electrical communication systems occurs every day. In this research, the electromagnetic compatibility(EMC) filter in the high powered breaker was designed and fabricated as a counter measure. The filter attenuated noise more than 20~50 dB in the range of 10 MHz~1.5 GHz. And, when the electric fast transient(EFT) of 4 kV in the level 4 of IEC 61000-4-4 was induced, it was soon suppressed to 600 V.

Key words : EMI Filter, EMC Filter, Feed-Through Capacitors, Ferrite Beads.

Ⅰ. Introduction

Recently, as the number of usage of various electronic devices increases rapidly, the demand for the power is also growing very much. Therefore, to supply electricity of high quality steadily and minimize the power loss, the voltage of power transmission and distribution is getting higher and higher to the maximum, and the demand for heavy electric machines such as high powered transformer, instrument transformer, and breaker, is also increasing[1]. The heavy electric machines includes all of machines and tools to transfer the electricity generated from the power plants to houses or factories. It must be insulated well in the high voltage, and do its functions properly even in the extreme working conditions. If some troubles or accidents occurred in the heavy electric machine, all of electronic tools and machines would shut down even though the power plants generated electricity. For example, in 1997, we had economical loss over 100 billion won caused by unexpected outage in factories of semiconductor, automobile, shipbuilding, electrics and electronics which all were core industries of Korea. Moreover, the loss would be anticipated to be increased over 300 billion won in 2010[2]. Besides, requirement of safe performance and accurate control in electrical and electronic devices and precise control systems, which can cause the loss in property and human life and even be expanded to a national disaster, are getting intensified. According to this, the Comite International Special des Perturbations Radioelectrique(CISPR), The Federal Communication Commission(FCC), the Voluntary Control Council for Interference(VCCI), the German Verband Deutscher Eleckrotechniker(VDE) have regulated for a countermeasure of electromagnetic environment[3],[4]. General paths of noise transfer are the radiation through free space, and the conduction through transmission lines or signal lines. Among these, the conductive noise is the hardest one to be put out due to its various forms of noise[4]. A general countermeasure for EMI is advising filter that have attenuation more than 40 dB in the range of 150 kHz~30 MHz(CISPR) or 450 kHz~30 MHz (FCC) with using the countermeasure power resource filter against EMI[5],[6]. However, the new forms of electromagnetic interference whose characteristics of broad band and high voltage have been made by increase of usage of electronic devices. As these interferences have difference electrical characteristics, a existing EMI filter which uses capacitors and common mode choke coils cannot be proper countermeasure[7]. And in induced components, interference of EFT has been increased by high speed switching and power increasement, and this could give direct or provisional damage to target tools. Currently, the EFT test is restricted to be done through the conductive immunity test established by International Electrotechnical Commission(IEC)[8], and for the safety of electrical control devices, the control system of wireless communication or factory automation system must be designed to stand the level 4 of IEC 61000-4-4[9].

Therefore, in this research, the EMC filter in the high powered breaker, one of the heavy electric machine, was suggested as a countermeasure for conductive noises.

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And the suggested EMC filter in the high powered breaker was attenuated 25~55 dB in the range of 10 MHz~1.5 GHz. When the EFT of 4 kV in the level 4 of IEC 61000-4-4 was induced, it was soon suppressed to 600 V, and the filter was also verified its excellence by satisfying the level 4 of IEC 61000-4-4.

Ⅱ. EMC Filter in the High Powered Breaker

2-1 Analysis of Conventional EMI Filters

Fig. 1 showed a structure of the typical EMI filter composed of common mode choke coils and capacitors.

The typical EMI filter(Fig. 1) could be deemed as the 4 port network in Fig. 2, U_S and U'_S, R_S and R'_S were two interference source and their resistances.

When 'Insertion loss' inserted network between source and load, it was decrease of electric power that occur in load[5]. IL, the insertion loss of this network, could be calculated by equation (1).

$$IL = 10\log\{(1+R_S/R_L-\omega^2 LC_y)^2 + \omega^2(L/R_L+C_yR_S)^2\} - 20\log(R_S+R_L)+20\log R_L \quad (1)$$

where L was an inductance of common mode choke coil of the typical EMI filter, R_L and R'_L were load resistances. In the equation 1 for the insertion loss, where C_y was fixed as 0.0032 μF, R_S, R_L=50 Ω, and L_{CM} was varied(2, 5, 10 mH), the actual measurements were compared with the ones calculated by simulations(Fig. 3).

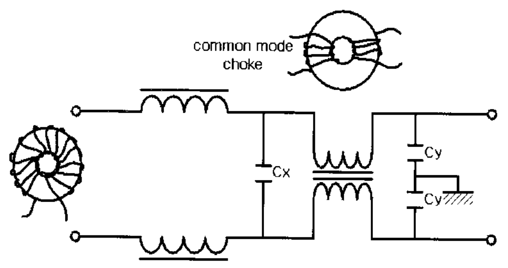


Fig. 1. Structure of typical EMI filter.

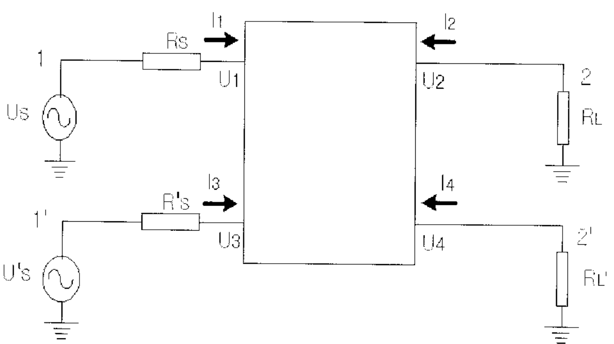


Fig. 2. 4-port network.

In the case of passive components such as filters or couplers, the insertion loss of 0 dB or Fig. 3(a) were supposed to output all of input power without any loss theoretically, however the real was different. Thus, the optimized values were found by this calculation (Fig. 4) L_{CM}=2.4 mH, C_y=0.0032 μF, C_x=0.47 μF.

The fabricated EMI filter by Fig. 2 was shown in Fig. 5.

It showed excellent attenuation characteristics of 60~90 dB in the range of 150 kHz~30 MHz according to CISPR standard(Figs. 6, 7).

However, shown in Fig. 1, when the EMC filter in the high powered breaker was designed with common mode choke coils and capacitors which were the components of typical line filters, there could be several problems occur[7].

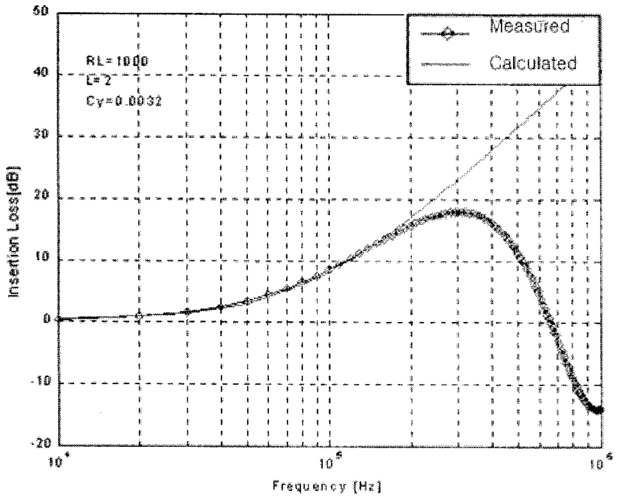
The common mode choke coil had frequency characteristics that resonance frequency was in the range of 100 kHz to around 10 MHz, and if the frequency were over the range, it would function as a capacitance, not an inductance, shown in Fig. 8(a). That was because stray capacitance, which existed between windings, had similar form of parallel connection with the inductance of the choke coil, and in the high frequency, the effect of this capacity elements became more important than the effect of inductance elements. Due to this, when choke was used in the range over resonance frequency, the by-pass circuit of noise could be formed. Inductance element of the choke could be somewhat improved by single winding or partition winding, but the broad band could be hardly achieved since its resonance usually occurred around several tens MHz[10]~[12].

Capacitors had frequency characteristics that resonance frequency occurred around several tens MHz like the common mode choke. That was because residual inductance, which occurred from lead lines or the electrode of C_y, had series connection with the capacitors, and made series resonance. In the range over this resonance frequency, the effect of inductance was more important than the effect of capacitance as well[10]~[12].

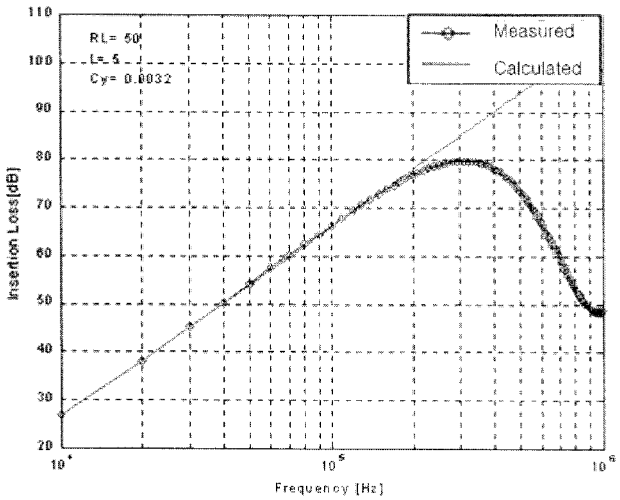
Since the structure of existing EMI filters shown in Fig. 5 had the resonance around several tens MHz, it could not do countermeasure in electromagnetic interference of new form that have broad band and high voltage characteristic.

2-2 Fabrication and Analysis of the EMC Filter in the High Powered Breaker

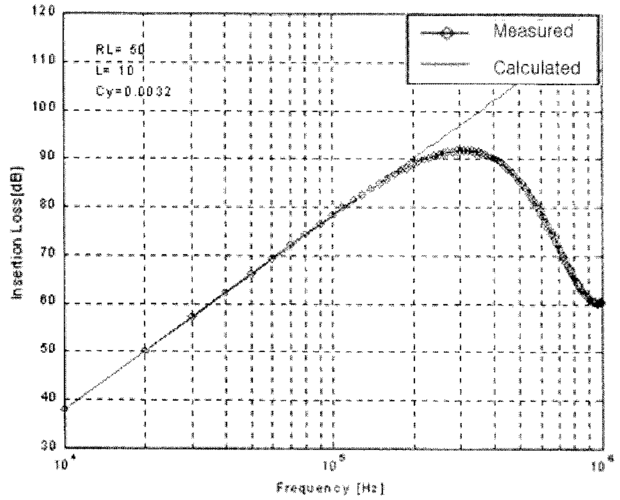
In this research, for the broad band, the EMC filter



(a) L_{CM}=2 mH



(b) L_{CM}=5 mH



(c) L_{CM}=10 mH

Fig. 3. Insertion loss of EMI filter.

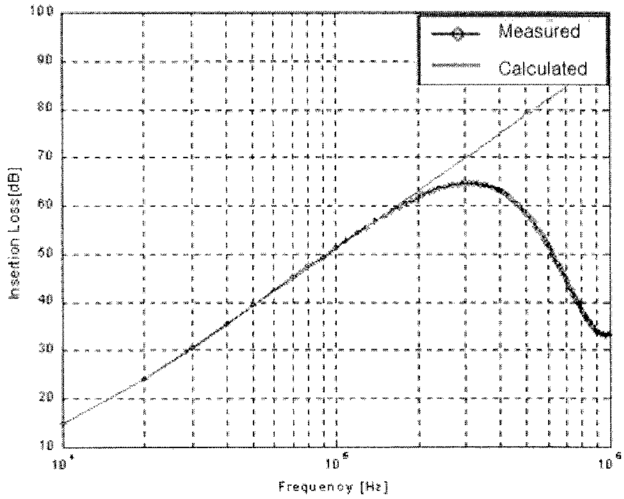


Fig. 4. Insertion loss of EMI filter using optimized element (L_{CM}=2.4 mH).

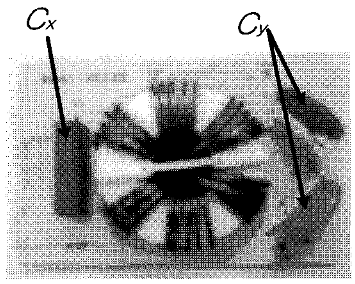


Fig. 5. Fabricated EMI filter.

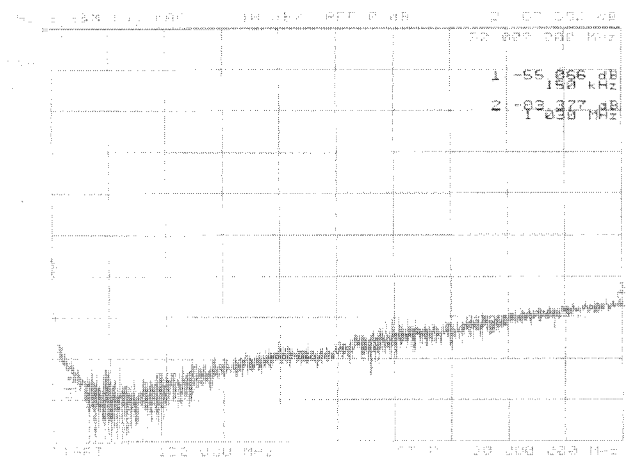


Fig. 6. CM measurement of fabricated EMI filter.

in the high powered breaker was designed with Ni-Zn ferrite beads of high permeability to make large inductance as the inductor(Fig. 9(a),(b)), and Feed-through capacitors, which did not have any resonance point, to restraint resonance effectively.

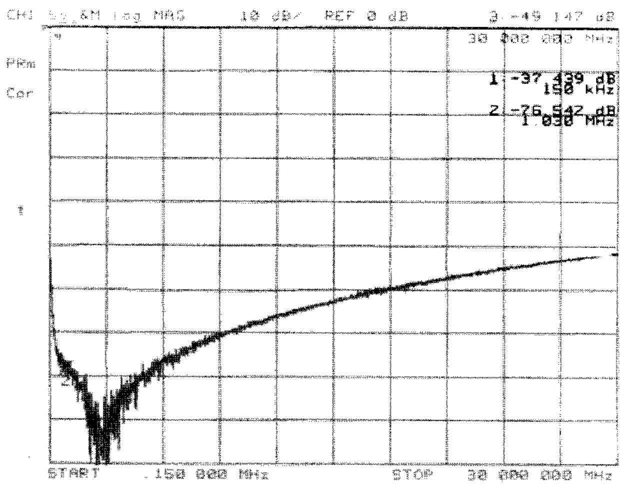
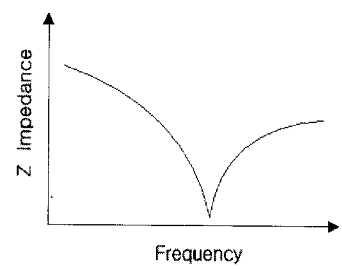
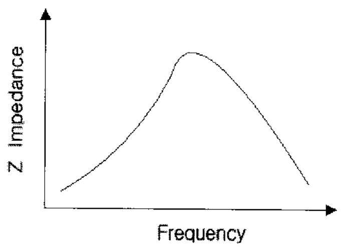


Fig. 7. DM measurement of fabricated EMI filter.



(a) High frequency characteristic of capacitors



(b) High frequency characteristic of inductor

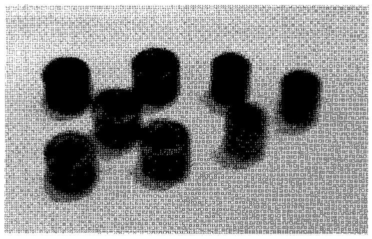
Fig. 8. High frequency characteristics of capacitors and inductor.

The suggested EMC filter in the high powered breaker was shown in Fig. 10.

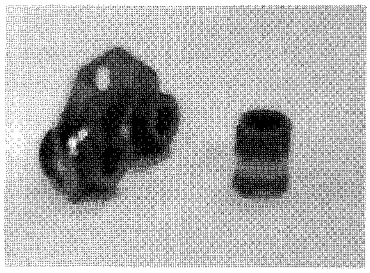
Fig. 11 showed the equivalent circuit of the EMC filter and transmission lines. Fig. 12(a) showed the equivalent circuit between the ground(G) and the signal wire(H), and also between the ground(G) and the neutral wire(N) in the EMC filter regarding the noise of differential mode.

ABCD matrices of differential mode could be determined from equation (2).

$$\begin{bmatrix} A_{DM} & B_{DM} \\ C_{DM} & D_{DM} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y_{C_1} & 1 \end{bmatrix} \begin{bmatrix} 1 & Z_f \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & Z_f \\ Y_{C_1} & Y_{C_1} Z_f + 1 \end{bmatrix} \qquad (2)$$



(a) Ferrite beads(Ni-Zn series)



(b) Feed-through capacitors

Fig. 9. Passive components of EMC filter in the high powered breaker.

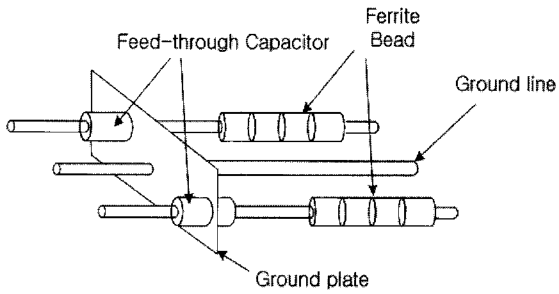


Fig. 10. Actual composition of EMC filter in the high powered breaker.

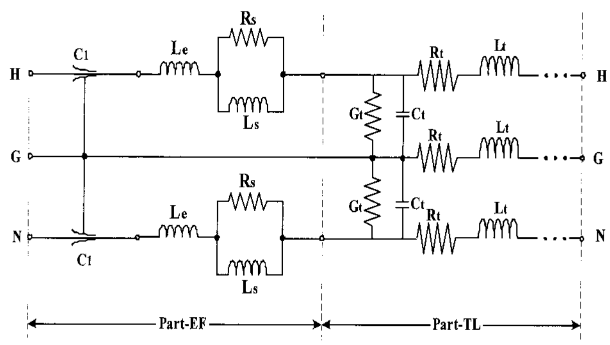
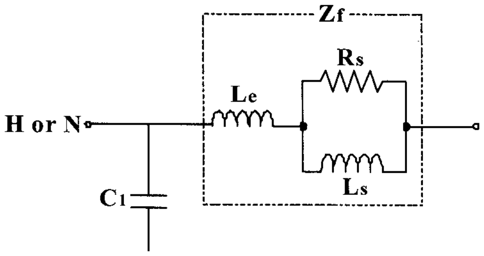


Fig. 11. Equivalent circuits of EMC filter in the high powered breaker and transmission line.

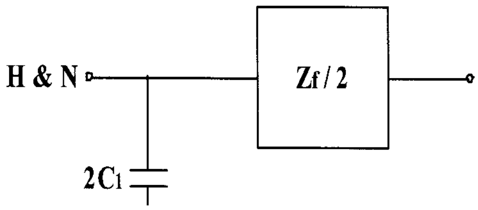
where,

$$Y_{C_1} = j2\pi f C_1,$$

$$Z_f = j\omega L_e + \left(\frac{1}{R_s} + \frac{1}{j\omega L_s} \right)^{-1} . \qquad (3)$$



(a) For differential-mode(DM)



(b) For common-mode(CM)

Fig. 12. Equivalent circuits of EMC filter(Part-EF).

Otherwise, the equivalent circuit regarding the noise of common mode was shown in Fig. 12(b). And, ABCD matrices about the common mode noise could be determined from equation (4).

$$\begin{bmatrix} A_{CM} & B_{CM} \\ C_{CM} & D_{CM} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 2Y_{C_1} & 1 \end{bmatrix} \begin{bmatrix} 1 & Z_f/2 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & Z_f \\ 2Y_{C_1} & Y_{C_1}Z_f+1 \end{bmatrix} \quad (4)$$

Relative permeability, μ_r was represented in equation (5)[13].

$$\mu_r = 1 + \frac{\mu_i}{1 + jf/f_m} \quad (5)$$

where μ_i was the initial permeability, f_m was the relaxation frequency, f was the measured frequency, μ_0 was the coefficient of the magnetic field($4\pi \times 10^{-7}$ [H/m]), μ' was inductive permeability, and μ'' was resistant permeability. In this study, the ferrite bead(μ_i= 2,000, f_m=3.12 MHz) was used, and other parameters were given as equation (6).

$$\begin{aligned} C_1 &= 2{,}000 \ \text{[pF]} \\ L_e &= 2\times10^{-8}\mu''_r\mu_0 \ln(b/a)\times l \ \text{[H/m]} \\ R_s &= 2\pi f_m \mu'_r \mu_0 lK \ [\Omega/\text{m}] \\ L_s &= \mu''_r \mu_0 lK \ \text{[H/m]} \end{aligned} \quad (6)$$

In here, a and b were the internal and external diameters of the ferrite bead, l was the length of the bead, and K(=0.003) was the value determined by the size of the bead. According to equation (2) and (4), the transfer coefficient, T could be determined from equation (7).

$$T(dB) = 20\log\left|\frac{2}{A_i + B_i + C_i + D_i}\right| + \alpha_p$$

i=DM or CM (7)

where α_p was the transmission loss(dB).

Ⅲ. Experiments and Results

Characteristics experiments of the EMC filter in the high powered breaker were conducted using network analyzer(HP 8753D) to examine frequency characteristics in the range of 10 MHz~1.5 GHz. Experiments of EFT characteristics were also conducted using Tektronix TDS 340A(100 MHz, 500 Ms/s) and burst-generator(EMV-System SFT4000) in time domain. Each parameter of ferrite beads were l=9.3 mm, D=12 mm, d=5.6 mm, and initial permeability was 2000(Ni-Zn series). And capacity of the Feed-through capacitors was 2,000 pF in 80 A/220 V, and 18 mm^2 thick cable for 3 leads 80 A was used for the transmission line. Fig. 13 showed experiments of frequency characteristics, and Fig. 14 showed experiments of EFT characteristics.

In Fig. 15 and 16, calculated values and actual values of noise in common mode or differential mode were compared. As a result, both patterns were very similar,

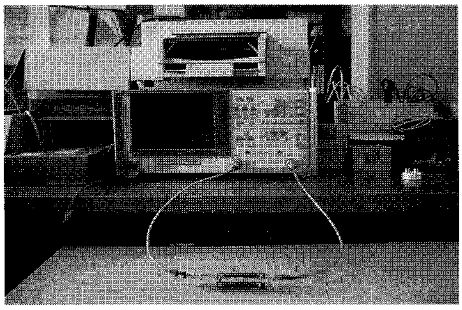


Fig. 13. Set-up for the analysis of the frequency characteristics of the EMC filter.

Fig. 14. Set-up for the analysis of the EFT characteristics of the EMC filter.

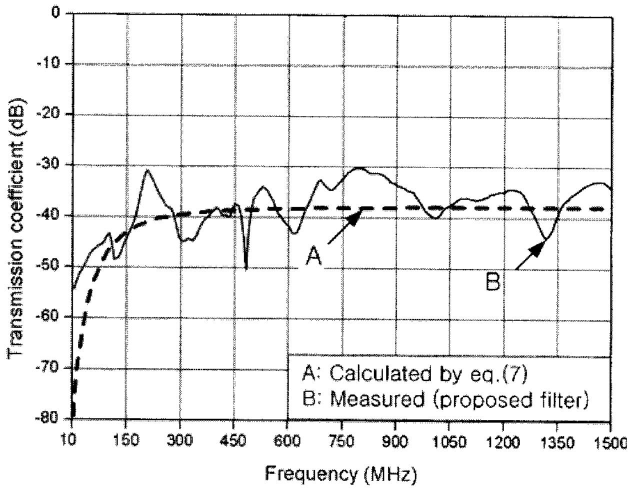


Fig. 15. Attenuation characteristics of common-mode in the high powered breaker's EMC filter.

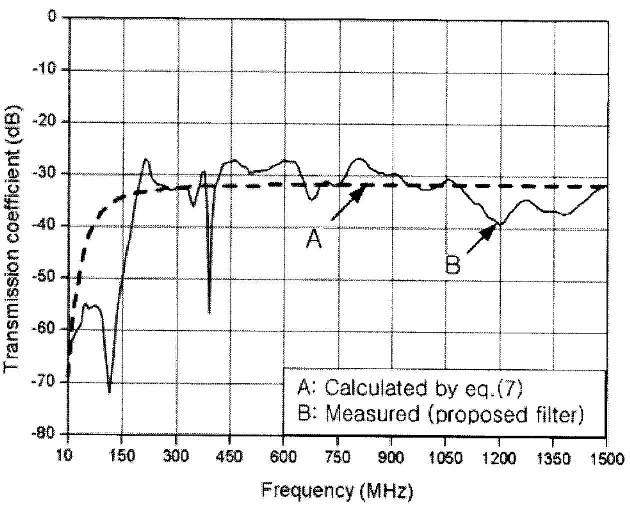
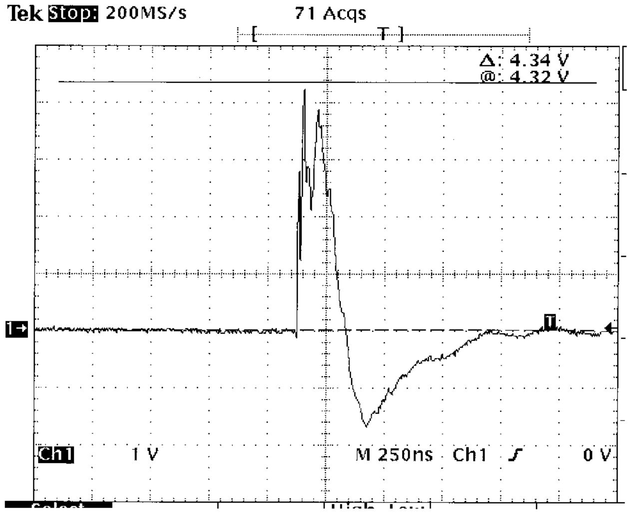


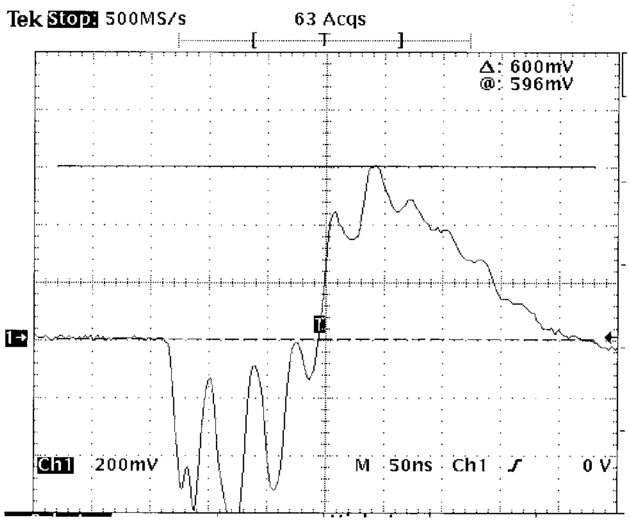
Fig. 16. Attenuation characteristics of differential-mode in the high powered breaker's EMC filter.

and the produced filter showed excellent attenuation characteristics that the common mode was 30~55 dB, and the differential mode was 25~70 dB in the range of 10 MHz~1.5 GHz.

And, for conducting EFT immunity tests according to the regulation of IEC 61000-4-4, the suggested EMC filter and non-filter condition were connected each other and the comparison results were shown in Fig. 17(a) and 17(b) when 4 kV in the level 4 of IEC 61000-4-4 was induced. The Y axis in Fig. 17(a) was 1 V, and it could be converted to 4,340 V(1:1,000 prove) which was maximum value of the voltage wave form. And in Fig. 17(b), the Y axis was 200 mV, and the maximum value of voltage wave form was 600 V(1:1,000 prove). Namely, when the 4 kV was induced, the EFT could be suppressed to 600 V.



(a) In case of there is no filter
(Y axis: 1 V/Div, X axis: 250 ns/Div, V_{max}=4.34 V)



(b) In case of there is filter
(Y axis: 200 mV/Div, X axis: 50 ns/Div, V_{max}=600 mV)

Fig. 17. The measured results of immunity test at level 4 of IEC61000-4-4(time domain).

Ⅳ. Conclusion

In this research, the high powered EMC filter choosing ferrite beads and Feed-through capacitors which had no resonance point was designed, and it satisfied electrical safety regulations. Especially, in the experiment with applying the ferrite bead(initial permeability: 2,000), and Feed-through capacitors(2,000 pF when internal voltage 2,000 V), the attenuation characteristics was 25~55 dB in the range of 10 MHz~1.5 GHz. In case of the EFT, when the Electric Fast Transient(EFT) of 4 kV in the level 4 of IEC 61000-4-4 was induced, it was suppressed to 600 V which was less than 1/6. The suggested EMC filter in the high powered breaker was installed and worked in the breaker's terminal, differently with existing countermeasures which were installed and worked in processor controllers, to supply high quality power without any electromagnetic interference. Hence, the best feature of it was to prevent the leakage of electromagnetic noise by enhancing immunity of houses or factory machines. Go forward the suggested EMC filter can be applicable not even for electronic · information devices, but also electronic · control devices as the very innovative countermeasure, namely, the range of its application can be expected very broad.

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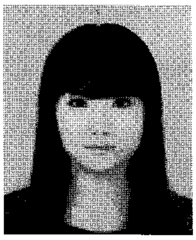

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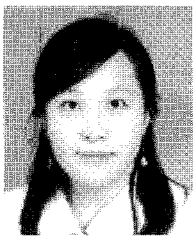

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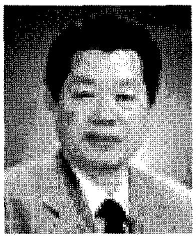
Dong Il Kim



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