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Non contact Coupler Design in Non contact Power Supply

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Abstract - In this paper, the electrical characteristics of the non-contact transformer is presented using conventional coupled inductor theory. Each non-contact transformer is analyzed through simulation and measurement.

In high power applications, non-contact transformer is so bulky and heavy that it should be split by some light transformers. So non-contact transformer needs several small transformer modules which are connected series or parallel to transfer the primary power to the secondary one.

This paper shows analytic result of the each non-contact transformer module and comparison result between series-connection and parallel- connection of the non-contact transformer. The results are verified on the simulation based on the theoretical analysis and the 30kW experimental prototype.

1. INTRODUCTION

Nowadays, Non-contact Power Transfer System(NCPTS) is widely used in many industry applications such as automated guided vehicles and medical applications. Conventional one drags long power cables directly and produces many particles because of mechanical friction between cables and surface of the nearby instruments, whereas NCPTS delivers electrical power to load with the help of non-contact transformer that has no mechanical contact. In this method NCPTS doesn't produce particles, thereby making it adaptable to the industry applications where clean circumstances are needed such as semi-conductor, LCD, and PDP manufacturing factory.

Fig. 1 shows non-contact transformer which is composed of long primary wire track over several-tens meter, several transformer cores with a large airgap, and secondary winding wounded around transformer core. Since these kinds of transformer have low coupling coefficient k (normally lower than 0.5) because of the large airgap, it's so difficult to transfer primary energy to secondary side. Also, since primary leakage inductance of the non-contact transformer is larger than the magnetizing inductance, much magnetizing current flows through the magnetizing inductance. To solve these problems, high frequency resonant converter(series resonant converter or series- parallel resonant converter) has been widely used for the NCPTS.[1~3].

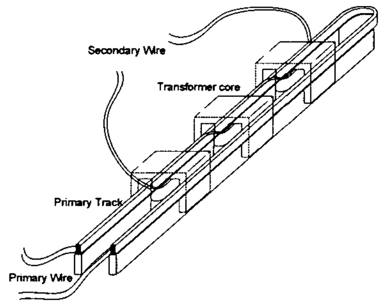

Fig. 1 Non-contact transformer

In this paper the electrical characteristics of non-contact transformer is presented using conventional coupled inductor theory. Non- contact transformer is constructed by adding many I-cores to make E shape so that it can be fit for primary track. In this case, the non-contact transformer becomes so bulky and heavy that it is very difficult to handle them and have maintenance problem. So non-contact transformer should be split with several small core modules to alleviate its weight. By doing so, there were some problems in modelling and analysing non-contact transformer parameters used for designing NCPTS.

This paper presents the analytical and numerical method to predict these values of the non-contact transformer and can present design guidelines for designing NCPTS. Furthermore, the comparison between series connection and parallel connection of the non-contact transformer is presented.

2. ANALYSIS

2.1 Equivalent Circuit of Transformer

Fig.2 shows a equivalent circuit of non-contact transformer which is replaced by conventional transformer model containing leakage inductance (L_{lk}), magnetizing inductance (L_m) and ideal transformer with its turns ratio, "a". And, L_P is primary inductance, L_S is secondary inductance, M is mutual inductance, and k is coupling factor.

$$M = \frac{L_{ser} - L_{par}}{4} \quad (1)$$

$$k = \frac{M}{\sqrt{L_P L_S}} \quad (2)$$

$$L_{lk} = L_P(1-k^2) \quad (3)$$

$$L_m = k^2 L_P \quad (4)$$

$$a = \frac{Ls}{M} \quad (5)$$

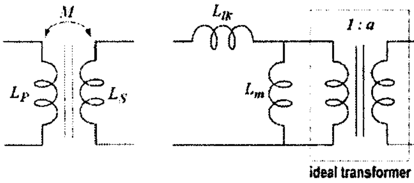

Fig. 2 Equivalent Circuit of transformer

In general, non-contact transformer has considerable airgap between primary and secondary side. Therefore, transformer leakage inductance is by far larger than magnetizing inductance. This results in poor coupling coefficient (k) and the overall system efficiency is reduced. In order to minimize the detrimental effects of large leakage inductance, small magnetizing inductance and poor coupling coefficient of non-contact transformer, a full-bridge series resonant converter topology is selected for NCPTS generally.

2.2 Series-Connection of transformer

Fig. 3 shows a non-contact transformer with its primary and secondary side which is connected in series with each transformer module and its load resistance is converted to AC resistance as defined in Eq.(6).[2] From Faraday's law, Eqs. (7) and (8) relate terminal voltages V_1 and V_2 to the terminal currents I_1 and I_2.

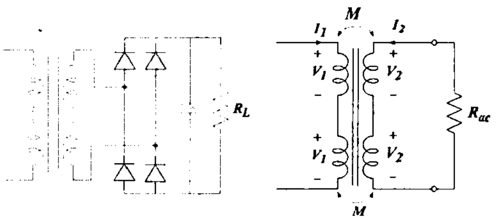

Fig.3 Series-connected non-contact transformer

$$R_{ac} = \frac{\pi^2}{8} R_L \quad (6)$$

$$V_1 = L_1\frac{dI_1}{dt} + M\frac{dI_2}{dt} \quad (7)$$

$$V_2 = M\frac{dI_1}{dt} + L_2\frac{dI_2}{dt} \quad (8)$$

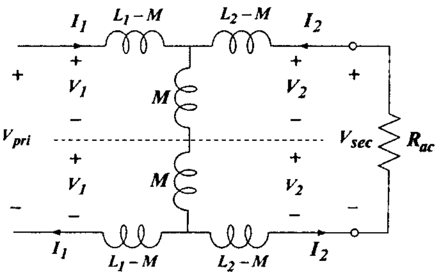

Fig. 4 T-equivalent circuit model of Fig. 3

Fig. 4 shows the T-equivalent circuit model of Fig. 3, where V_{pri}, V_{sec} are the terminal voltages of series-connected non-contact transformer. Eqs. (9)~(12) describe the relationship in Fig. 4.

$$V_1 = (L_1 - M)\frac{dI_1}{dt} + M\frac{d}{dt}(I_1 + I_2) \quad (9)$$

$$V_2 = (L_2 - M)\frac{dI_2}{dt} + M\frac{d}{dt}(I_1 + I_2) \quad (10)$$

$$V_{pri} = 2(L_1 - M)\frac{dI_1}{dt} + 2M\frac{d}{dt}(I_1 + I_2) \quad (11)$$

$$V_{sec} = 2(L_2 - M)\frac{dI_2}{dt} + 2M\frac{d}{dt}(I_1 + I_2) \quad (12)$$

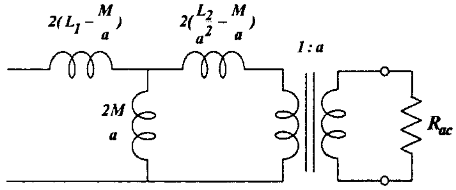

Fig. 5 Simplified circuit model of Fig. 4

In some cases, $2(L_2 - M)$ can be a negative value. To make this value positive, mutual inductance (M) is divided by arbitrary constant "a". [3] Fig. 5 shows transformer model with insertion of ideal transformer.

If we let $2(\frac{L_2}{a^2} - \frac{M}{a}) = 0$, then $a = \frac{L_2}{M}$, where "a" is the turns ratio of ideal transformer. Fig. 6 shows a simplified model of the series-connected non-contact transformer.

From Fig. 6, $L_{lk} = L_1 - \frac{M}{a}$, $L_m = \frac{M}{a}$ are the measured values of each transformer module, therefore, overall leakage inductance and magnetizing inductance of two series- connected non-contact transformer modules become twice those of single transformer module and ideal transformer turns ratio "a" remains unchanged. From above mentioned result, if we connect N number of transformer module in series, then its total leakage and magnetizing inductances values become N times of each transformer module. Whereas ideal transformer turns ratio remains unchanged

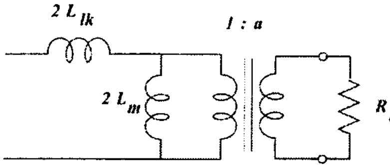

Fig. 6 Simplified circuit model of Fig. 5

2.2 Parallel-Connection of transformer

Fig. 7 shows a non-contact transformer with its primary side is series-connected and secondary side is parallel- connected and its load resistance is converter to AC load resistance using Eq. (1).

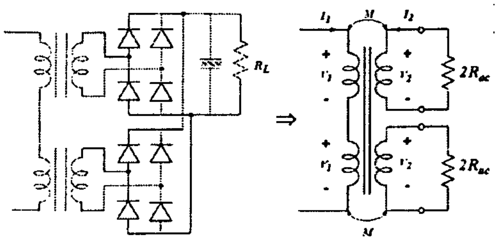

Fig. 7 Parallel-connected non-contact Transformer

Fig. 8 depicts an equivalent circuit model of Fig. 7 with its load resistance is reflected to the primary side. In Fig. 8, L_{lk}, L_m and a are the measured values of each single transformer module same as in series-connection. With simple numerical manipulation, Fig. 8 can be redrawn as simplified non-contact transformer model with its parallel-connected secondary side as in Fig. 9. From Fig. 9, the overall leakage inductance and magnetizing inductance of two parallel-connected non-contact transformer become twice those of single transformer module as in the case of series connection, but ideal transformer turns ratio becomes "a/2". If we extend this concept to N secondary side parallel-connected non-contact transformer, then total leakage and magnetizing inductance values are N times those of each transformer module. Whereas ideal transformer turns ration becomes "a/N".

3. CONCLUSION

In this paper the electrical characteristics of non-contact transformer is presented using conventional coupled inductor theory. Non-contact transformer is constructed by adding many I-cores to make E shape so that it can be fit for primary track. In this case, the non-contact transformer becomes so bulky and heavy that it is very difficult to handle them and have maintenance problem. So non-contact transformer should be split with several small core modules to alleviate its weight.

This paper presents the analytical and numerical method to predict these values of the non-contact transformer and can present design guidelines for designing NCPTS. Furthermore, the comparison between series connection and parallel connection of the non-contact transformer is presented.

Table I shows each non-contact transformer parameter with N number series-connected transformer and N number parallel-connected transformer.

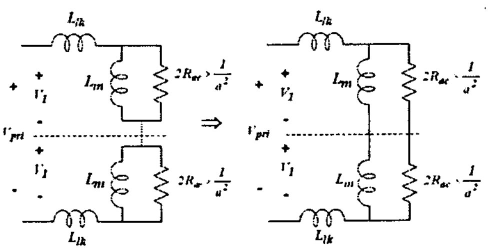

Fig. 8 Equivalent circuit model of Fig. 7

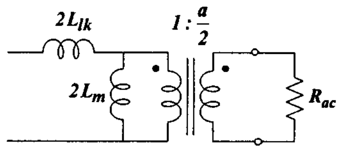

Fig. 9 Simplified model of Fig. 8

TABLE I
Transformer parameters with N number of Module

	SeriesConnection	ParallelConnection
Leakage Inductance	NL_{lk}	NL_{lk}
Magnetizing Inductance	NL_m	NL_m
Transformer turnsratio	a	$\frac{a}{N}$

[참 고 문 헌]

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