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Transfer Effect Ratio of Loosely Coupled Coils for Wireless Power through CB Wall under Station Blackout(SBO)

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1. Introduction

Unlike design basis accidents, some inherent uncertainties of the reliability of instrumentations are expected while subjected to harsh environments(e.g., high temperature and pressure, high humidity, and radioactivity) occurring in severe nuclear accident conditions. By the these conditions, instrumentations have had the bad situation like a station blackout(SBO) as the severe accident in nuclear power plants.

In recent years, there has been an increasing interest in wireless power transfer technology, In particular, significant processing has been charted for inductively coupled systems [1].

In this paper, we introduce some new method as transfer effect ratio of loosely coupled coils for wireless power through the CB(Container Building) wall as an alternative method under a station blackout of severe accident conditions in nuclear power plants.

2. Preparation Experiment

According to 10 CFR 50.2, station blackout means "the complete loss of alternating current (ac) electric power to the essential and nonessential switchgear buses in a nuclear power plant (i.e., loss of offsite electric power system concurrent with turbine trip and unavailability of the onsite emergency ac power system). In this case, it is not possible to supply from the electric power system in the plants. Therefore, we prepare a new method as loosely coupled coils for wireless power [2-3] through the CB(Container Building) wall under a station blackout.

2.1. Review of a Simulation Model

Recently the Massachusetts Institute of Technology has proposed a new scheme based on strongly coupled magnetic resonances, thus presenting a potential breakthrough for a midrange wireless energy transfer[4-5]. The scheme was carried with a power transfer of 60W, end-to-end system efficiency of 15%, and RF-to-RF coupling efficiency of 40% for a distance of 2m, which is more than three times the coil diameter.

In comparison with previous noncontact wireless power transmission technology, magnetic resonance coupling has some essential differences. A system using resonant coupling can be nearly omnidirectional and efficient, with low interference and low losses into environmental objects, irrespective of the geometry of the surrounding space. These characteristics are due to the physical nature of the resonances.

Magnetic resonance coupling is a new concept in wireless energy transmission, previous analyses were based on pure physical theory and failed to provide tangible findings for electrical engineers[6]. There have been few reports on practical design[7]. It is intuitively understood that efficiency is decreased as the distance between the sending and receiving coils is increased. However, it is not as easily understood why the optimum distance between the power and sending coil is not zero. Also, the reason why the efficiency of magnetic resonance system is higher than magnetic induction system was not clearly established in previous analysis.

In this case, a simple equivalent circuit model for a wireless energy transfer system via coupled magnetic resonances was applied to the experiment. The node equations were obtained a system consisting of four coils and were analytically solved for a lossless case. From the solution, it can be easily understood how the system achieves high coupling efficiency. A model at an electric design automation tool was established, which enabled to design the system for a simple case and predict the characteristics of a system consisting of more than four coils. The parameters of the model were extracted from parameter conditions as transfer effect ratio of loosely coupled coils for wireless power through CB(Container Building) wall under station blackout, and the model was justified by simulation tool.

2.2. Field Conditions and System Design

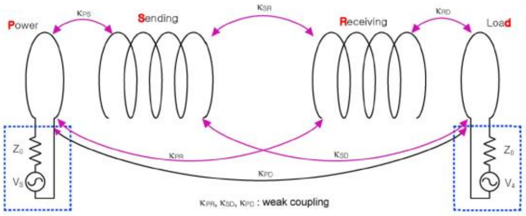

Fig. 1 Schematic of a wireless energy transfer system using coupled magnetic resonances

As show in Fig.1, it's schematic of a wireless energy transfer system using coupled magnetic resonances, Fig.

2, the system is composed of four coils: power, sending, receiving, and load coils. The system can be analyzed in a form where all four coils are coupled with each other.

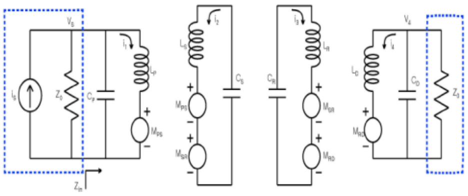

Fig. 2 System composed of four coils: power, sending, receiving, and load coils

2.3. Field Simulation of CB Conditions

A system consisting of four coils can be interpreted as an expansion of a transformer, which consists of two coils between wall thickness of the container building. Fig.3. shows steel structure of reinforced concrete (RC) with tandom of CB for Wulsung Unit 1.

Fig. 4 shows a system consists of two coils through the inside wall to the outside wall having about 1m thickness which was built in reinforced concrete (RC) is a composite material in which concrete's relatively low tensile strength and ductility are counteracted by the inclusion of reinforcement having higher tensile strength and/or ductility.

2.3.1. CB conditions

- CB was built in reinforced concrete (RC) which is a composite material with steel structure & tandom structure
- Wall thickness : 1[m]

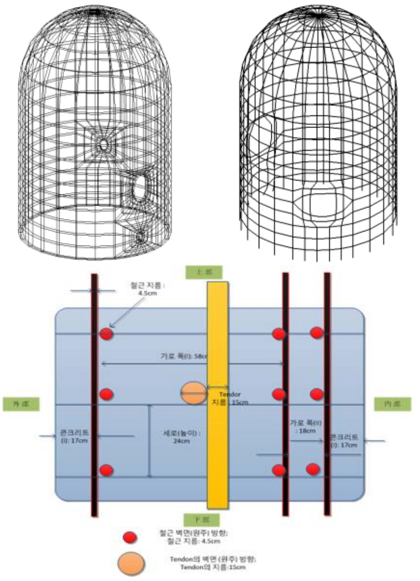

Fig. 3 Steel structure of reinforced concrete (RC) with tandom of CB for Wulsung Unit 1

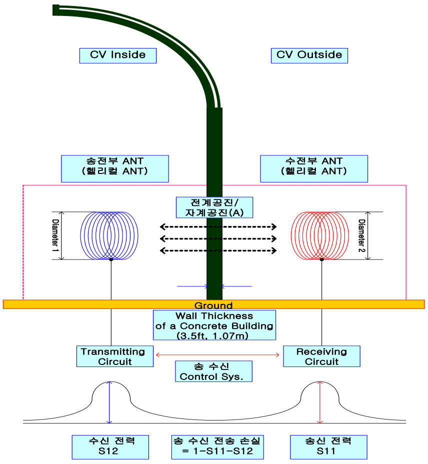

Fig. 4 A system consists of two kinds of coil at wall thickness of container building

2.3.2. Simplified circuit schematic

Fig. 5. shows simplified circuit schematic at resonance frequency

- Two kinds of coil (Sending & Receiving function)
- Coil quality factor : Q (~ 150)

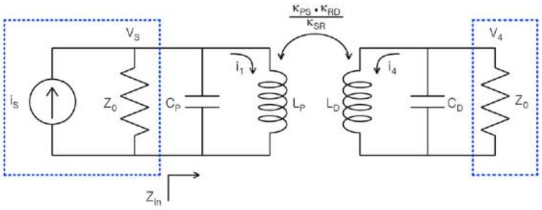

Fig. 5 Simplified circuit schematic at resonance frequency

3. Simulation Results

As an equivalent circuit model that can describe wireless energy transfer systems via coupled magnetic resonances for the CB thickness wall.

The solution shows that the transmission efficiency can be decreased simply by adjusting the spacing between the power and the sending coils or between the receiving and the load coils.

The system design can be calculated the frequency characteristics, and then an equivalent circuit model was developed from the node equation and established in an electric design automation tool. Fig. 6. shows a transfer gain curve by simulation parameter of sending & receiving coils (Coil Dia. = 15 cm, Coil Turns = 2.5, Operating Freq. = 46 MHz, Gain = -20 dB). Fig. 7 . shows simulation results for container building(CB) (Coil Dia. = 15 cm, Coil Turns = 2.5, Operating Freq. = 46 MHz, Gain = -20 dB).

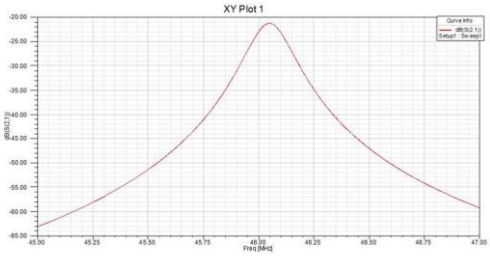

Fig. 6 Transfer gain curve by simulation parameter of sending & receiving coils (Coil Dia. = 15 cm, Coil Turns = 2.5, Operating Freq. = 46 MHz, Gain = -20 dB)

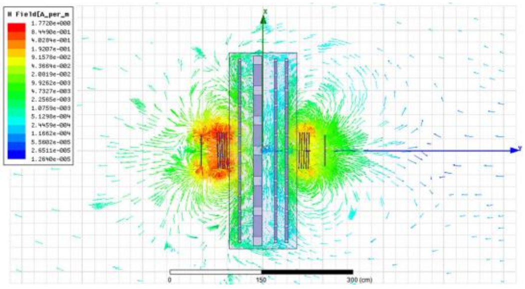

Fig. 7. Simulation results for container building(CB) (Coil Dia. = 15 cm, Coil Turns = 2.5, Operating Freq. = 46 MHz, Gain = -20 dB)

The parameters for the model were extracted, and simulation results were compared with other parameters by the summary table 1.

Table 1. Simulation results were compared with other parameters

Coil Dia. (cm)	Coil Turns	Operating Freq.(MHz)	Wall Hight x Thickness(cm)	Gain (dB)	Gain (%)
30	5.25	10.0	325x100	-25.0	0.32
30	2.50	20.0	325 x100	-40.0	0.01
30	1.50	37.0	325 x100	-40.0	0.01
15	2.50	46.0	325 x100	-20.0	1.00
10	2.50	74.0	325 x100	-24.0	0.40
10	2.50	74.0	325 x100	-23.0	0.50

The final simulation results are as follows.

- Transmission efficiency is not good results, due to the electronic shields of reinforcement having higher tensile strength and tandom structure.
- Although the best transmission efficiency is about ~1%. (Coil Dia. = 15 cm, Coil Turns = 2.5, Operating Freq. = 46 MHz, Gain = -20 dB)
- In near future, it will be possible to get good efficiency 10~20%, if they were using another adaptive parameters like a high frequency(GHz band) and/or any other radiation methods.

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