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Parametric Analysis of 50kVA Shared Transformer / Reactor According to Currents, Turns and Distance Between Transformer and Reactor Core

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Abstract

Passive elements, transformer and reactor, were combined into a single element to reduce the volume of PCS(Power Conditioning Systme). This is called a shared model, but there has been little research conducted because of the new model. If the inductance is very low, the material area increases. In addition, the current density decreases, and short-circuit currents can occur. If it is enormous, the load loss is increased considerably due to the increase in eddy current loss and stray loss. The temperature of the windings and the device itself will increase. Therefore, finding the value of inductance will help in the low cost, safe, and efficient design of the transformer. Accordingly, each inductance was measured by setting various conditions through FEM(Finite element analysis).

System: PCS, such as inverters and converters, are needed to convert solar energy to a form of power suitable for the purpose. In addition, the advantages of PCS, such as small size, high efficiency, high power factor, high reliability, and low cost, are required. Among them, there are special devices that can compensate for size and cost issues. For a typical transformer and reactor to be replaced by a shared model, the output or performance of the two devices must first be similar. The shared model was designed by combining the transformer cores and reactor cores with the same size and specifications for a fair comparison. The essential element, inductance, was measured during the transformer design process. The transformer, reactor, and shared models are shown with different currents and turns. In the shared model, the primary coil performs both the transformer core and the reactor core. At this time, a gap is formed between the two devices. The changes in inductance according to the gap distance are shown in the text by FEM analysis.

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1. Introduction

Electrical energy is almost dependent on thermal power and nuclear power[1]. This adversely affects resource depletion and environmental pollution[2]. For this reason, there is a great need for an alternative energy source. For example, there is growing interest in renewable energy (such as solar energy, wind energy, and fuel cells)[3,4]. Photovoltaic systems require PCS(Power Conditioning Systme) technology to integrate and operate the system efficiently to utilize energy storage devices effectively[5,6]. Therefore, the system needs PCS that require the advantages of a small inverter, high power factor, low harmonic output, high reliability, maximum output operation, and low cost[7,8]. This can have advantages of small size and low cost through a shared transformer/reactor[9,10]. This study examined the

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interactions that occur when two cores are approached by combining two passive elements (transformers and reactors). To solve a problem, a model is needed that is analyzed through FEM(Finite element analysis)[11]. In this study, the transformer inductance was analyzed and the difference between the general model and the shared model was determined.

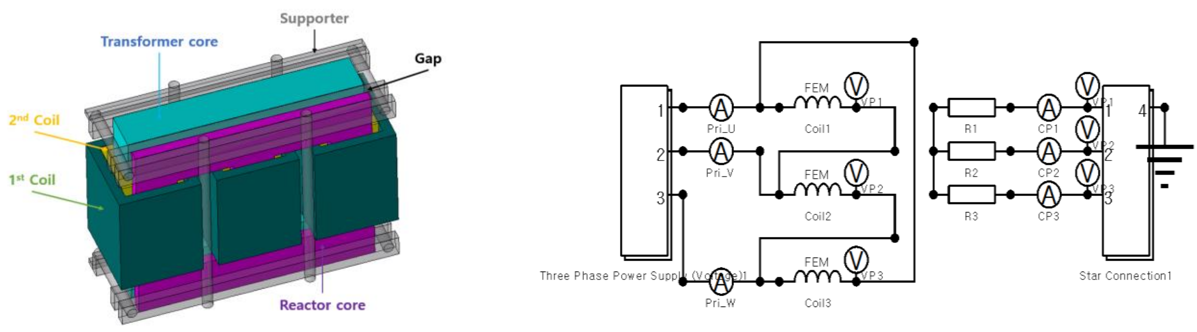
2. Shared model and Individual models configuration

In a general transformer, a reactor core was inserted with a space between a primary coil and a secondary coil. Figure 1 shows the 3D shape of the shared transformer/reactor. This is the basic model for FEM analysis. The primary coil serves as a transformer input part and a reactor.

As shown in Fig. 1 (b), the most common delta-wye connection method was used. This study aimed to maintain the performance of the general transformer and reactor while using a shared model. Designed with the same size and specifications, the transformer and reactor were compared with the shared model based on 50kVA capacity. Table 1 lists the detailed specifications of the model and the results of the performance comparison. The voltage and current were measured to determine power loss; 380V and 45 A were applied, respectively. The transformer came in at 379V and 44.5A, with an efficiency of 98%. In the case of the shared model, the results showed 375V and 44A, with an efficiency of 97%. According to the above result, similar performance with a shared model can be seen. Therefore, the gain of 55 kg and 1.5 m^3 space can be obtained.

Table 1: The results of the specification and performance

Component	Unit	Transformer				Reactor		Shared transformer/reactor			
Number of turns	turn	1st Coil	200	2nd Coil	116	1st Coil	200	1st Coil	200	2nd Coil	116
Voltage	V	In	380	Out	379	Out	380	In	380	Out	375
Current	A	In	45.3	Out	44.5	Out	45	In	44.8	Out	44
Max flux density	T	1.55				1.22		2.06			
Weight	Kg	206.9				83.3		235.3			
Volume	m^3	35				20		40			



(a) (b)

Figure 1. Design (a) Shared Transformer/reactor (b) Circuit(delta-wye)

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3. Result of inductance value according to condition

Inductance is an important factor in the overall design of a transformer. Inductance adversely affects flux loss, voltage drop, and efficiency. When designing a shared model, being aware of the changes in inductance is an important design requirement. Factors that change the inductance of a typical transformer are the number of turns and current. The inductance was confirmed by changing the number of turns and current based on a capacity of 50 kVA. Initially, the current was fixed to 45A to change the number of turns. The second changes the current by fixing the number of turns to 200 turns. The comparison targets are the shared model, transformer, and reactor. In addition, in the shared model, there is a gap between the transformer and the reactor. This gap will change the inductance. Therefore, FEM analysis was performed according to the gap distance. In order to obtain the self-inductance and leakage inductance, first export the real part Re(I) and imaginary part Im(I) of the current in the primary coil, as well as the real part Re(V) and imaginary part Im(V)of the voltage. It is possible to obtain the self-inductance and leakage inductance by subsitituting Re(I), Im(I), Re(V), and Im(V) obtained using equation (1) ~ (5) below.

Step 1: In the case of AC current, voltage and current are expressed using the equation. V is voltage applied to the primary coil (complex number), I is current in the primary coil (complex number), Z is impedance, R is resistance, j is imaginary unit number, X is reactance, L is inductance, ϖ is angular frequency.

$$V = I \times Z = I \times (R + jX) = I \times (R + j\varpi L) \tag{1}$$

Step 2: The following equation expresses the angular frequency ϖ.

$$\varpi = 2\pi f \tag{2}$$

Step 3: The values of R and L are as follows in equation (1). $Re(V), Im(V)$ are real and imaginary parts of the voltage applied to the primary coil. $Re(I), Im(I)$ are real and imaginary parts of the current in the primary coil.

$\bar{I}$ is conjugated complex number of I

$$R + j\varpi L = \frac{V}{I} = \frac{V \cdot \bar{I}}{I \cdot \bar{I}} = \frac{\{Re(V) + j\,Im(V)\}\{Re(I) - j\,Im(I)\}}{\{Re(I) + j\,Im(I)\}\,\{Re(I) - j\,Im(I)\}} \tag{3}$$

Step 4: Equation (3) is divided into real and imaginary parts.

$$R + j\varpi L = \frac{Im(V) \cdot Re(I) - Re(V) \cdot Im(I)}{Re(I)^2 + Im(I)^2} \tag{4}$$

Step 5: Therfore, the L value is

$$\varpi L = \frac{Im(V) \cdot Re(I) - Re(V) \cdot Im(I)}{Re(I)^2 + Im(I)^2} \tag{5}$$

3.1. Inductance according to current and turns

Inductance is an essential parameter in designing a transformer. The factors that change the inductance of a typical transformer are the number of turns and the current. This set based on the number of turns (200), the current (45A), and capacity (50 kVA). Transformers, reactors, and shared models were used to determine the inductance by varying the number of turns and current. The results are shown in Figure 2. Each device was composed of three phases (u-v-w) and FEM analysis of self-inductance and mutual inductance (u-v, v-w, and w-u).

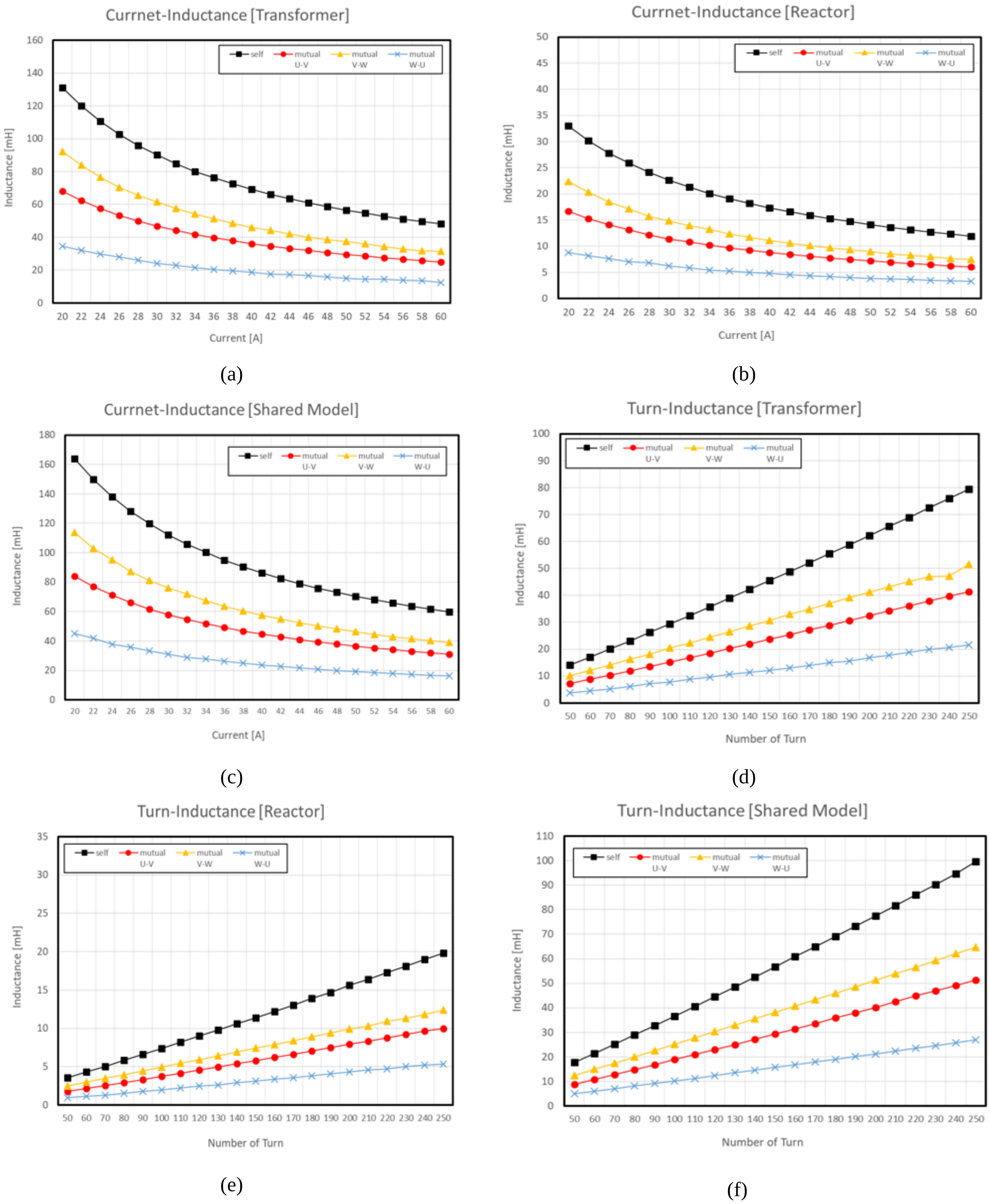

Figure 2. Inductance according to current and turns

(a) According to current (transformer) (b) According to current (reactor)
(c) According to current (shared model) (d) According to turns (transformer)
(e) According to turns (reactor) (f) According to turns (shared model)

3.2. Inductance according to gap distance between transformer and reactor core

The model used for analysis consisted of a different type from the typical transformer. The primary coil performed the functions of the transformer core and the reactor core simultaneously. A gap was formed as the transformer and reactor were combined, as shown in Fig. 1 (a). The inductance will change accordingly. Therefore, as shown in Fig. 3, FEM analysis was performed to examine the change in self-inductance and mutual inductance (u-v, v-w, and w-u) according to the gap distance.

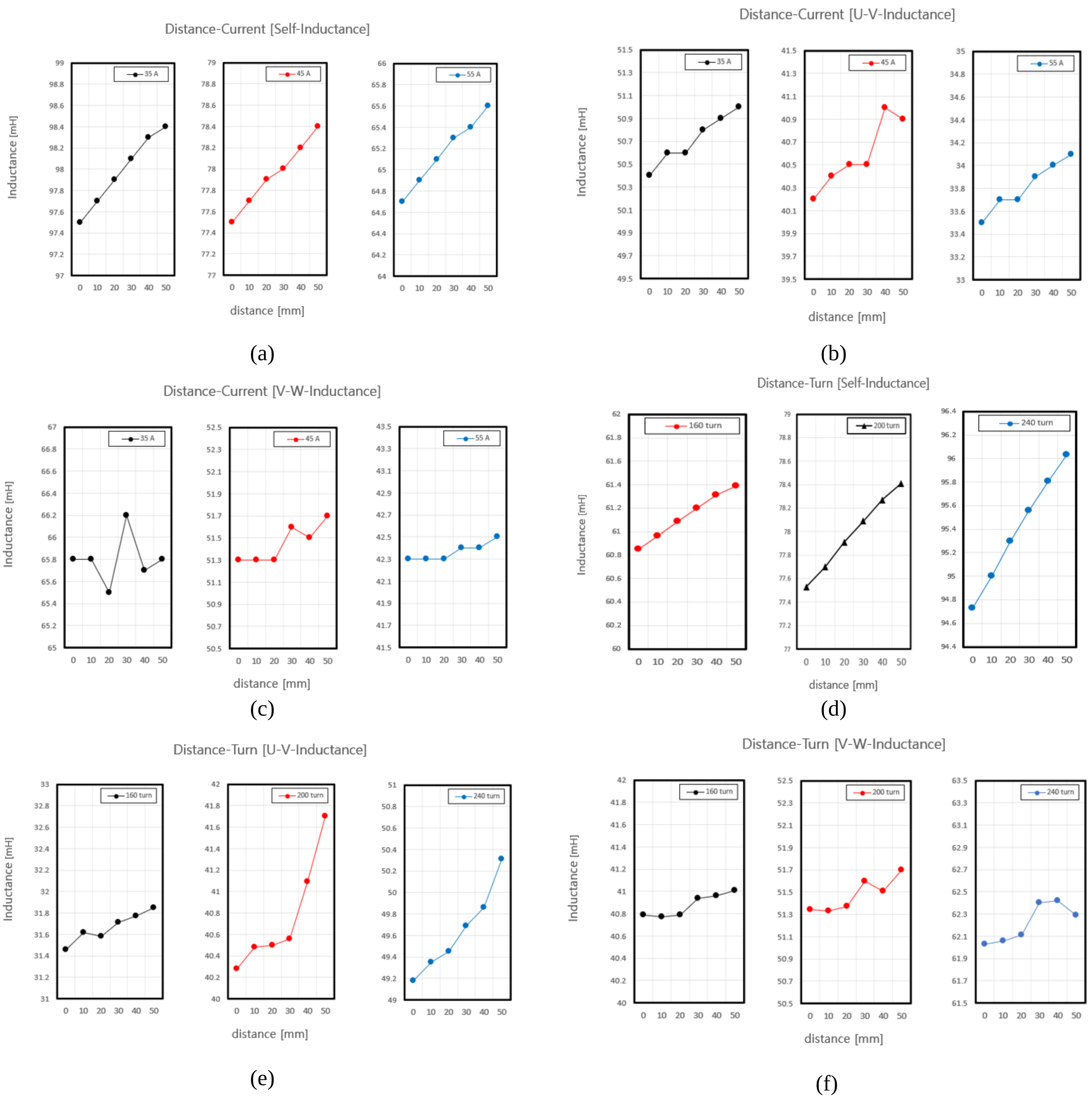

Figure 3. Inductance according to gap distance between transformer and reactor core

(a) According to gap and current(self-inductance) (b) According to gap and current(U-V-inductance) (c) According to gap and current(V-W-inductance) (d) According to gap and turns(self-inductance) (e) According to gap and turns(U-V-inductance) (f) According to gap and turns(V-W-inductance)

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4. Conclusion

For the miniaturization of PCS, there is a way to combine a reactor and transformer into a shared model. As this research is still in transition, various interpretation methods need to be studied. This study analyzed the detailed specifications of the shared model. The self-inductance and mutual inductance were also analyzed by FEM. The results are also based on the distance of the gap that occurs when the two devices are combined. The results may be useful for designing the equivalent circuit of a shared model in the future.

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