Technical Report

Technical Trends Related to Cores for High Power, High Efficiency Reactors

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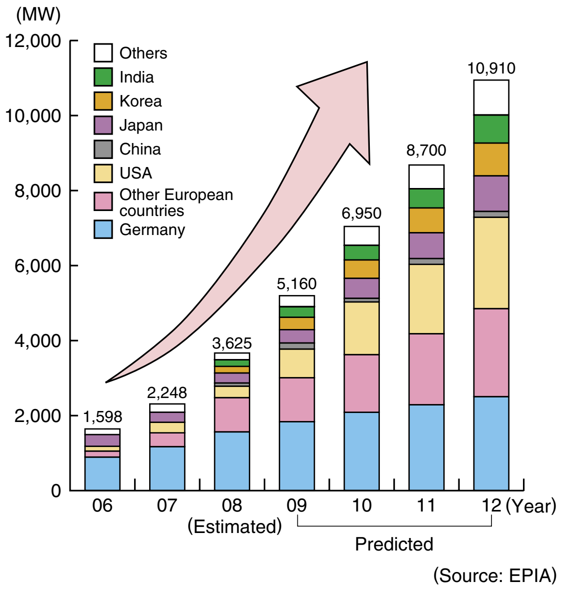
1. Introduction

Awareness of environmental issues such as global warming has increased, so interest in natural energy has increased worldwide. Solar power has especially attracted attention and has become more common based on government policies, especially in Europe (such as Germany and Spain). In Japan, the governmental subsidies system was restarted, so demand for solar power will increase, and in the United States the amount of generated power is expected to increase (Figure 1).

Figure 1 World power generation amount using solar cells according to region
(Dempa Shimbun, December 11, 2008, P. 1)



This document will explain required characteristics for high power reactor cores and TDK's proposal using solar power generation as an application example in harmony with the theme "Technical Trends Related to Cores for High Power, High Efficiency Reactors."

2. Role of the reactor and required characteristics

In solar power generation systems, DC power is generated by solar panels. However, this DC power cannot directly be used for homes. Therefore, it must be converted to AC power by using a power conditioner. It is then used in homes or is sold to a power company (Figure 2).

Figure 2

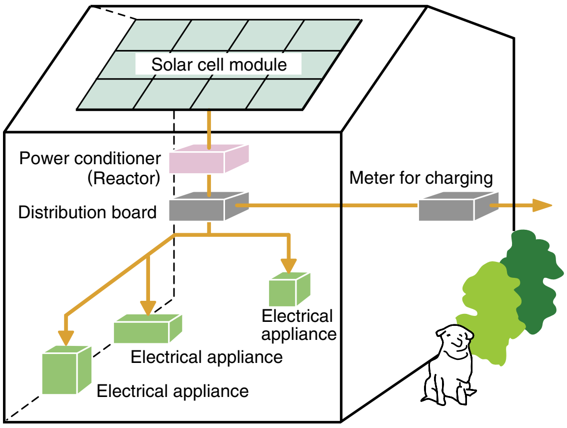
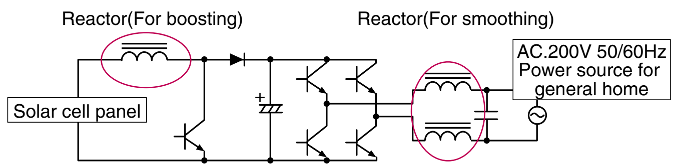


Figure 3 shows the inside of a power conditioner.
DC power generated by panels is boosted by a converter, and is then converted to AC power by an inverter.
Reactors are used by the booster portion and the portion that smoothes AC ripples (Figure 3).
Note: There are also cases where a transformer is used for boosting instead of a reactor.

Figure 3



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The efficiency of the power conditioner is important for using the generated power effectively.
However, the efficiency is easily reduced due to loss by the semiconductor and reactor.

Reactors consist of a core and wires that handle magnetic flux. The following are their loss factors.

- Copper loss related to wire electrical resistance
- Core loss related to the core (Iron loss)

Copper loss depends on the length and thickness of the used wires, and iron loss depends on the material and size of the core. The following are the required characteristics of cores for high power reactors.

- High saturation flux density → Low copper loss (Can be smaller, wire length can be shorter even with the same number of windings)
- Low loss → Low iron loss

Ferrite cores have low loss and can be shaped freely, so they are optimal for core reactors in achieving high efficiency.

3. Ferrite core characteristics and development trends

Metallic magnetic materials are often used for high power reactor cores. This is because of the following reasons.

- Metallic magnetic materials have a high saturation flux density, so they are difficult to saturate and can easily be made smaller
- Switching element loss is high at high frequencies, so the current switching frequency is from 16 to 20kHz, and loss of metallic material is within the tolerance range

However, in order to achieve lower loss, it is necessary to use magnetic materials with lower loss. Ferrite cores have lower loss at high frequencies than metallic magnetic materials. Iron loss of ferrite cores is 1/10th that of metallic magnetic materials in the 16 to 20kHz frequency range where high power reactors operate. For example, as shown in Table 1, iron loss of PE22 material, which is TDK's representative high power core material, is less than 1/20th that of metallic magnetic materials.

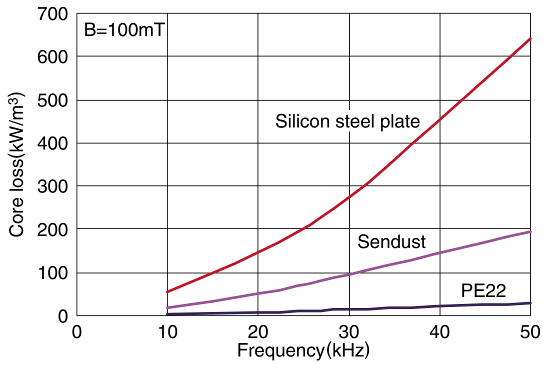
Table 1 Comparison of iron loss

Item	Silicon steel plate	TDK PE22
F=17kHz B=100mT	21.78 W/kg	1.26 W/kg
F=17kHz B=40mT	3.74 W/kg	0.10 W/kg

Of course, copper loss and other losses are factors for reactors, so differences in iron loss do not directly affect reactor loss. However, it is believed that this contributes toward lower loss.

As shown in Figure 4, the difference with iron loss between ferrite and other materials becomes greater at higher frequencies. In the future, as higher frequencies become more common, low loss ferrite will become even more important.

Figure 4 Comparison of material characteristics (Iron loss)



On the other hand, the saturation flux density is half that of metallic magnetic materials, which prevents ferrite from being more commonly used.

TDK has developed PE90 with a high saturation flux density in the high temperature range that can be used for power conditioner reactors and other high power reactors.

4. Major characteristics of PE90

Table 2 shows a comparison between PE90 and PE22.

It has a high saturation flux density in the high temperature range (100°C). It can also handle a larger magnetic energy per unit volume than conventional ferrite materials. Core loss is smaller than conventional ferrite materials, and it can be much smaller than metallic magnetic materials.

Table 2

Material				PE22	PE90
Initial permeability	μi	[23℃]		1800	2200
Curie temperature	Tc		°C	>200	>250
Saturation flux density H=1194A/m	Bs	[23℃]	mT	510	530
		[100℃]		410	430
Residual flux density	Br	[23℃]	mT	140	170
Coercive force	Hc	[23℃]	A/m	16	13
Core loss 25kHz-200mT	Pcv	[90℃]	kW/m^3	79	60
		[100℃]		80	68
100kHz-200mT		[100℃]		520	480
Specific resistance	ρ		Ω・m	3.0	6.0
Apparent density	dapp		kg/m^3	4.8×10^3	4.9×10^3

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A certain volume is needed for it to be used with high power. Ceramics such as those used with ferrite cores are difficult to fire evenly when the value is large, which can lead to cracks that cause the characteristics to deteriorate. However, PE90 is based on our many years of accumulated techniques, so we are able to produce large sizes.

Generally, the loss with ferrite cores is less at higher frequencies than with metallic magnetic materials. Therefore, we will continue to focus our development on saturation flux density for high power. As will be explained in the following, inductance and magnetic flux density of reactors can be reduced when higher frequencies are used, but there is also the possibility that they will be used at high temperatures. Therefore, it is necessary to pursue saturation flux density at high temperatures.

5. Examples of reactor designs using ferrite cores

The following will give an overview of reactors that use ferrite cores. As mentioned previously, ferrite cores have low loss and are effective for reducing reactor loss.

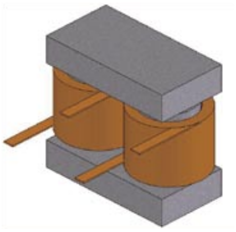
Figure 5 shows an example of a basic reactor. Wires are wound with two poles and are fixed with a top and bottom plate core. The inductance can be adjusted by using an air gap between the pole cores and plate cores.

The following are the advantages of using ferrite.

- When rectangular wire with a good filling rate is used, circular and elliptical types are more desirable iron core shapes than square cross-sections. Ferrite cores can easily be shaped, so they are easy to use.
- The location and size of the GAP for adjusting the inductance has a lot of freedom, so it is possible to create the optimal design according to the magnetic flux flow.

When PE90 is used as a replacement for conventional materials, the magnetic flux density is higher, so it is possible to reduce the number of windings. As a result, it can be made smaller. Copper loss is also lower than with conventional materials, so it is possible to create reactors with lower loss.

Figure 5 Design example



Reactors with ferrite cores have low magnetic flux density, so they are normally larger than reactors using metallic cores. However, by using the optimal design based on the above characteristics, it is possible to create reactors with low loss while minimizing the increase in overall size.

6. Future development

In the past, switching frequencies were from 15 to 20kHz due to semiconductor switching loss. Currently, though, switching elements using SiC, which has lower switching loss than Si, are being developed that will make it possible to achieve switching frequencies of up to 100kHz in the future*. In this case, higher frequencies allow for peripheral devices such as reactors to be smaller, and other merits such as lower costs and lighter weight can also be expected.

The low loss characteristics of ferrite make it very effective for higher frequencies. Therefore, TDK will continue to develop better materials and sizes for reactors in order to be compatible with next generation reactors. We will contribute toward better energy efficiency in order to reduce the impact on the environment.

* Nikkei Electronics, November 17, 2008, p.50-51

• Please note that the articles from the April 2, 2009 Edition of the Dempa Shimbun contained in this chapter have been edited by our company.