Development of Medium-Voltage PM Motors

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Abstract

With increased awareness regarding Climate Change and energy saving, there are growing needs for Medium-Voltage (MV) induction motor with variable speed and for its increased efficiency.

We have proposed an energy saving solution by using an MV induction motor driving system that uses the MV inverters, THYFREC VT730S ("VT730S" hereafter). To realize a further high efficiency system, we have developed an MV Permanent Magnet synchronous motor ("PM motor" hereafter).

MV inverters used in the drive unit are our conventional model, the VT730S. We added PM motor drive technologies.

1 Preface

With growing interest in Climate Change and energy saving, there is an increasing need for Medium-Voltage (MV) motors with variable speed.

In the field of variable speed control for MV motors, we released THYFREC V1000 into the market in 1979. This equipment has an output-transformer and drives an MV motor. Since 2005, we have been selling direct MV inverters with a multi-stage cell system.

Since then, we have proposed and supplied its energy saving systems by turning MV Induction Motors (IMs) variable speed to wide-ranging industry customers. In the field of motors, we have contributed to energy saving by realizing high efficiencies for low-voltage Permanent Magnet synchronous motors ("PM motor" hereafter). It uses permanent magnets for the rotor poles.

In order to achieve further efficiency gain and more energy saving benefit, we have developed the MV PM motor. As a drive unit, we added an MV PM motor drive function in our conventional model, THYFREC VT730S ("VT730S" hereafter).

This paper introduces MV PM motors and MV inverters for motor drive.

2 PM Motor

2.1 PM Motor Efficiency

The IM generates the electric field by a current induced in secondary conductors. The PM motor has no secondary copper loss as it uses permanent magnets in the rotor. Fig. 1 shows a comparison of construction between the IM and PM motor. The basic stator structure is the same, but the rotor construction is different.

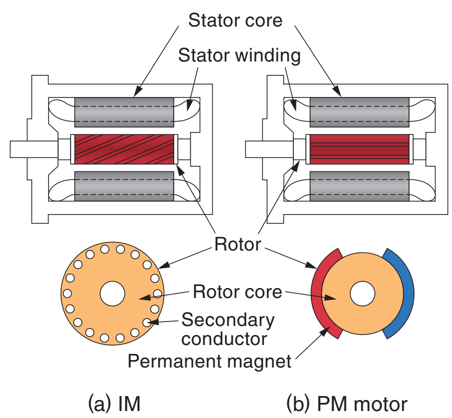


Fig. 1 Comparison of Construction between IM and PM Motor

The stator structure is the same, but the rotor construction is different.

Fig. 2 shows the comparison of losses between the IM and the PM motor. Compared with the IM, losses can be reduced remarkably, resulting in the improvement of efficiency by 2% to 4%.

2.2 Low Torque Ripples and Low Cogging Torque

To replace an IM with a PM motor, it is necessary to consider some mechanical challenges (noise and vibration). There is concern of an increase in noise and vibration if the stator's natural resonance frequency should coincide with the torque ripples and cogging torque. As a countermeasure, the magnet shape and the method of magnet allocation should be optimized by an electromagnetic field analysis using simulation. Torque ripples and cogging torque can then be relieved.

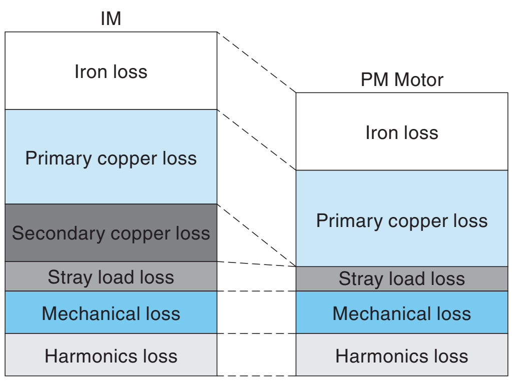


Fig. 2 Comparison of Losses between IM and PM Motor

Since there is no generation of secondary copper loss in the PM motor, total loss generation can be kept small.

Figs. 3 to 6 show the effects of design optimization. It shows the amount of torque ripples and cogging torque that was reduced to smaller values due to the optimum magnet design.

3 MV Inverters

3.1 MV Inverter Specifications

We added the PM motor control functions to Meiden's IEC-compliant MV inverter product VT730S.

Table 1 shows major ratings of the VT730S. In regard to the rated values of applicable motors, for reference, values of Meiden standard 4-pole cage-rotor type 3-phase induction motors are shown there under the output voltages of 3300V and 6600V. The MV PM motor offers better efficiencies than the IM; therefore, this is a great advantage by introducing the MV PM motor.

3.2 Main Circuit Configuration

The MV inverter VT730S employs a multistage cell system. Fig. 7 shows the main circuit configuration. A MV power is fed from an input transformer.

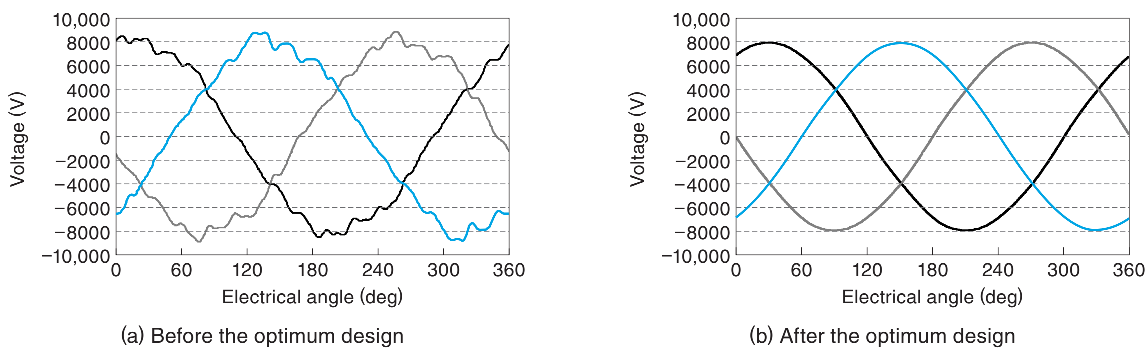


Fig. 3 On-Load Voltage Waveforms

Voltage waveforms under loaded conditions are shown, observed before and after the design optimization.

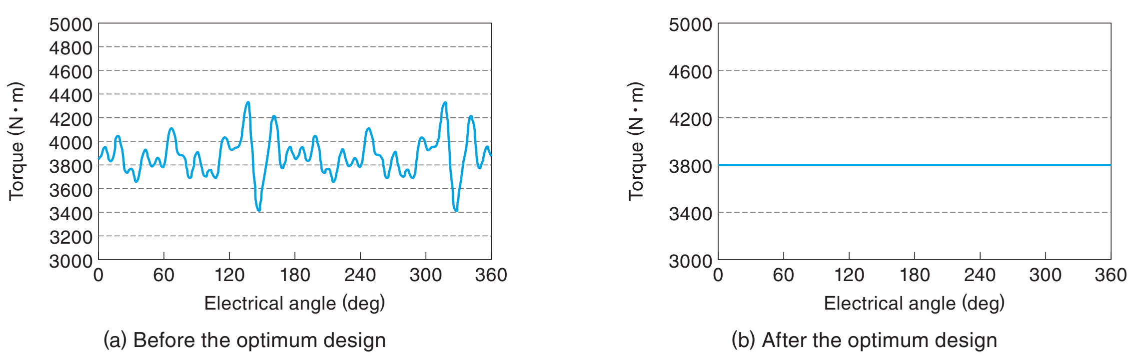
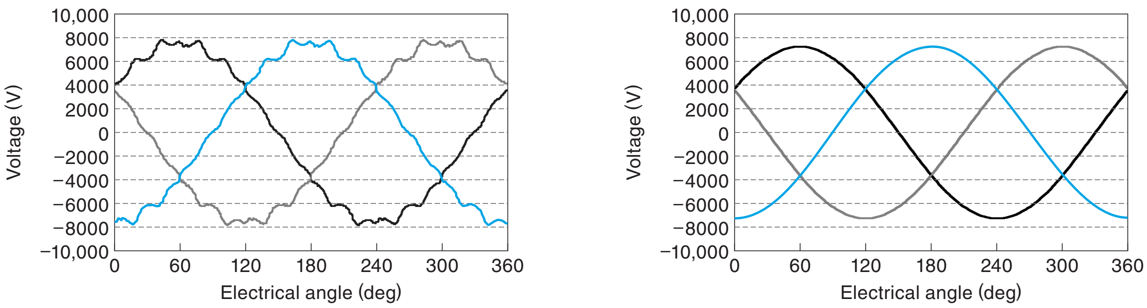


Fig. 4 Torque Waveforms

Torque waveforms are shown, observed before and after the design optimization.

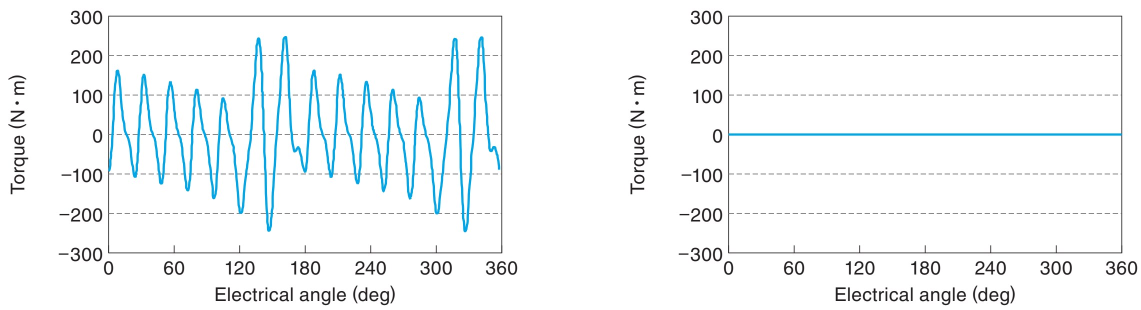


(a) Before the optimum design

(b) After the optimum design

Fig. 5 **No-Load Induced Voltage Waveforms**

Voltage waveforms under no load conditions are shown, observed before and after the design of optimization.



(a) Before the optimum design

(b) After the optimum design

Fig. 6 **Cogging Torque Waveforms**

Cogging torque waveforms are shown, observed before and after the design of optimization.

Table 1 **Major Ratings of the VT730S**

Ratings of the VT730S are shown. Applicable motor capacities are based on the 4-pole IM and they are presented as reference values.

System		3kV class					6kV class						
Type	**VT730S-□**	235L	335L	475L	950L	1250L	330H	500H	710H	1000H	1500H	2000H	2500H
Standard overload	**Rated capacity (kVA)**	332	457	634	1217	1520	446	663	914	1269	1909	2435	3041
	Rated current (A)	58	80	111	213	266	39	58	80	111	167	213	266
	Applicable motor (kW)	235	335	475	950	1250	330	500	710	1000	1500	2000	2500
	Overload durability	120% for 1 minute											
Heavy overload	**Rated capacity (kVA)**	263	366	503	972	1212	354	526	732	1006	1520	1943	2423
	Rated current (A)	46	64	88	170	212	31	46	64	88	133	170	212
	Applicable motor (kW)	190	270	380	750	950	250	390	560	750	1200	1570	2000
	Overload durability	150% for 1 minute											

On the transformer's secondary side, there are nine (9) 3kV circuits and 18 (eighteen) 6kV circuits. Voltage per cell unit is 635V. When star (wye) connections are used, a line voltage of 3300V (6600V for 6kV system) can be acquired for 3kV system. While the PM motor is idling, an induced voltage appears. However, since features of multistage cell system are utilized, there is a feature of suppressing surge voltages that are applied between terminals.

3.3 PM Motor Control Function

Unlike the conventional programs that can control induction motors, our approach is to control the PM motors by simply developing or modifying the control programs. For the control of PM motors, a sensorless control system has been adopted because it does not need any feedback signal of motor revolution value. Since no revolution sensor is needed, the overall system can be simplified.

4 Verification Test

4.1 Motor Specifications for Verification

As with pump driving motors, we made a beta IM and a PM motor unit with the same ratings for verification test. **Table 2** shows specifications of the beta unit. The purpose is to verify that efficiencies of PM motors are compared with those of IMs, and to check if there is any problem when a motor is combined with a pump. We compared the efficiencies with the condition of the frame numbers (bodies) of motors that are identical with each other.

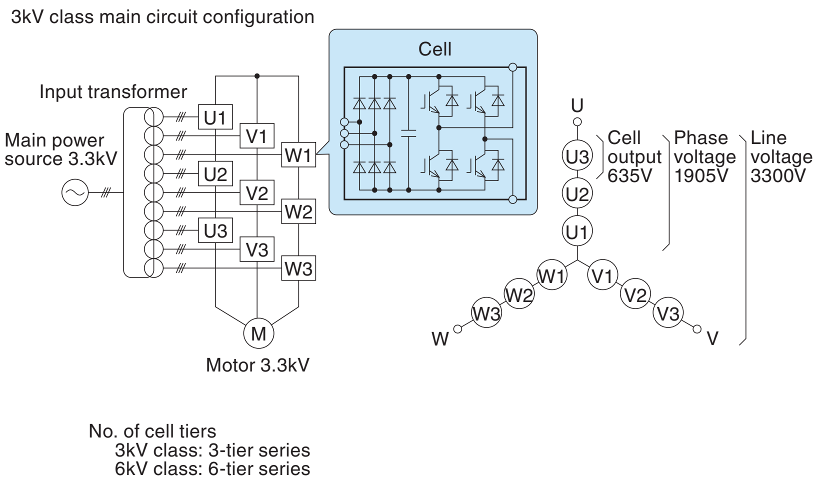


Fig. 7 Main Circuit Configuration

The main circuit configuration of the VT730S is shown.

Table 2 Specifications of Beta Unit

Specifications of beta IM and PM motor for verification test are shown.

Type	Vertical IM	Vertical PM motor
Rated output	240kW	240kW
Voltage	6kV	6kV
No. of poles	10	10
Type of protection	Drip-proof guarded (IP22)	Drip-proof guarded (IP22)
Heat resistance class	155 (F)	155 (F)
Cooling system	Free ventilation type (IC01)	Free ventilation type (IC01)
Frame No.	400LM	400LM
Driving system	VVVF	VVVF
Rated revolution	585min^{-1}	585min^{-1}

4.2 Result of Efficiency Measurement

In our testing facility, motor efficiencies were measured and compared with design values to check the adequacy of the designing approach. In addition, PM motor efficiencies were compared with IM efficiencies in combining them with inverters. **Fig. 8** shows the efficiency data from IM verification test and **Fig. 9** shows graphs of efficiency data obtained from a PM motor verification test.

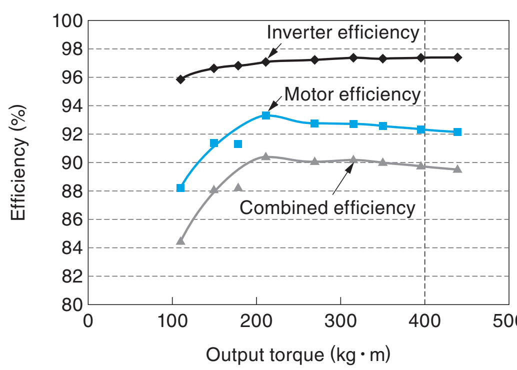


Fig. 8 Efficiency Graph (Induction Motor, IM)

Efficiencies of the IM and inverters as well as combined efficiencies are shown.

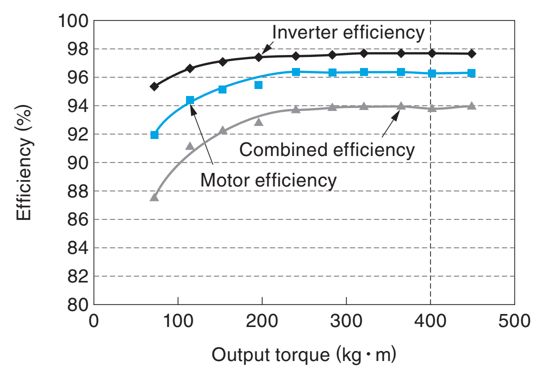


Fig. 9 Efficiency Graph (PM Motor)

Efficiencies of the PM motor and inverters as well as combined efficiencies are shown. We were able to confirm that the PM motor efficiency was higher by approximately 4% than the IM efficiency from the results from the beta unit for verification test.

We confirmed that the system's efficiency in combination with our medium-voltage inverters stays as high as the world's highest level.

4.3 Pump Combination Test and Evaluation

In cooperation with a pump supplier, we conducted the test in combination with pumps and confirmed that there were no problems even though the IMs are replaced with PM motors.

A pump test was carried out in accordance with JIS B8301 "Testing Methods for Centrifugal Pumps, Mixed Flow Pumps and Axial Flow Pumps." It was confirmed that the result of the PM motor and IM testing shows there is no problem in practical usage because the measured values are kept within the permissible margin of error above Class 2 specified in the above-mentioned standard.

5 Postscript

This paper introduced the features of our MV PM motors and our MV inverters with PM motor control functions. Our shop test identified the performance characteristics of a motor unit and the adequacy of our design approach was verified. By conducting the pump combination test, it was confirmed that no mechanical problem arised when an IM was replaced with a PM motor.

Even when inverters are applied to an ordinary facility where constant speed drive is carried out, variable speed drive can be carried out and it can maximize energy saving. In addition, if existing motors are replaced with PM motors, system efficiencies can make remarkable improvements.

We will continue to offer solutions for the world's top level system efficiencies to our customers for the benefit of energy saving.