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Optimal Operation of Variable Speed Electrical Drives For HVAC Applications

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Abstract. A large part of the produced electrical energy is consumed by ventilators, pumps and compressors, the so-called HVAC applications. A lot of this energy can be saved by speed control, but even with the large saving obtained alone by introduction of variable speed, it is still essential to optimize the control of the variable speed drive and to optimize the electrical machine with respect to efficiency. Experiments are made with energy optimal induction motor control on a 2.2 kW variable speed pump system. It is demonstrated that 10% of the consumed energy can typically be saved by energy optimal motor control compared with constant V/Hz control. In a comparison of induction motors and permanent magnet synchronous motors for a variable speed pump application it is shown that for 2.2 kW motors an investment in high efficiency or PM motors are typically paid back within 2.5 years and 7 years respectively. For a 90 kW PM motor the pay-back time would be 24 years. It is today not profitable to use PM motors for variable speed HVAC applications above 2 kW rated motor power. A further study is required to determine this limit in power rating more precisely.

1 Introduction

It is widely accepted that variable speed is a key factor for reduction of energy consumption in processes that load the drive machine with a torque which is a square or a quasi-square function of speed. Typical applications of this type are pumps, ventilators and compressors, the so-called HVAC applications. And as HVAC applications make up a large part of the total electrical energy consumption, it is evident that variable speed drives are means by which a lot of energy can be saved. But even with the large saving obtained alone by introduction of variable speed, it is still essential to optimize the control of the variable speed drive and to optimize the electrical machine with respect to efficiency. By investigation of statistical material on energy consumed by electrical motors it is found that most energy is used by small machines (approximately 1 - 50 kW). In [1] and [2] it was estimated that electrical motors with ratings below 52 kW consume 73% of the total energy used by electrical motors, and dissipate 89 % of the total electrical motor losses. So with regard to saving energy by proper control and good motor construction, the main effort should be concentrated on reducing the losses in drives of that size.

The contribution of this paper is to analyze the aspects of energy efficiency of variable speed control in HVAC applications: 1. control of the motor drive, 2. motor type. In both cases the analysis is done with basis in a traditional voltage source frequency converter driving a three phase induction motor. The first analysis is based on experiments where energy savings in a

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variable speed drive obtained by energy optimal control are compared with constant V/Hz control in a realistic 2.2 kW pump system. The second analysis is a comparison between using induction motors and permanent magnet synchronous motors, and the purpose is to quantify the profitability of using a high-efficiency induction motor or a permanent magnet synchronous motor instead of a standard induction motor.

2 Energy Optimal Control of Variable Speed Pump Motor Drive

When an induction motor is fed by a frequency converter it is possible to reduce the flux in the machine at low load. The reason to do that is to reduce the core losses and the stator current, so the overall losses in the drive are reduced. A side-effect is that the acoustic noise is reduced as well. This control principle is especially applicable in HVAC applications where the load is reduced with speed, and where the controlled process (pump and ventilator) operates with reduced output most of the time. The traditional way to realize flux reduction in HVAC-drives is to use a predefined variable torque V/Hz-ratio curve which is speed dependent, see Figure I. Because the same V/*Hz* is used at a given speed, no matter how the load changes, the flux reduction must be made quite conservative to avoid instability, and it does not provide full minimization of drive losses. A more sophisticated solution is energy optimal control, where the V/Hz-ratio depends on both load and speed, see Figure 1. In that way the losses can come closer the loss minimum. Control strategies such as power factor control, model-based control and search control have been discussed in many papers, including [I].

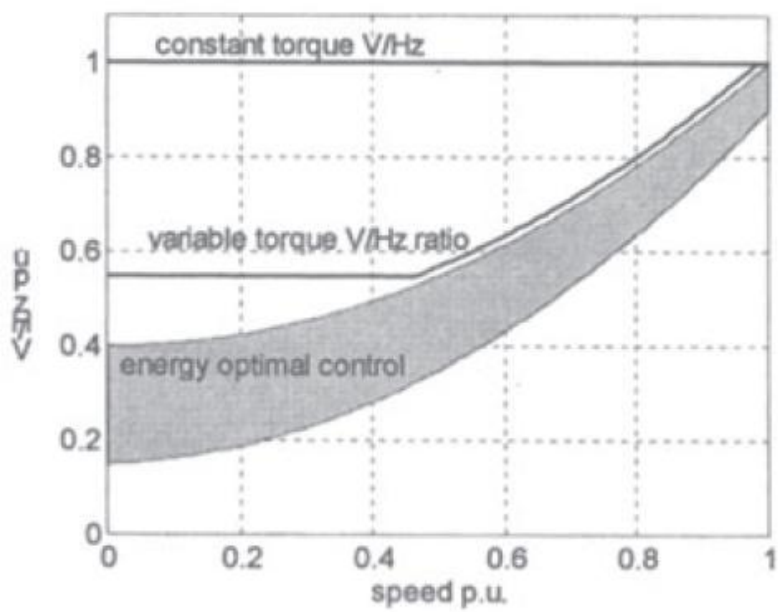

Figure 1: Different Strategies of V/Hz ratio control for induction motors in HVAC

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Vol-22-Issue-16-August-2019

Energy optimal control strategies that ensure maximal efficiency in any load case have been developed and tested experimentally. The load of the 2.2 kW motor was a realistic water-pump-system, see Figure 2a. The motor drive energy consumption was measured during a six minute test cycle with typical variations of water pressure and water flow, see Figure 2b. The measurements were done with constant V/*Hz* and with energy optimal control. The main results are shown in Table 1. In this case, where the average motor loading is 20 %, the consumed energy was reduced with 10 % by energy optimal control. If the average loading is higher than 20 % the percentage of saved energy will diminish.

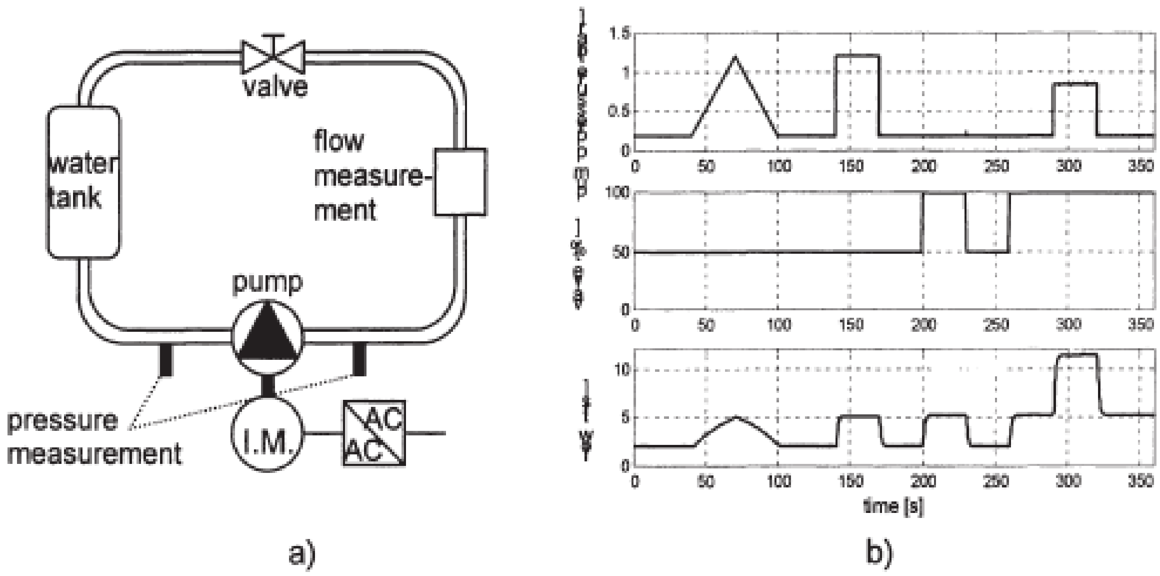

Figure 2: a) Scheme of experimental 2.2 kW pump system. b) Pressure difference over the pump, valve opening and liquid flow during the six min. test cycle.

3 Comparisons of Induction Motor and PM Motor

Standard induction motors are most often used in variable speed drives for HVAC applications. A way to improve the drive efficiency is to use a high-efficiency induction motor or a permanent magnet synchronous motor instead. A permanent magnet motor has a higher nominal efficiency than its corresponding induction motor, but on the other hand the efficiency of the induction motor can be increased at low load by flux reduction. In HVAC applications the motor will often operate at low load, and therefore it is not trivial to analyze further which motor is best suited for HVAC drive applications.

ISSN:0971-1260
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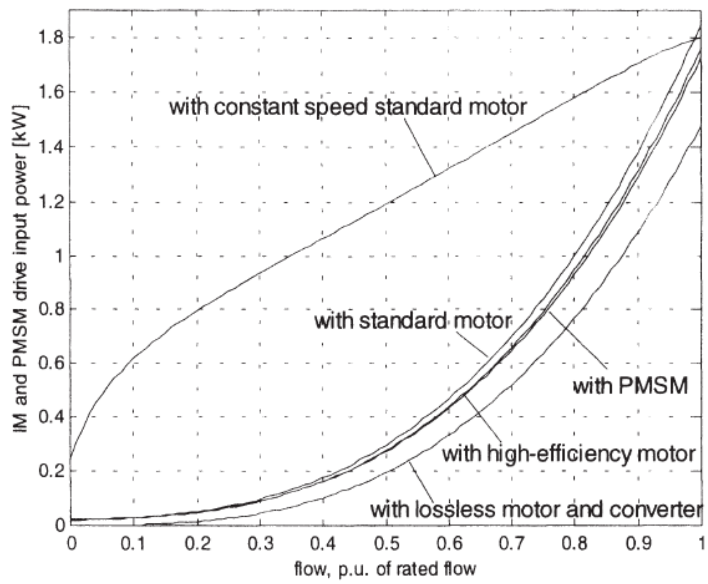

Figure 3: Induction motor and PM motor drive input power as function of pump flow

The starting point is that the drive is equipped with a 2.2 kW standard induction motor driving a pump without head. The objective is to estimate how much better the drive will be if a high-efficiency motor or a PM motor is used instead, and how long the pay-back times are for the investment in more expensive motors. The high efficiency motor used here is a standard motor which is improved with a longer stack, better iron and more copper. The PM motor is made from a standard motor stator frame and constructed with surface mounted neodynium-iron-bor magnets on the rotor surface. The induction motor losses are calculated by use of experimentally verified motor models, and the PM motor losses are calculated by use the SPEED motor designer software. In all cases the motors are controlled with optimal drive efficiency. A calculation of how much power the drives consume as function of pump flow (proportional to speed) is shown on Figure 3. The high-efficiency and PM motor drive performances are almost equal, and better than the standard motor drive. As references are also shown the curves for a motor connected directly to the grid and for a fictitious motor drive without any losses.

The curves on Figure 3 are used to calculate the annual energy consumption when the pump operates with a typical share between high and low load, the average motor load is 30 %. The calculated energy consumption is listed in Table 2, converted into Euro and assuming an energy price of 0.0705 Euro/kWh. The numbers demonstrate the same as Figure 3: the PM motor drive is slightly better than the high-efficiency motor drive, and both are much better than the standard motor drive. The energy expenses, however, have to be related to the extra prices of the PM motor and the high-efficiency motor. From the prices of magnets it is estimated that a PM motor is 250 Euro more expensive than a standard motor. A high-efficiency motor is 70 Euro more expensive than a standard motor. Relating these numbers to the annual costs in Table 2, the pay-back times in Table 3 are obtained, see [3] for details.

These show that if it is chosen to use a high-efficiency motor instead of a standard motor, the extra investment is earned within 2.5 years. This is typically the same as the payback time for an

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investment when changing from constant to variable speed. The 7 years pay-back time for a PM motor is normally more than is accepted. A similar study is made in [3] and [4] for a 90 kW motor drive, and it shows that a PM motor has a pay-back time of 24 year. This indicates that PM motors are still only profitable in sizes above 2 kW. It should be noted that these pay-back times are based on assumptions of motor loading. If, for example, the average motor loading is 25 % instead of 30 %, the following pay-back times are obtained for a 2.2 kW motor drive: high-efficiency motor: 3.5 years, PM motor: 9.5 years.

Table 2: Typical Annual Energy cost for a 2.2 kW pump drive, and annual cost related to the standard motor drive

Loss less drive	PM motor drive	High-efficiency motor drive	Standard motor drive	Constant speed drive
410 Euro	496 Euro	505 Euro	532 Euro	862 Euro
23%	6.7%	5.2%	0%	62%

Table 3: Pay-back time for choosing another motor than a standarad induction motor

	2.2 kW motor	90 kW motor
High-efficiency motor	2.5 years	-
Permanent magnet motor	7 years	24 years

4 Conclusion

It is proved that energy optimal control is definitely a means for optimizing the efficiency of a variable speed drive for HVAC. For a 2.2 kW motor driving a pump 10 % of the consumed energy can typically be saved compared with constant V/Hz control. For the same drive system the extra cost of a high-efficiency motor instead of a standard motor is typically paid back within 2.5 years. For a PM motor the payback time is 7 years. It is today not profitable to use PM motors for variable speed HV AC applications above 2 kW rated motor power.

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ISSN:0971-1260
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