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ELECTRICAL PERFORMANCE OPTIMIZATION OF AN HVAC DUAL FLOW

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Abstract – This work highlight potential gains linked to the control of HVAC system used in buildings. For this, the modelling of electrical system is realized in order to optimize its behaviour. This study is based on the calculation of losses generated in ventilator motors and variable speed drivers to determine the optimal control mode and to evaluate the energy saving.

Keywords – HVAC dual flow, Electronic driver, Electrical motor, Optimization.

1. INTRODUCTION

Inside the building, HVAC dual flow assures the exchange air flow and the temperature stabilization following the user request. Based on the operation, it is divided into two groups: the first includes the electrical and air handling part, ensuring the flow of air in desired normal operation and maximum flow in incident and the second is the thermal part, ensuring the desired temperature.

The PREDIS platform of Grenoble Electrical Engineering Laboratory is one of the places of experimentation in order to make research on building energy saving in France. In this platform, all electrical and thermal equipments are modelled for a global modelling in order to find the intelligent control strategies.

Focus on the HVAC dual flow modelling, this paper examines its electrical part and optimal control mode.

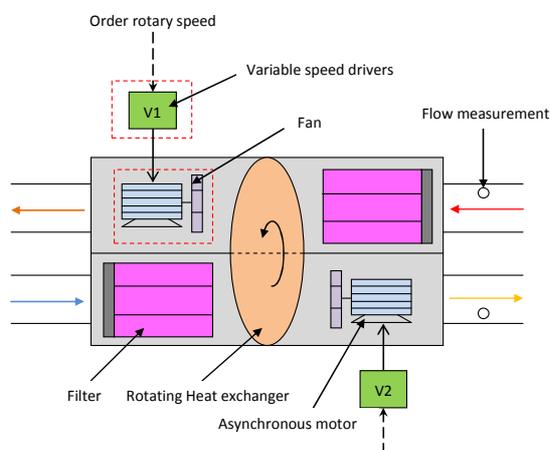


Fig. 1. Structure of the PREDIS HVAC dual flow.

The electrical part contains two speed variable devices and two electric motors associated with the extraction and blowing air. Its performance is decided by the control mode included in the variable speed driver.

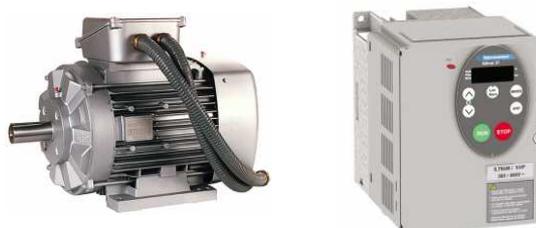


Fig. 2. Siemens induction machine and Schneider Electric variable speed driver.

2. MODELLING

This part is dedicated to the modelling of electrical parts (motor and speed drive). Models are made for the objective of power consumption evaluation; they are parameterized by variables (voltage, frequency, load torque ...) but not for design needs (geometrical parameterization). One of the goals is also to build fast analytical model in order to embed them in real time controller for future works.

2.1. INDUCTION MACHINE

In order to simulate the permanent operation of induction machine (asynchronous motor), this model is constructed by using the equivalent circuit. Based on the electrical expressions, all permanent performances will be easy to calculate [1]-[3]-[4].

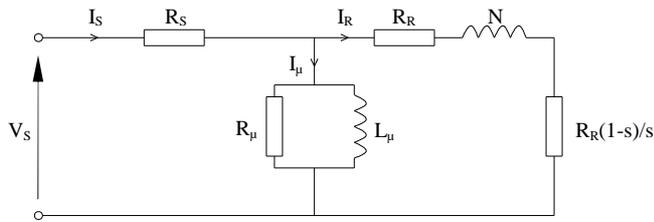


Fig. 3. Asynchronous motor equivalent circuit in permanent operation.

Thanks to motor datasheet from manufacturer, this model can be used to determine the motor parameters by solving this equation system:

$$\begin{aligned}
 I_S(R_S, R_R, N, R_\mu, L_\mu, f_n, s_n) &= I_n \\
 \cos \phi(R_S, R_R, N, R_\mu, L_\mu, f_n, s_n) &= \cos \phi_n \\
 C_u(R_S, R_R, N, R_\mu, L_\mu, f_n, s_n, f_r) &= C_n \quad (1) \\
 I_S(R_S, R_R, N, R_\mu, L_\mu, f_n, 1) &= I_{start} \\
 C_u(R_S, R_R, N, R_\mu, L_\mu, f_n, 1, f_r) &= C_{start}
 \end{aligned}$$

Table I. Motor parameters identification

Datasheet	
Nominal current (I_n)	1.73 A
Nominal power factor ($\cos \phi_n$)	0.86
Nominal speed	2855 rpm
Nominal frequency (f_n)	50 Hz
Nominal torque (C_n)	2.5 Nm
Starting current (I_{start})	9.69 A
Starting torque (C_{start})	5.75 Nm
Motor parameters	
R_S	13.9 Ω
R_R	7.1 Ω
N	41 mH
R_μ	$1.71 \times 10^4 \Omega$
L_μ	795 mH

By applying these parameters, motor characteristic curves in permanent operation can be plotted. Each operating point from datasheet are marked by a cross in Fig. 4, Fig. 5, and Fig. 6 [4]

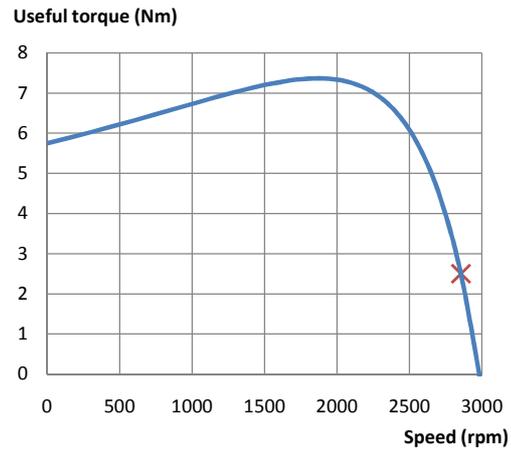


Fig. 4. Asynchronous motor useful torque.

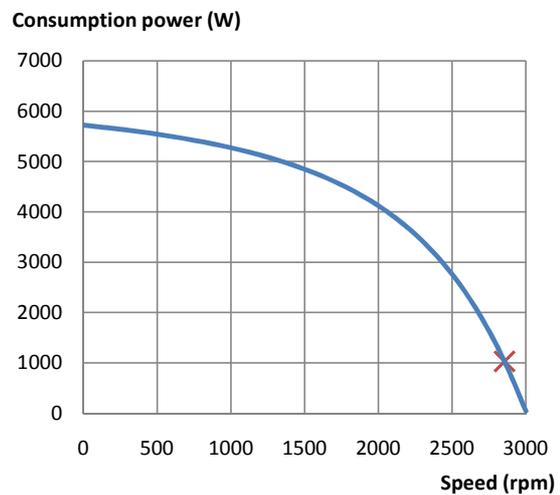


Fig. 5. Asynchronous motor power consumption.

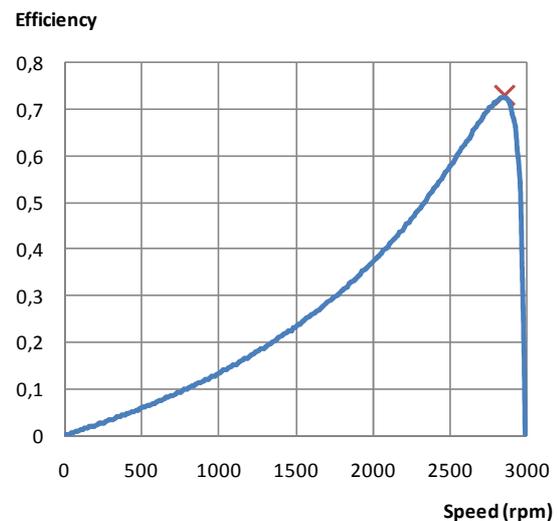


Fig. 6. Asynchronous motor efficiency.

2.2. VARIABLE SPEED DRIVER

In this component, losses of control circuit are lower than global losses (about 1000 times) and then not included in our modelling. So, for studying the performance of this device, only the power electronic circuit is considered. The structure of this circuit is the following:

- A three-phase rectifier is connected to the building supply network and generates a DC voltage ripple.
- To limit the discontinuous of the DC voltage, a capacitor is integrated in the intermediate circuit.
- For the motor power supply, a three-phase inverter generates the power signal voltage and frequency variables.

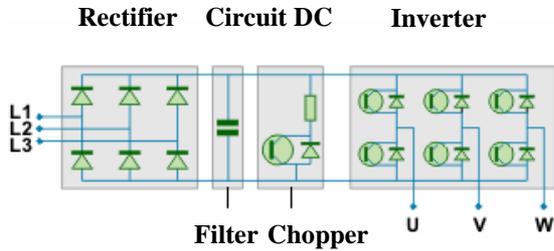


Fig. 7. Power electronic circuit of variable speed driver

In this electronic circuit, because of high switching frequency (12000 Hz) in mode PWM, almost all the losses are the losses of the three-phase inverter. Inside the inverter, there are six switches which one comprises a transistor (IGBT) and an anti-parallel diode. Their losses are also divided into two types of losses: conduction losses and switching losses [2]-[5].

Conduction losses:

- IGBT:

$$\Delta P_{IGBT_cond} = V_{CE0} I_{IGBTmoy} + R_{IGBT} I_{IGBTeff}^2 \quad (2)$$

V_{CE0} : Threshold voltage
 $I_{IGBTmoy}$: IGBT average current
 R_{IGBT} : IGBT resistance
 $I_{IGBTeff}$: IGBT effective current

- Anti-parallel diode:

$$\Delta P_{d_cond} = V_{d0} I_{dmoy} + R_d I_{deff}^2 \quad (3)$$

V_{d0} : Threshold voltage
 I_{dmoy} : Diode average current
 R_d : Diode Resistance
 I_{deff} : Diode effective current

Switching losses: are divided into opening losses and closing losses. They are determined by switching power multiplied by switching frequency.

- IGBT:

$$W_{on} = \frac{W_{onref}}{E_{ref} \cdot I_{ref}} \cdot E \cdot I \quad (4)$$

$$W_{off} = \frac{W_{offref}}{E_{ref} \cdot I_{ref}} \cdot E \cdot I \quad (5)$$

W_{on}, W_{off} : Switching on/off energy
 E_{ref}, I_{ref} : Reference Voltage/Current DC
 W_{refon}, W_{refoff} : Reference Switching energy
 E, I : Voltage/Current DC

- Anti-parallel diode:

$$W_{d_com} \approx W_{doff_com} = I_d \frac{Q_{rr_ref}}{I_{d_ref}} E \quad (6)$$

I_d : Diode current
 I_{d_ref} : Reference diode current
 Q_{rr_ref} : Reference reverse recover charge
 E : Voltage DC

IGBT current (A)

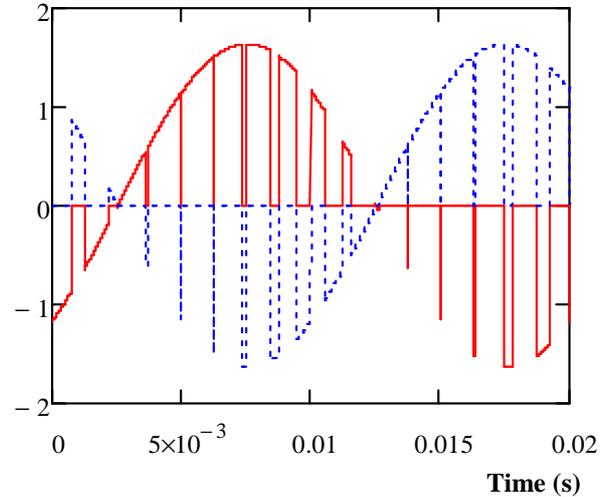


Fig. 8. Speed drive switching current

The losses of switching components are calculated on the table below:

Table II. Switching losses

Losses	AP-Diode	IGBT
Conduction	0.12 W	0.55 W
Switching	3.9 W	7 W

We can conclude that switching losses are the most important in the operation of variable speed driver and are enough great enough to make good approximation of losses for our modelling.

3. CONTROL – COMMAND

3.1. CONTROL MODE: VARIABLE TORQUE

The type of HVAC Load is an aerodynamics one. According to the aerodynamics theory, the motor rotation speed follows a linear law with the flow and a quadratic law with the torque.

In the case of the PREDIS platform, this load was determined by measurement (dots on Fig. 9) and a law was identified in order to measures.

$$C = k \cdot \Omega_R^2 = 1.25e-7 \times \Omega_R^2 \quad (7)$$

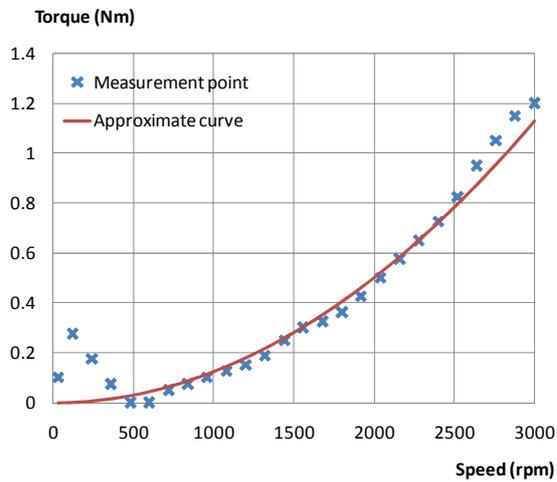


Fig. 9. HVAC fan torque measurement and approximated identified law

The variable speed driver can allow controlling the motor in different mode. A classical control is the control law $V/f = \text{constant}$. In the case of fan or pump, the torque is quadratic depending on the rotation speed; a specific control mode for variable torque is also available.

To identify this control mode, we made measurements in the platform PREDIS. Using an identification method, the relationship between voltage and frequency is determined by this function:

$$V = a \cdot f^b + c = 0.662 f^{1.475} + 12,938 \quad (8)$$

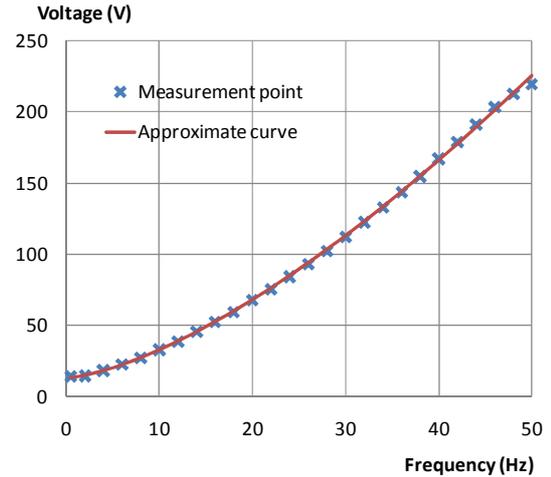


Fig. 10. $V(f)$ law for variable torque control

3.2. CONTROL MODE: OPTIMAL RESEARCH

Our objective is to optimize overall performance of system {motor + variable speed driver}. Thanks to our models, and using the CADES software which is developed for modelling and optimization by G2Elab, both motor and speed driver was composed in order to make a global model. CADES computes gradients of the model automatically in order to make fast constrained optimization. The optimal parameters for the variable torque control law were found and reported in equation (9).

$$V = a \cdot f^b + c = 0.231 f^{1.749} + 3.5 \quad (9)$$

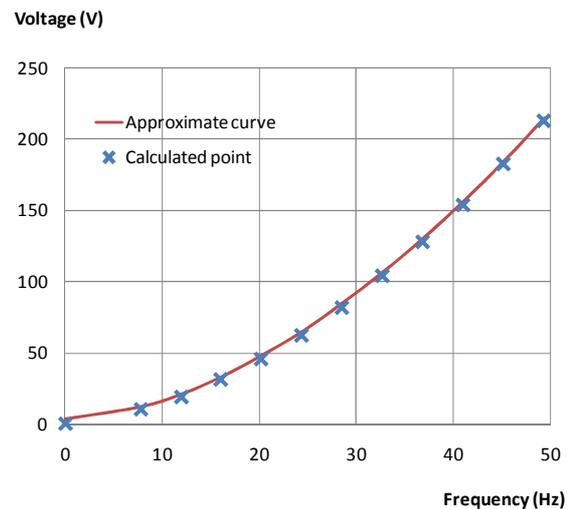


Fig. 11. Optimal parameters for the variable torque control law found with an optimization approach

3.3. COMPARISON RESULTS

On these figures below, the optimal control mode is always better than others, for the entire speed range.

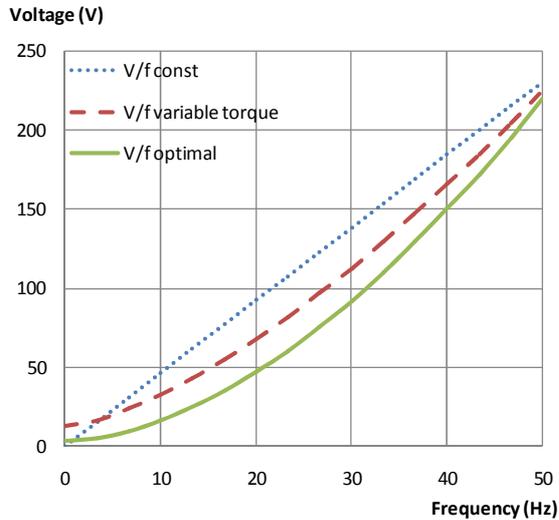


Fig. 12. Comparison controls

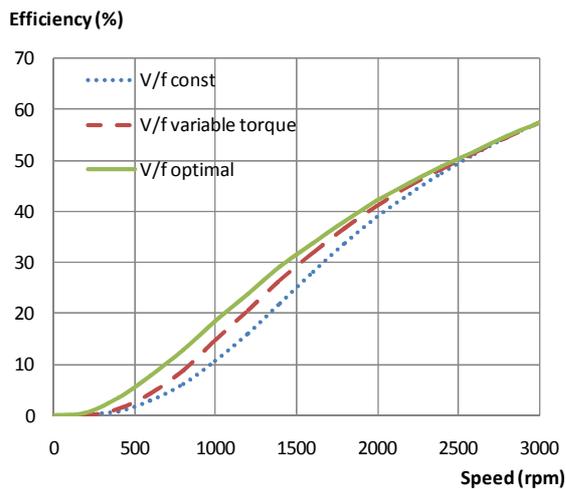


Fig. 13. Comparison efficiencies

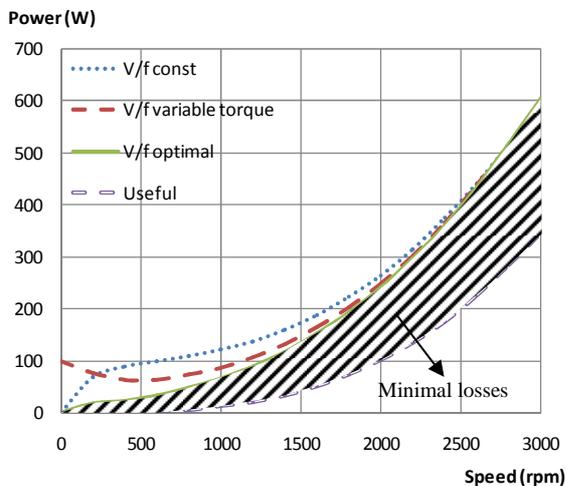


Fig. 14. Comparison powers consumption

It is possible to quantify the efficiency gains of this optimal control mode by considering an actual operation of the HVAC. The average flow rates measured in the PREDIS platform during several days (Fig. 15 in last page) is $600 \text{ m}^3/\text{h}$ while the maximum flow is $1500 \text{ m}^3/\text{h}$. Indeed, the HVAC has been designed to provide cooling during summer nights; it must support a maximum flow rate more than the average flow (about 10 volumes per hour). However, the system variable speed drive + motor has been optimized to run optimally at a speed of 3000 rpm (corresponding to $1500 \text{ m}^3/\text{h}$) and a load torque of 2.5 Nm which is double of the measure.

Meanwhile, the optimal control mode improves essentially the performance for operating points lower than the rated operation. This allows saving of 14% energy in comparison to the control mode installed.

Table III. Consumption energy per year

Control mode	Energy (MWh)	Gain (%)	Cost (€) (10 cts/kWh)
V/f constant	1.3	- 23	132
V(f) variable torque	1.1	ref	107
V(f) optimal	0.9	14	93

4. CONCLUSIONS AND PROSPECTS

In order to optimize the electrical operation of a HVAC, induction motor and speed drive of the PREDIS dual flow HVAC were modelled.

The desired control mode improves the performance of 14% relative to the initial control mode. Indeed, we found that the average operation of the HVAC is lower than the rated operation, which leaves considerable room for improvement, achieved by our control mode.

We founded that if technician, in charge of the HVAC installation, forgot to switch from the V/f law to the variable torque law, a lack of 23% of energy saving can be reached.

In term of prospects, the models developed will be used for the global modelling of HVAC including aerodynamics and thermal part. Then, the HVAC will be coupled with models of buildings. The models developed will also be used to optimize overall building and especially playing on the instructions of HVAC (depending on the desired temperatures and measured the number of occupants and their activities ...).

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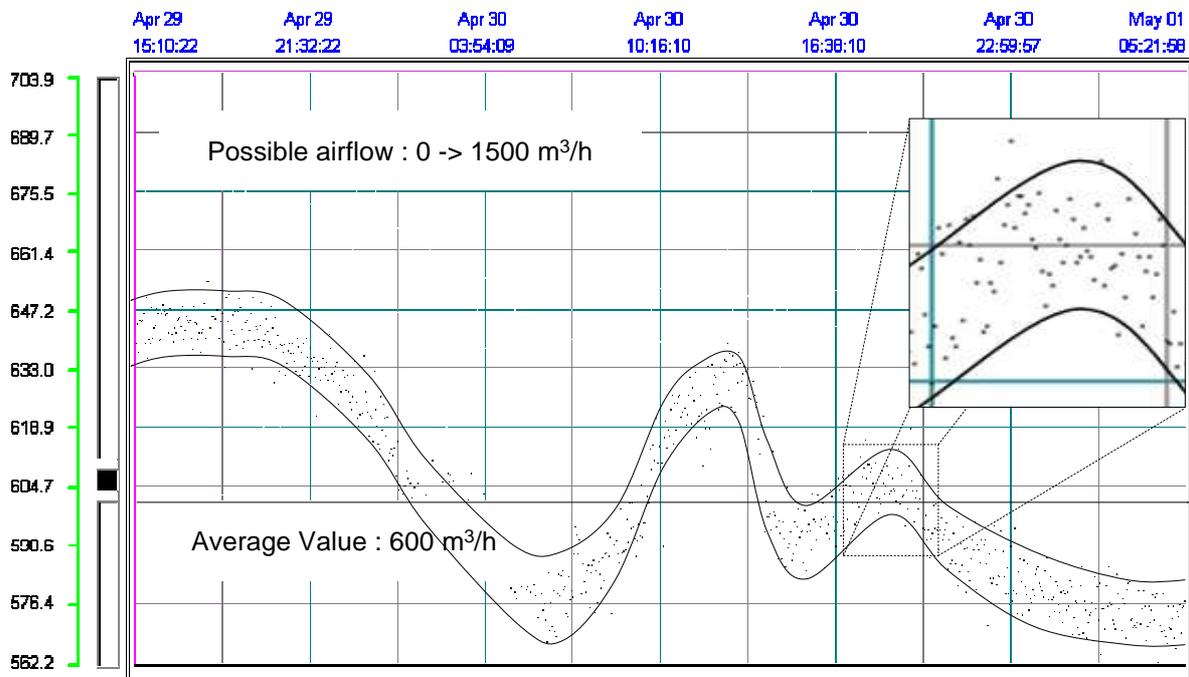


Fig. 15. Airflow measured of platform PREDIS