Control of the DC Output Voltage of the AC/DC Converter Using Adaptive Fuzzy: Application to PMSM

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Abstract: *The absorbed current by the converter is rich in harmonics. This provokes the disruption of the network and influences on the consumers joined to the same node. On the other hand, because of its structure and of the absence of the degree of liberty in the control, the converter consummates a reactive power. In order to minimize the harmonics of side network, several techniques of passive filtering and/or active are used. He is more economical of using some filters set in resonance to the frequency of the harmonic to eliminate. In the exercises, the passive filters have some inconveniences this who renders the delicate conception. For it, we interest us only to the active filtering. The aim of this paper is of understating the harmonics of side network and optimizing the exchange a reactive energy between the network and the converter, including the control of the power factor and the DC-link voltage using adaptive fuzzy logic controller (AFLC).*

Key words: *AC/DC converter, adaptive fuzzy logic controller (AFLC), permanent magnet synchronous machine (PMSM).*

1. Introduction

Industrial and domestic equipments actually use a large variety of power electronic circuits such as switch mode power converters, adjustable speed drives, rectifiers or dimmers. These ones lead to significant energy savings and productivity benefits. But unfortunately, they also present non-linear impedance to the supply network, and therefore generate non-sinusoidal currents with poor power factor. The outcome of these wide-band current harmonics includes substantially higher losses for the transformers and the power lines, possible over voltages and overheating destroying equipments, and disturbances of communication equipments and precision instruments [1].In order to reduce conducted disturbances introduced by this equipment in the network (low order harmonics, reactive power consumption), it is necessary to develop techniques which gives both power control and an optimal power factor. The first approach consists in the design of LC filters. But, passive filters are not well adapted as they do not take into account the time variation of the loads and the network [2]. They can also lead to resonance phenomena. So, since several years, a more interesting technique is studied: the active filter based either on voltage source or on currents source inverters yielding the harmonic currents needed by the load [3,4]. However, their control needs to use automatic control theory to improve their efficiency.

Fuzzy control technique has been successfully applied to the control of motor drives in recent years. This strategy was proposed by Zadeh in 1965 to describe complicated systems which are hard to analyze using traditional mathematics[5], it's only since the 1970's that fuzzy logic theory has found wide popularity in various applications such as economics, management, medicine, or process control.

Indeed, Mamdani and al. were the first to report on the application of fuzzy set theory to control a small laboratory steam engine [6]. The success of this study led many scientists to attempt to control industrial processes such as chemical reactors, automatic trains, or nuclear reactors using fuzzy algorithms. The results of these experiments showed that fuzzy controllers perform better, or at least well as, adaptive controllers.

Moreover, this technique offers the advantage of requiring only a simple mathematical model to formulate the algorithm, which can easily be implemented by a digital computer. These features are appreciated for nonlinear processes for which there is no reliable model and complex systems where the model is useless due to the large number of equations involved. Additionally, fuzzy logic control strategy is used more frequently for the control of electrical machines such as DC or induction motors [7, 8].

Nevertheless, the main problem with fuzzy logic is that there is no systematic procedure for the design of fuzzy controller [9, 10, 11].

In this paper, the fuzzy logic control is applied in order to minimize harmonics introduced by the line converter, improving the power factor and keeping the DC-link voltage constant. Using the AFLC, the line currents are shaped to sinusoidal with a unity power factor, for various operating conditions; which is an interesting advantage. In this study, digital simulation results are obtained using MATLAB software.

2. Circuit configuration

The proposed system configuration is shows in Fig.1. It's composed by rectifier flowed by inverter feds the permanent magnet synchronous machine (PMSM). A bridge rectifier made up of six power transistors with inverse parallel diodes is used (switches are considered ideal) in the main circuit to achieve bidirectional power flow capability. The left side (input) bridge, connected to supply through impedance Zs composed of Rs , Ls representing the AC side resistance and inductance is operated to absorb sinusoidal current, in phase with the line voltages. In order to obtain fast response of the input converter, an hysteresis current control technique can be adopted, with ensures that each line current follows its reference with minimum error (within the hysteresis band Δi) and with minimum delay. In order to maintain DC link voltage Vc, irrespective of reference Vcref and load variations, a closed loop introduced. Voltage Vc is low pass filtered to obtain its average.

The output of the filter is compared with its reference Vcref and resulting error signal is fed to fuzzy logic controller which provides the control signal Iref. The reference current Iref is multiplied by three equilibrates sinusoidal signals, of amplitude unit at the frequency of the network and in phase with the supply voltages. The instantaneous and reference currents are compared and the error signals are generated from which the comparators with hysteresis produce the trigger pulses of the transistors.

3. Control strategy

The proposed control system shown in Fig.1 consists of two parts, the DC voltage and AC line current control.

3.1. Fuzzy voltage control

The block diagram of fuzzy logic DC-link voltage control is shown in Fig.2. The fuzzy controller is constituted by four stages: fuzzification, rules execution, defuzzification and adaptation mechanism of the gain.

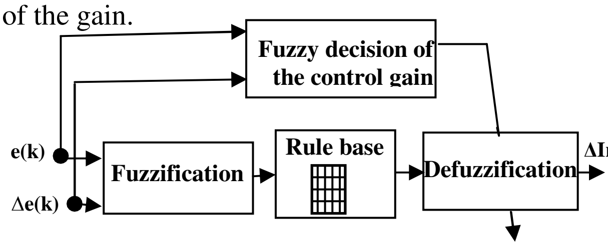

Fig. 2. Fuzzy controller structure.

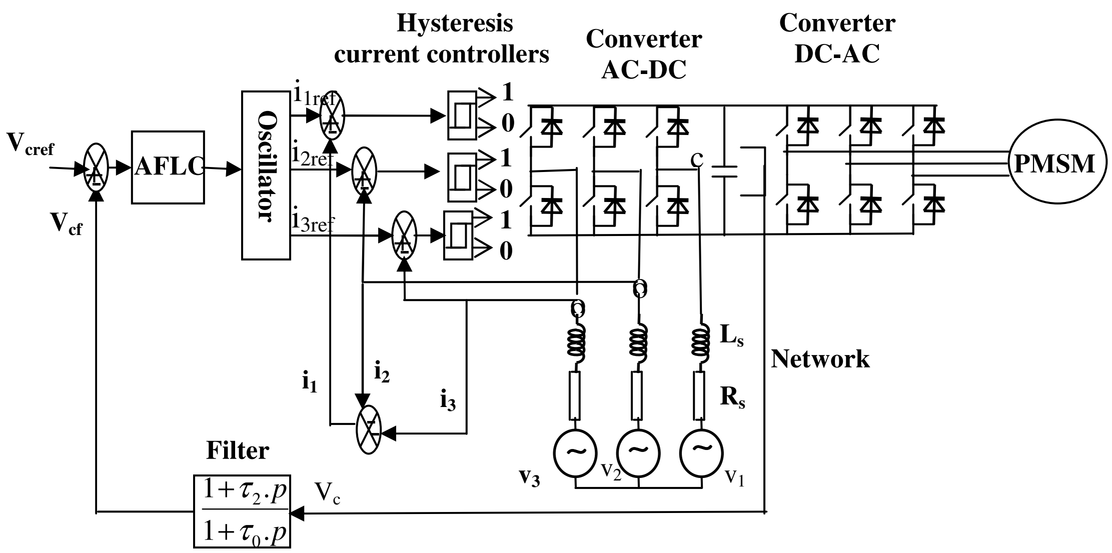

Fig. 1. Main circuit with proposed control system.

The rule base is the principal component of the fuzzy controller; it indicates how the controller behaves to response to any input situation. The rule base is constituted by collection of If-Then rules of the form:

$$R_j : If\ e(k) is A_j\ and\ \Delta e(k) is B_j\ Then\ I_{ref}(k) is C_j \quad j = 1..m \tag{1}$$

Where A_j, B_j and C_j are fuzzy sets such as: NL (negative large), NM (negative medium), etc. defining fuzzy partition on the controller input space .With e(k) and Δe(k) are scaled and normalised version of the error $e_v(k)$ and the change of error $\Delta e_v(k)$ given by:

$$e_v(k) = v_{cf}(k) - v_{cref}(k)$$
$$\Delta e_v(k) = e_v(k) - e_v(k-1) \tag{2}$$

where

$$e(k) = ge.e(k)$$
$$\Delta e(k) = gce.\Delta e(k \tag{3}$$

With ge and gce, constant inputs gain which play an essential role, since they determine the control performances. The expression "$e(k)$ *is* A_j" is implemented by membership function indicating the grade of membership of $e(k)$ in the fuzzy set A_j as in Fig.3, this operation is called fuzzification. The shape of the membership function is quite arbitrary and depends on the user's preference. For simplicity, triangular and trapezoidal shapes are usually used.

The logical operators "*and*" and "*Then*" can be interpreted as *min* or algebraic product, and various inference and defuzzification algorithms can be used to produce crisp output value. If the operators "*and*" and "*Then*" are implemented as algebraic product, the max-product inference and the center of gravity defuzzification methods are adopted in this paper.

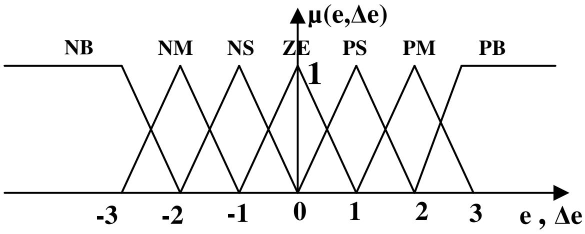

Fig. 3. Membership Functions

In most fuzzy control studies, the gain associated with the control output must be constant and as low possible in order to a void the instability problem. This increases considerably the response time of the system. To solve this problem, we consider the output gain gu as a fuzzy variable [12-13]. Therefore the gain must be adapted at every situation of the system as a function of the error and its variation. We chose fuzzy sets of variable gain whose corresponding membership functions are represented by Fig. 4.

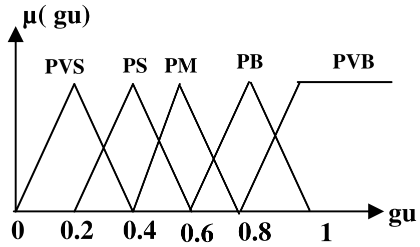

Fig. 4. Membership functions of the output gain.

The decision matrix on the control gain is given in Table I.

Table I
Decision Control Gain

Δe \ e	NB	NM	NS	ZE	PS	PM	PB
NB	PVB	PVB	PB	PM	PS	PVS	PVS
NM	PVB	PB	PM	PS	PVS	PVS	PVS
NS	PB	PM	PS	PVS	PVS	PVS	PS
ZE	PM	PS	PVS	PVS	PVS	PS	PM
PS	PS	PVS	PVS	PVS	PS	PM	PB
PM	PVS	PVS	PVS	PS	PM	PB	PVB
PB	PVB	PVB	PS	PM	PB	PVB	PVB

3.2. Calculation of reference current

The current reference amplitude equals the integral of the output of AFC as shown in Fig.5 and is given by the following equation:

$$I_{ref}(k) = I_{ref}(k-1) + T_s\ .g_u\ .\Delta I_{ref}(k) \tag{4}$$

If a sinusoidal line current is required, the current command (reference) should have the form:

$$I_{i\,ref}(k) = I_{ref}(k)\sin\left(\omega t - (k-1)\frac{2\pi}{3}\right) \quad (5)$$

with i=1,2, or3.

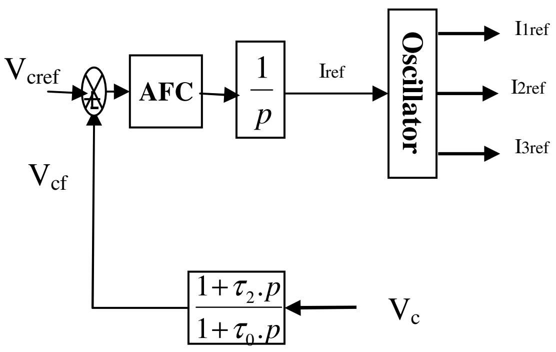

Fig. 5. Block diagram of adaptive fuzzy voltage control.

To obtain a very fast of the input converter, a hysteresis current technique can be adopted, which ensures that each line current follows its reference within the hysteresis band Δi. The AC line current is controlled by the transistors converter in a bang-bang mode. A high switching frequency is given by the following equation:

$$f_{\max} = \frac{U_{\max}}{8L_s\Delta i} \quad (6)$$

where:

$U_{\max}$: max value of line to line supply voltage.

L_s: the AC side inductance.

Δi: hysteresis band.

The achievable bandwidth of the current control loop depends on the switching frequency of the PWM converter.

4. Calculation of power factor and powers

To simplify the calculations of the input powers, the three phase quantities (voltage-current) of AC side are transformed into two *d-q* orthogonal axes according to park transform:

$$[V_{dqo}] = [A][V_{123}],\ [I_{dqo}] = [A][I_{123}] \quad (7)$$

where

$[V_{123}]$, $[I_{123}]$: real vectors.

$[V_{dqo}]$, $[I_{dqo}]$: transformed vectors.

$[A]$: matrix transform.

The transformed voltages and currents contain zero sequence components, such as v_o, i_o. However, because the zero sequence components are all zero in the balanced system, they can be omitted.

The total input powers and power factor in terms of *d-q* variables are given by the following equations:

$$P = V_d I_d - V_q I_q \quad (8)$$

$$Q = V_q I_d - V_d I_q \quad (9)$$

$$PF = \frac{P}{\sqrt{P^2 + Q^2}} \quad (10)$$

P, Q: real and reactive powers.

PF : power factor.

5. Simulation results

Simulation results for the control of DC output voltage and minimization line current harmonic using adaptive fuzzy logic controller are represented. Several tests have been performed in order to prove the efficiency of the proposed control.

5.1 Rectifying Mode

The results show, after a rapid transient response due to the starting of the machine, that the DC voltage is regulated well around the reference V_{cref} = 240V (see Fig.6). The input current has a sinusoidal form and in the phase with line voltage (see Fig.7), which minimizes the harmonics and reactive power consumed by the rectifier. In Fig.8, the power factor is near unity.

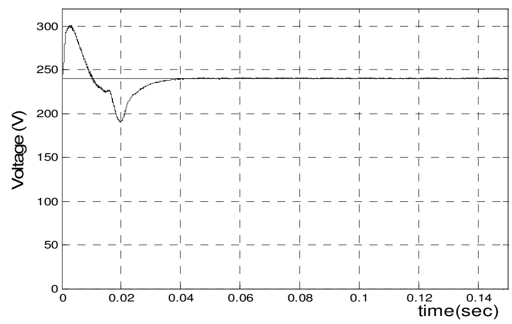

Fig. 6. DC link voltage.

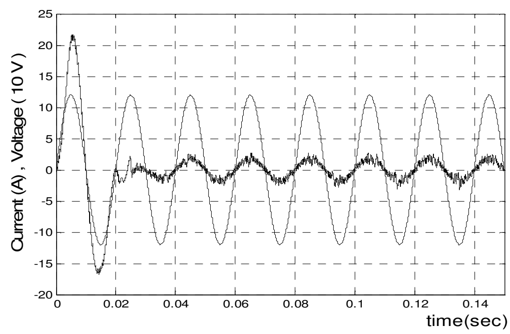

Fig. 7. Line voltage and supply current.

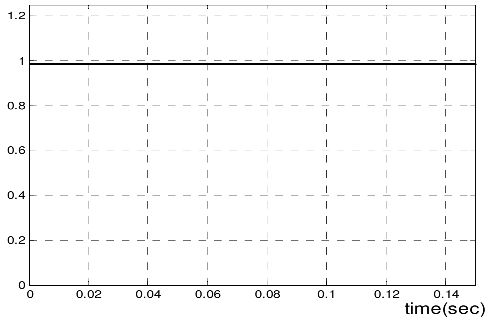

Fig. 8. Power factor.

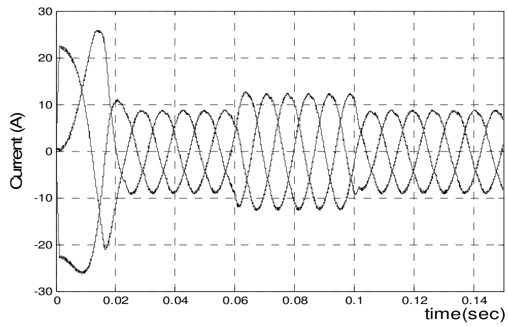

Fig.11. Stator currents.

To confirm the effectiveness of the proposed control, a step load torque has been applied between 0,06s and 0,1s (from 5 Nm to 7 Nm). Fig.9 shows that the line current is approximately sinusoidal. The rapid change of the line current shows that the system has a very good dynamic response to load variation. The reactive power is not affected by this external disturbance and input real power peaks are observed with a sign depending on the increasing or decreasing of step load torque (see Fig.10). The stator currents are represented by Fig.11, after starting phase and the variation test of the load torque (between 0.06s and 0.1s from 5 Nm to 7 Nm), the machine current save the sinusoidal form.

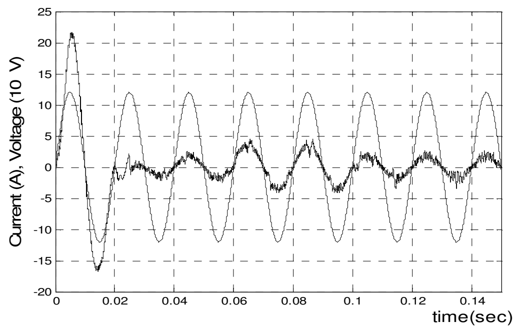

Fig. 9. Line voltage and supply current.

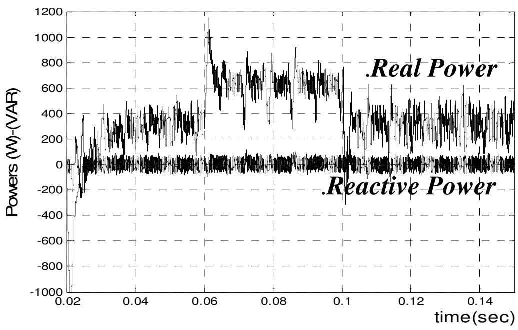

Fig. 10. Input real and reactive powers.

5.2 Reference voltage change

In Fig.12, a double change of the reference is shown 240-260 and 220V. It can be noted that after the transient response, the DC voltage follows its reference, there is no overshoot and the settling time is very small.

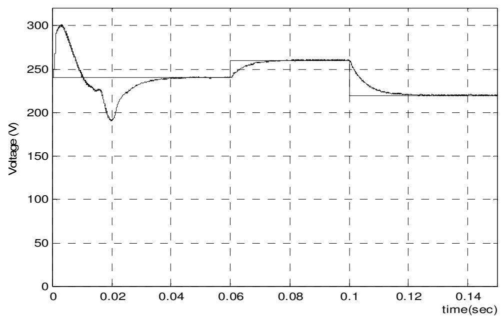

Fig. 12. DC link voltage.

6. Conclusion

In this paper, the fuzzy adaptive controller is used to minimize harmonics of side network introduced by the converter, including the control of power factor and DC-link voltage. Several tests have been performed in order to prove the efficiency of the type of the control. Simulation results confirm the validity of this control technique. An experimental study on the proposed converter system is left for future studies.

Appendix

AC source : Ueff = 147 V; *Ls* = 0.006 mH.
DC link : C = 450 μF; Vcref = 240 V.
Sampling time Ts = 0.1 ms; Δi = 0.5 A; fmax = 8.66 kHz.
Filter: $\tau 0$ =0.00025 s; $\tau 2$ =0.005 s.

Parameters of PMSM:

Pn = 1Kw; Vn = 120 V; Rs = 1.4 Ω; Lds = 6.6 mH; Lqs = 5.8 mH; Lmd = 5 mH; Lds = 5.8 mH; J = 0.00176 kg.m^2; f = 0.00038818 Nm/rd/s; np =3; Φe =0.1546 Wb**.**

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