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Predictive Control of Linear Electric Generator with Plate Mover

Pierre Kenfack[1] , Stève Ngoffe Perabi[2] , Abraham Dandoussou1 and Jean Maurice Nyobe Yome3

Abstract

The predictive control through the instantaneous powers algorithm of linear generator with plate mover was studied. This command is based on the selection of the Sabc switch configuration which allows minimizing a criterion. The value of the system voltage vector that minimizes the defined cost function J is used over the next sampling period. The several predictive control methods based on instantaneous powers is proposed, a control approach where the well-known power control is combined with a predictive selection of voltage vectors.

Keywords

Predictive control; Instantaneous powers; Voltage vector; Linear electric generator

Introduction

Predictive control (or compensation or early correction) is an advanced technique for controlling automation. The principle of this technique is to use a dynamic model of the process inside the controller in real time in order to anticipate the future behavior of the process. The predictive control theory is used in many fields of science. Although its applications in power electronics can be found, its number is still low. The advantage of predictive control is the use of the system model for the prediction of the future behaviour of the controllers variables. Predictive control includes deadbeat control, tracking control and model predictive control. Predictive control is widely recognized as a high practical control technology with high performance. It has a significant and widespread impact on industrial process control. In addition, predictive control is more a methodology than a single technique. The difference in the various methods is mainly the way the problem is translated into a mathematical formulation [1,2].

In the literature, several control strategies have been proposed for the control of electrical machines. Many algorithms are developed for predictive control. In this study predictive control using both active and reactive powers is developed. This command is combined with the choice of the voltage vector Up [3]. The applied command uses a single voltage Up vector per sampling period. The choice of the voltage vector is made by minimizing the defined cost function J. Predictive control by the instantaneous power algorithm can be performed with: (a) The frequency of fixed or constant switches; (b) The frequency of the switches varies.

In order to generate the reference signals used for the predictive control of the linear electric motor with plate mover, the instantaneous power control algorithm will be presented.

Methods

Linear electric generator description

Linear generators have been and continue to be designed considering a large variety of topologies. They are classified according to the morphology and the AC-type. Linear generators are flat or tubular. They have a long stator : the mover is shorter than the stator or a short stator : the mover is longer than the stator. The stator slots are of single layer type or double layer one. Beyond the energy efficiency, linear motor concepts exhibit the following: high velocity , high acceleration, high accuracy of the position sensing and high lifetime with less maintenance [4,5].

The fixed parts (stators) of the linear electric generator are made of a magnetic circuit in M300-35A rectangular form, in laminated sheets equipped with the slots intended for three-phase winding aluminum bars. The magnetic circuit is laminated in stacked plates cut to their thickness (of 0.5 mm). The number of stacked plates is proportional to the width of the magnetic circuit. The plate is punch-cut in a single operation from a strip of sheet metal, first insulated on both sides by a phenolic class H varnish. The plate whole profile has a circle shaped that will help stack plates for the appropriate height of the magnetic circuit to be dipped in the oven. The side of the plate bore has 36 slots intended to receive the winding bars after stacking [6].

The coil is a three-phase-series bar star. Each bar is composed of a rectangular aluminum section (7 mm × 2 mm) to ensure transverse field compensation of Roebel slot process. Bar winding have several advantages over traditional winding: good slot filling factor (greater than 90%); minimization of solid insulation and the potential difference between bars; better performance; and good thermal behavior in the slot. The difficulty in carrying out winding with more than one layer, together with the additional losses are disadvantages because it is a low-voltage winding.

Linear electric generator is protected by an aluminium cover called enclosure against ingress of moisture, dust, atmospheric impurities and any foreign materials.

The PM mover consists of a PMs made of NdFeB (54 mm × 5 mm × 3mm alternating North-South), which are magnetized in the transversal direction. The magnets are glued to a brass frame. The friction sheet is made of bronze 0.1 mm thick to ensure strength and mechanical rigidity. Anaerobic glue (polymerized in the absence of air) of acrylic type is used. The linear electric motor is a parallelepipedic structure with two air gaps (Figure 1).

***Corresponding author:** Pierre Kenfack, Department of Electrical and Power Engineering, Higher Technical Teachers' Training College (HTTTC), University of Buea, Cameroon, Tel: 677603617; E-Mail: pierrekenfack2003@yahoo.fr

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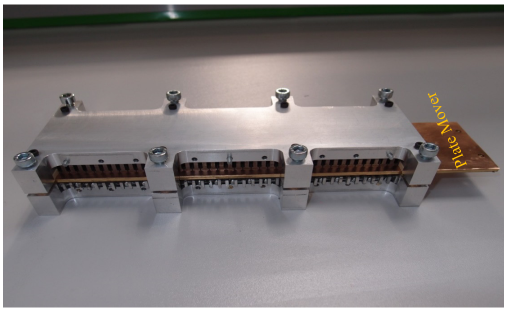

Figure 1: Linear electric generator.

Algorithm for controlling instantaneous powers

A new mathematical approach to instantaneous powers was

proposed in the early 1980s. This method is based on the measurement of three-phase instantaneous variables present on the network with or without a homopolar component. This method is valid in permanent mode as well as in transient mode.

In this control algorithm (Figure 2), the measurements of voltages and currents expressed in three-phase form (a, b, c) are converted to an equivalent two-phase (α-β) system using the Concordia transform which leaves the power unchanged[7-11].

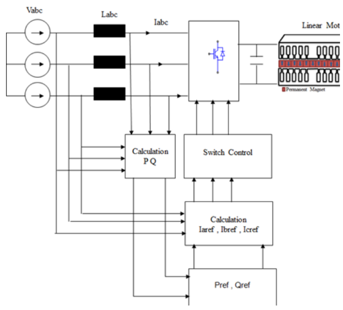

Figure 2: Control based on instantaneous powers.

$$\begin{cases} \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \\ \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \end{cases} \quad (1)$$

The instantaneous real power P and the instantaneous reactive power Q can be expressed in an equivalent way in a two-phase system by:

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (2)$$

The real and imaginary instantaneous powers are given by equation (3).

$$\begin{cases} P = v_\alpha i_\alpha + v_\beta i_\beta \\ Q = v_\alpha i_\beta - v_\beta i_\alpha \end{cases} \quad (3)$$

The real instantaneous power as well as the imaginary instantaneous power can be expressed as follows:

$$\begin{cases} P_{ref} = P + \Delta P \\ Q_{ref} = Q + \Delta Q \end{cases} \quad (4)$$

The real instantaneous power as well as the imaginary instantaneous power can be expressed as follows:

P and Q are respectively the active and reactive powers. ΔP and ΔQ are the power difference or power error (Pref- P) and (Qref- Q).

The reference currents are calculated by the following formula (5):

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} P^* \\ Q^* \end{bmatrix} \quad (5)$$

The instantaneous power method has the following characteristics: (a) It is a theory inherent in three-phase systems; (b) It can be applied to any type of three-phase systems (equilibrium or imbalance, with or without harmonics); (c) It is based on instantaneous values, which gives good dynamic response times; and (d) Simple calculation method [12-22].

The active reference power (Pref) is generated by the voltage across the linear electric generator, controlled by the capacitor. The reference reactive power is zero, the power factor is unit.

Results

Simulation data and results

Several simulations have been carried out. Instantaneous power method has been tested. The simulation parameters are listed in Table 1.

Table 1: Main data of simulation.

Quantity	Units	Value	Quantity	Units	Value
Network voltage	V	230	Frequency of switches	kHz	10
Network inductance	mH	5	Reference active power	kW	7.2
Network resistance	Ω	1	Reference reactive power	Var	0
Network frequency	Hz	50	DC-link capacitance Resistive load	μF Ω	200 50

The control method is based on the instantaneous power. In the form of powers (active and reactive), voltage and current have been measured, respectively (Figures 3-5).

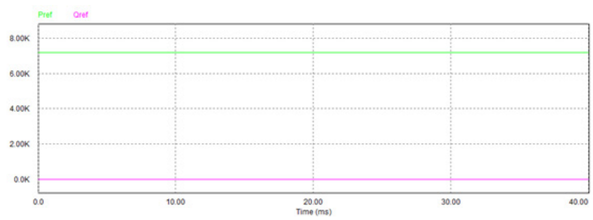

Figure 3: Active and reactive powers (P, Q).

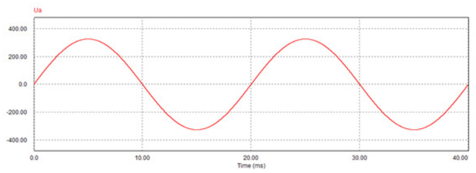

Figure 4: Phase voltage (Ua).

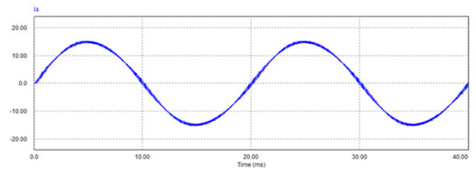

Figure 5: Phase current (Ia).

Predictive control based on instantaneous powers

-The prediction uses the mathematical model of the converter. Let us differentiate equation (3)

$$\begin{cases} \frac{dP}{dt} = v_\alpha \frac{di_\alpha}{dt} + i_\alpha \frac{dv_\alpha}{dt} + v_\beta \frac{dv_\beta}{dt} + i_\beta \frac{dv_\beta}{dt} \\ \frac{dQ}{dt} = v_\alpha \frac{di_\beta}{dt} + i_\beta \frac{dv_\alpha}{dt} - v_\beta \frac{di_\alpha}{dt} - i_\alpha \frac{dv_\beta}{dt} \end{cases} \quad (6)$$

We have:

$$\frac{dI_L}{dt} = \frac{U - U_i}{L} \quad (7)$$

The output voltage of the linear electric generator with plate mover being sinusoidal and balanced, equation (6) can be rewritten by substituting (7).

$$\begin{cases} \frac{dP}{dt} = v_\alpha \left[\frac{v_\alpha - v_{p\alpha}}{L} + \omega i_\beta\right] + v_\beta \left[\frac{v_\beta - v_{p\beta}}{L} - \omega i_\alpha\right] \\ \frac{dQ}{dt} = v_\alpha \left[\frac{v_\beta - v_{p\beta}}{L} - \omega i_\alpha\right] - v_\beta \left[\frac{v_\alpha - v_{p\alpha}}{L} + \omega i_\beta\right] \end{cases} \quad (8)$$

Let us make the following assumptions:

$$\frac{dP}{dt} = \frac{(P + \Delta P) - P}{\Delta t}; \quad P + \Delta P = P_P$$

$$\frac{dQ}{dt} = \frac{(Q + \Delta Q) - Q}{\Delta t}; \quad Q + \Delta Q = Q_P$$

Δt =Ts (sampling period)

Vpα and Vpβ: branch voltage in the Concordia landmark.

Pp and Qp are respectively the predicted active and reactive powers.

The predicted powers are calculated using the following equations (4) and (5).

$$\begin{cases} P_P = T_S \left[v_\alpha \left[\frac{v_\alpha - v_{p\alpha}}{L} + \omega i_\beta\right] + v_\beta \left[\frac{v_\beta - v_{p\beta}}{L} - \omega i_\alpha\right]\right] + P \\ Q_P = T_S \left[v_\alpha \left[\frac{v_\beta - v_{p\beta}}{L} - \omega i_\alpha\right] - v_\beta \left[\frac{v_\alpha - v_{p\alpha}}{L} + \omega i_\beta\right]\right] + Q \end{cases} \quad (9)$$

The active and reactive powers (P, Q) are calculated for the different values of the branch voltage vector Vp. The cost function that minimizes is noted J, and defined as follows:

$$J = \sqrt{(P_{ref} - P_p)^2 + (Q_{ref} - Q_p)^2} \quad (10)$$

The smallest value of the cost function J is used to select the branch voltage vector. This voltage vector is chosen for the next sampling period.

Figure 6 illustrates the steps of the instantaneous power algorithm for prediction.

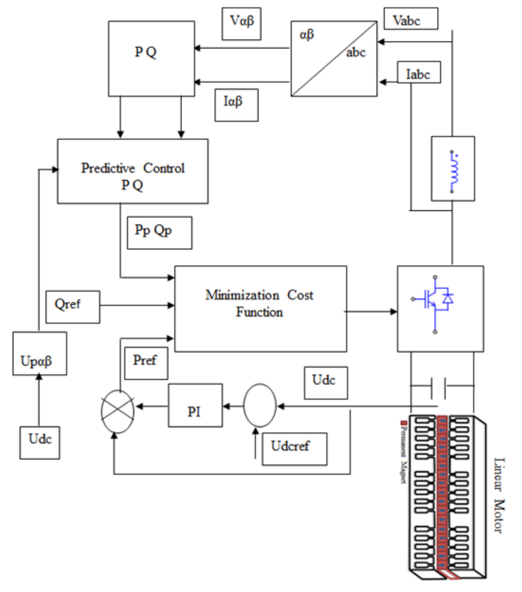

Figure 6: PInstantaneous power algorithm for prediction.

The calculations are made with the data in Table 2, the power factor being the unit (Table 2).

Table 2: Main data of calculation.

Quantity	Units	Value	Quantity	Units	Value
Vαβ δ	V o	200 45	P	W	600
iαβ δ	A o	2.82 90	Q	Var	-600
Udc	V	600	Pref	W	600
XL	Ω	6.28	Qref	Var	0
TS	μsec	50			

Table 3 shows the values of the predicted active and reactive powers Pp and Qp (Table 3).

Table 3: Predicted active and reactive powers Pp and Qp.

Quantity	Quantity	Units	Value	Quantity	Units	Value	Quantity	Units	Value
UP	PP	W	-	QP	Var	-	J	VA	-
UP0	PP0	W	909.12	QP0	Var	-590.8	J0	VA	666.8
UP1	PP1	W	484.8	QP1	Var	-1015.1	J1	VA	1021.6
UP2	PP2	W	329.5	QP2	Var	-435.5	J2	VA	512.7
UP3	PP3	W	753.8	QP3	Var	-11.3	J3	VA	154.2
UP4	PP4	W	1333.3	QP4	Var	-166.6	J4	VA	752
UP5	PP5	W	1488.6	QP5	Var	-746.1	J5	VA	1160.3
UP6	PP6	W	1064.4	QP6	Var	-1170.4	J6	VA	1259.2

The powers Pp and Qp are calculated from equation (9) for all voltage phasor vectors. The minimum value of the cost function J is shown in Table 3 in red. This vector will be considered for the next sampling period (Figures 3-6)

Conclusion

This paper has been devoted to the research of predictive control methods for instantaneous powers, which could be competitive to well-known controls as: switching table based direct power control and direct power control with space vector modular. Therefore, the paper proposes several predictive control methods based on instantaneous powers, a control approach where the well-known power control is combined with a predictive selection of voltage vectors. The switching frequency on its part can be divided into two groups: variable switching frequency and constant switching frequency.

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Author Affiliation

Top

[1]Department of Electrical and Power Engineering, Higher Technical Teachers' Training College (HTTTC), University of Buea, Kumba, Cameroon

[2]Department of Electrical Engineering and Industrial Computing, Institut Universitaire de Technologie (IUT), University of Douala, Douala, Cameroon

[3]Department of Computer Sciences, Ecole Normale Supérieure d'Enseignement Technique (ENSET), University of Douala , Douala, Cameroon

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