

POWER QUALITY IMPROVEMENT OF FUZZY BASED PREDICTIVE CONTROL APF

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Abstract: Even many techniques proposed the Modeling and designing of the PV Cell and its interface to the grid, it suffers from many controlling problems due the nonlinear characteristics of the Load. This paper presents a fuzzy logic control for controlling the dc voltage in predictive control scheme. The Four-Leg voltage source inverter is used to inject power. The inverter can thus be utilized as: 1) power converter to inject power generated from RES to the grid, and 2) shunt APF to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current. All of these functions may be accomplished either individually or simultaneously. With such a control, the combination of grid-interfacing inverter and the 3-phase 4-wire linear/non-linear unbalanced load at point of common coupling appears as balanced linear load to the grid. This new control concept is demonstrated with extensive MATLAB/Simulink simulation studies.

Keywords: Active power filter, current control, four-leg converters, predictive control.

I.INTRODUCTION

Renewable generation affects power quality due to its nonlinearity, since solar generation plants and wind power generators must be connected to the grid through high-power static PWM converters. The nonuniform nature of power generation directly

affects voltage regulation and creates voltage distortion in power systems. This new scenario in power distribution systems will require more sophisticated compensation techniques.

Although active power filters implemented with three-phase four-leg voltage-source inverters. the primary contribution of this paper is a predictive control algorithm designed and implemented specifically for this application. Traditionally, active power filters have been controlled using pretuned controllers, such as PI-type or adaptive, for the current as well as for the dc-voltage loops this is designed based on the equivalent linear model, while the predictive model uses nonlinear model that is closer to the real operating conditions. An accurate model obtained using predictive controllers improves the performance of the active power filter, especially during transient operating conditions, because it can quickly follow the current-reference signal while maintaining a constant dc-voltage.

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This paper presents the mathematical model of the 4L-VSI and the principles of operation of the proposed predictive control scheme, including the design procedure. The complete description of the selected current reference generator implemented in the active power filter is also presented. Finally, the proposed active power filter and the effectiveness of

the associated control scheme compensation are demonstrated through simulation.

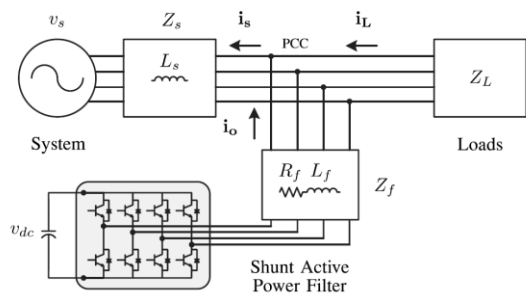


Fig.1. Three-phase equivalent circuit of the proposed shunt active power filter.

II FOUR-LEG CONVERTER MODEL

An active power filter is connected in parallel at the point of common coupling to compensate current harmonics, current unbalance, and reactive power. It is composed by an electrolytic capacitor, a four-leg PWM converter, and a first-order output ripple filter, as shown in Fig.1. This circuit considers the power system equivalent impedance Z_s , the converter output ripple filter impedance Z_f , and the load impedance Z_L .

The four-leg PWM converter topology is shown in Fig.2. This converter topology is similar to the conventional three-phase converter with the fourth leg connected to the neutral bus of the system. The fourth leg increases switching states from 8 (2^3) to 16 (2^4), improving control flexibility and output voltage quality, and is suitable for current unbalanced compensation.

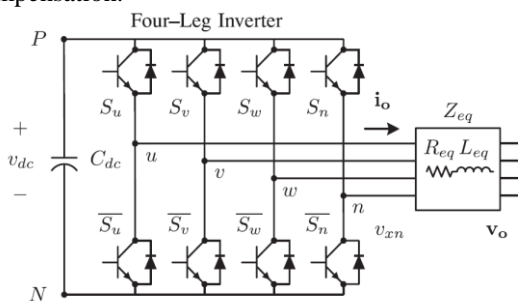


Fig.2. Two-level four-leg PWM-VSI topology.

The voltage in any leg x of the converter, measured from the neutral point (n), can be expressed in terms of switching states, as follows:

$$v_{xn} = S_x - S_n \text{ vdc}, \quad x = u, v, w, n. \quad (1)$$

The mathematical model of the filter derived from the equivalent circuit shown in Fig. 2 is

$$v_o = v_{xn} - R_{eq} i_o - L_{eq} \frac{di_o}{dt} \quad (2)$$

where R_{eq} and L_{eq} are the 4L-VSI output parameters expressed as Thevenin impedances at the converter output terminals Z_{eq} . Therefore, the Thevenin equivalent impedance is determined by a series connection of the ripple filter impedance Z_f and a parallel arrangement between the system equivalent impedance Z_s and the load impedance Z_L .

$$Z_{eq} = \frac{Z_s Z_L}{Z_s + Z_L} + Z_f = Z_s + Z_f \quad (3)$$

For this model, it is assumed that $Z_L \gg Z_s$, that the resistive part of the system's equivalent impedance is neglected, and that the series reactance is in the range of 3–7% p.u., which is an acceptable approximation of the real system. Finally, in (2) $R_{eq} = R_f$ and $L_{eq} = L_s + L_f$.

III FUZZY LOGIC CONTROLLER

Over the past few decades, the use of fuzzy set theory, or fuzzy logic, in control systems has gained widespread popularity, especially in Japan. In 1970s, Japanese scientists have been instrumental in transforming the theory of fuzzy logic into a technological realization. Today, fuzzy logic-based control systems, or simply fuzzy logic controllers (FLCs), can be found in a growing number of products, from washing machines, speedboats, air conditioner, handheld auto focus cameras etc. The inference engine is the heart of a fuzzy controller and fuzzy rules operation. Its actual operation divided in three steps as shown in fig 3.

- i) Fuzzification – actual inputs are fuzzified and fuzzy inputs are obtained.
- ii) Fuzzy processing – processing fuzzy inputs according to the rules set and producing fuzzy outputs.
- iii) Defuzzification – producing a crisp real value for a fuzzy output.

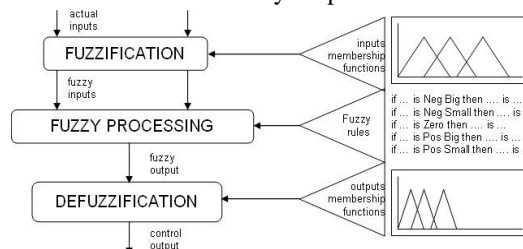


Fig.3. Operation of a Fuzzy Controller

IV DIGITAL PREDICTIVE CURRENT CONTROL

The block diagram of the proposed digital predictive current control scheme is shown in Fig.4.

This control scheme is basically an optimization algorithm and, therefore, it has to be implemented in a microprocessor. Consequently, the analysis has to be developed using discrete mathematics in order to consider additional restrictions such as time delays and approximations

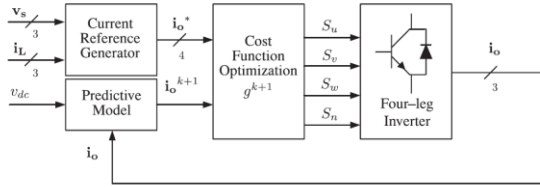


Fig.4 Proposed predictive digital current control block diagram.

The main characteristic of predictive control is the use of the system model to predict the future behavior of the variables to be controlled. The controller uses this information to select the optimum switching state that will be applied to the power converter, according to predefined optimization criteria. The predictive control algorithm is easy to implement and to understand, and it can be implemented with three main blocks, as shown in Fig.4.

1) *Current Reference Generator*: This unit is designed to generate the required current reference that is used to compensate the undesirable load current components. In this case, the system voltages, the load currents, and the dc-voltage converter are measured, while the neutral output current and neutral load current are generated directly from these signals (IV).

2) *Prediction Model*: The converter model is used to predict the output converter current. Since the controller operates in discrete time, both the controller and the system model must be represented in a discrete time domain. The discrete time model consists of a recursive matrix equation that represents this prediction system. This means that for a given sampling time T_s , knowing the converter switching states and control variables at instant kT_s , it is possible to predict the next states at any instant $[k + 1]T_s$. Due to the first-order nature of the state equations that describe the model in (1)–(2), a sufficiently accurate first-order approximation of the derivative is considered in this paper.

$$\frac{dx}{dt} \approx \frac{x[k + 1] - x[k]}{T_s} \quad (4)$$

The 16 possible output current predicted values can be obtained from (2) and (4) as

$$i_o[k + 1] = \frac{T_s}{L_{eq}} (v_{xn}[k] - v_o[k]) + \left(1 - \frac{R_{eq}T_s}{L_{eq}}\right) i_o[k] \quad (5)$$

As shown in (5), in order to predict the output current \mathbf{i}_o at the instant $(k + 1)$, the input voltage value \mathbf{v}_o and the converter output voltage v_{xN} , are required. The algorithm calculates all 16 values associated with the possible combinations that the state variables can achieve.

3) *Cost Function Optimization*: In order to select the optimal switching state that must be applied to the power converter, the 16 predicted values obtained for $\mathbf{i}_o[k + 1]$ are compared with the reference using a cost function g , as follows:

$$g[k + 1] = (i_{ou}^*[k + 1] - i_{ou}[k + 1])^2 + (i_{ov}^*[k + 1] - i_{ov}[k + 1])^2 + (i_{ow}^*[k + 1] - i_{ow}[k + 1])^2 + (i_{on}^*[k + 1] - i_{on}[k + 1])^2 \quad (6)$$

The output current (\mathbf{i}_o) is equal to the reference (\mathbf{i}_o) when $g = 0$. Therefore, the optimization goal of the cost function is to achieve a g value close to zero. The voltage vector \mathbf{v}_{xN} that minimizes the cost function is chosen and then applied at the next sampling state. During each sampling state, the switching state that generates the minimum value of g is selected from the 16 possible function values. The algorithm selects the switching state that produces this minimal value and applies it to the converter during the $k + 1$ state.

V. CURRENT REFERENCE GENERATION

A dq -based current reference generator scheme is used to obtain the active power filter current reference signals. This scheme presents a fast and accurate signal tracking capability. This characteristic avoids voltage fluctuations that deteriorate the current reference signal affecting compensation performance. The current reference signals are obtained from the corresponding load currents as shown in Fig. 5. This module calculates the reference signal currents required by the converter to compensate reactive power, current harmonic, and current imbalance.

The dq -based scheme operates in a rotating reference frame; therefore, the measured currents must be multiplied by the $\sin(\omega t)$ and $\cos(\omega t)$ signals. By using dq -transformation, the d current component is synchronized with the corresponding phase-to-neutral system voltage, and the q current component

is phase-shifted by 90 degrees. The $\sin(\omega t)$ and $\cos(\omega t)$ synchronized reference signals are obtained from a synchronous reference frame (SRF) PLL. The SRF-PLL generates a pure sinusoidal waveform even when the system voltage is severely

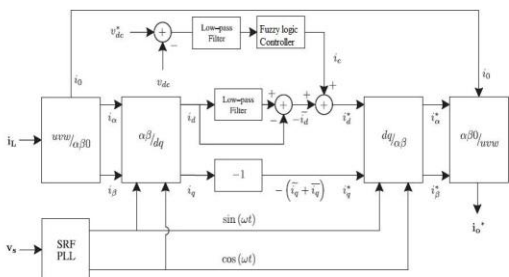


Fig.5. dq-based current reference generator block diagram.

distorted. Tracking errors are eliminated, since SRF-PLLs are designed to avoid phase voltage unbalancing, harmonics (i.e., less than 5% and 3% in fifth and seventh, respectively), and offset caused by the nonlinear load conditions and measurement errors. Equation (7) shows the relationship between the real currents $i_{Lx}(t)$ ($x = u, v, w$) and the associated dq components (i_d and i_q)

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin \omega t & \cos \omega t \\ -\cos \omega t & \sin \omega t \end{bmatrix} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Lu} \\ i_{Lv} \\ i_{Lw} \end{bmatrix} \quad (7)$$

A low-pass filter (LFP) extracts the dc component of the phase currents i_d to generate the harmonic reference components $-\tilde{i}_d$. The reactive reference components of the phase-currents are obtained by phase-shifting the corresponding ac and dc components of i_q by 180° . In order to keep the dc-voltage constant, the amplitude of the converter reference current must be modified by adding an active power reference signal i_e with the d -component, as will be explained in Section IV-A. The resulting signals i_d^* and i_q^* are transformed back to a three-phase system by applying the inverse Park and Clark transformation, as shown in (8). The cutoff frequency of the LPF used in this paper is 20 Hz

$$\begin{bmatrix} i_{ou}^* \\ i_{ov}^* \\ i_{ow}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sin \omega t & -\cos \omega t \\ 0 & \cos \omega t & \sin \omega t \end{bmatrix} \begin{bmatrix} i_o \\ i_d^* \\ i_q^* \end{bmatrix} \quad (8)$$

The current that flows through the neutral of the load is compensated by injecting the same instantaneous value obtained from the phase-currents, phase-shifted by 180° , as shown next $i_{on}^* = -(i_{Lu} + i_{Lv} + i_{Lw})$ (10)

A. DC-Voltage Control

The dc-voltage converter is controlled with a Fuzzy logic controller. This is an important issue in the evaluation, since the cost function (6) is designed using only current references, in order to avoid the use of weighting factors. Generally, these weighting factors are obtained experimentally, and they are not well defined when different operating conditions are required. Additionally, the slow dynamic response of the voltage across the electrolytic capacitor does not affect the current transient response.

VI.SIMULATIONS AND EXPERIMENTAL RESULTS

TABLE I
SIMULATION PARAMETERS

Parameter	value
Source voltage	415V
System frequency	50Hz
dc-voltage	800V
dc capacitor	10000[μF]
L_f	1mH

A simulation model for the three-phase four-leg PWM converter with the parameters shown in Table I has been developed using MATLAB-Simulink. The objective is to verify the current harmonic compensation effectiveness of the proposed control scheme under different operating conditions. A six-pulse rectifier was used as a nonlinear load.

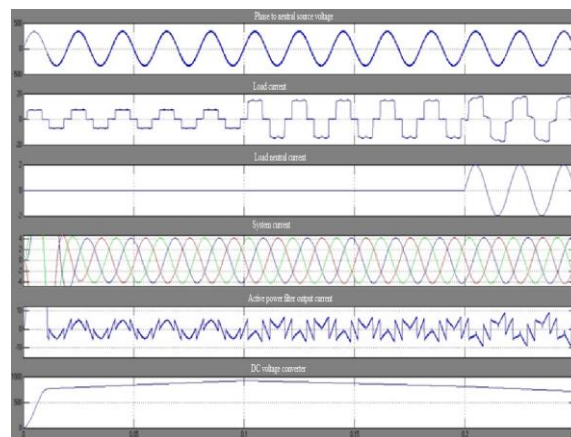


Fig. 5. Simulated waveforms of the proposed control scheme. (a) Phase to neutral source voltage. (b) Load Current. (c) Load neutral current. (d) System currents. (e) Active power filter output current (f) DC voltage converter.

TABLE II
SIMULATION RESULT

	%THD
Compensation with PI controller	2.52
Compensation with Fuzzy logic controller	0.42

VII.CONCLUSION

Improved dynamic current harmonics and a reactive power compensation scheme for power distribution systems with generation from renewable sources has been proposed to improve the current quality of the distribution system. Advantages of the proposed scheme are related to its simplicity, modelling, and implementation. The use of a predictive control algorithm for the converter current loop proved to be an effective solution for active power filter applications, improving current tracking capability, and transient response. Simulated results have proved that the proposed predictive control algorithm using fuzzy logic controller is a good alternative to classical linear control methods. The predictive current control algorithm is a stable and robust solution. Simulated results have shown the compensation effectiveness of the proposed active power filter.

VIII.REFERENCES

- [1] M. Aredes, J. Hafner, and K. Heumann, "Three-phase four-wire shunt active filter control strategies," *IEEE Trans. Power Electron.*, vol. 12, no. 2, pp. 311–318, Mar. 1997.
- [2] N. Prabhakar and M. Mishra, "Dynamic hysteresis current control to minimize switching for three-phase four-leg VSI topology to compensate nonlinear load," *IEEE Trans. Power Electron.*, vol. 25, no. 8, pp. 1935–1942, Aug. 2010.
- [3] X.Wei, "Study on digital pi control of current loop in active power filter," in *Proc. 2010 Int. Conf. Electr. Control Eng.*, Jun. 2010, pp. 4287–4290.
- [4] J. Rodriguez, J. Pontt, C. Silva, P. Correa, P. Lezana, P. Cortes, and U. Ammann, "Predictive current control of a voltage source inverter," *IEEE Trans. Ind. Electron.*, vol. 54, no. 1, pp. 495–503, Feb. 2007.