Active Power Filter for Renewable Power Generation Systems Presence of Non-Linear Loads

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Abstract: ***The performance analysis of four-leg voltage-source inverter using a Fuzzy logic control scheme is presented. The use of a four-leg voltage-source inverter allows the reduction of current harmonic components, as well as unbalanced/Negative sequence currents generated by single-phase nonlinear loads. It compares THD analysis at predictive current control and fuzzy logic control. The compensation performance of the proposed active power filters.***

Keywords: Active power filter, Current control, Predictive control, Four-leg converters.

1. Introduction

DG's affects power quality due to its nonlinearity. The non-uniform nature of power generation directly affects voltage regulation and creates volt-age 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 (4L-VSI) have already been presented in technical literature [2]–[6], the primary contribution of this paper is Fuzzy logic controller designed and implemented specifically for this application. Traditionally, active power filters have been controlled using a predictive control technique, such as PI-type or adaptive, for the current as well as for the dc-voltage loops. Fuzzy controllers use the non-linear model, which is closer to real operating conditions compare to predictive control. An accurate model obtained using fuzzy controller 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.

2. Four-Leg Converter Model

Both types of power generation use AC/AC and DC/AC static PWM converters for voltage conversion and battery banks for long-term energy storage. These converters perform maximum power point tracking to extract the maximum energy possible from wind and sun. The electrical energy consumption behaviour is random and unpredictable.

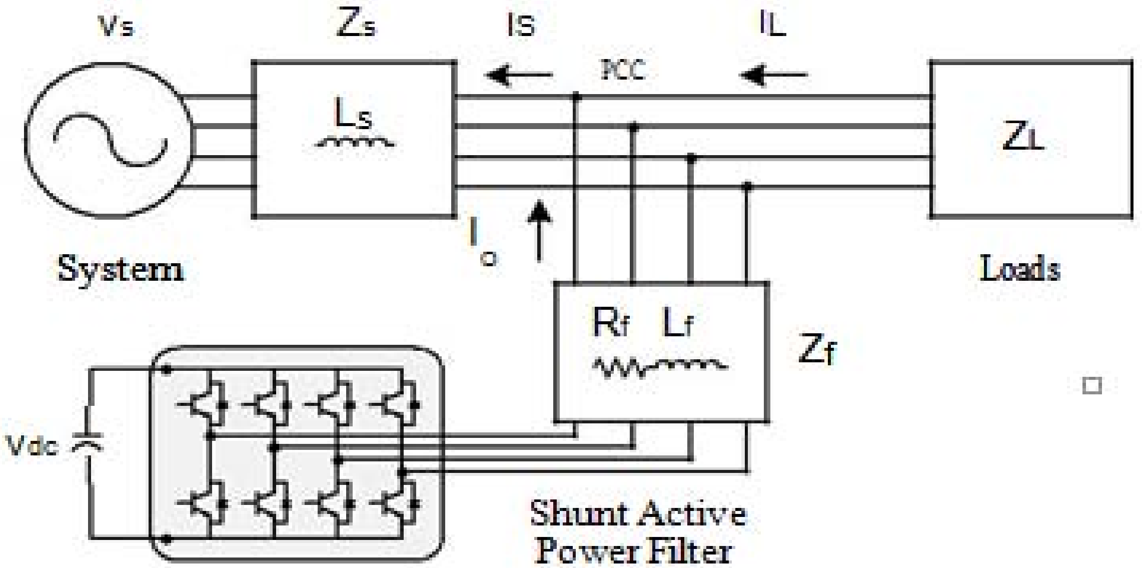


Figure 1: Three-phase equivalent circuit

Fig1. Three-phase equivalent circuit of the proposed shunt active power filter. The voltage in any leg x of the converter, measured from the negative point of the dc-voltage (N), can be expressed in terms of switching states, as follows

$$v_{xN} = S_x v_{dc}, \quad x = u,\ v,\ w,\ n. \tag{1}$$

equivalent circuit shown in fig 1 is,

$$\mathbf{v_o} = v_{xN} - R_{eq}\,\mathbf{i_o} - L_{eq}\frac{d\,\mathbf{i_o}}{dt}, \tag{2}$$

It is composed by an electrolytic capacitor, a four-leg PWM converter, and a first-order output ripple filter, as shown in Fig.1.

3. Predictive Current Control

The block diagram of the proposed digital predictive current control scheme is shown in Fig. 2.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 tim delays and approximations. The main characteristic of predictive control is the use of the system model to predict the future behaviour of the variables to be controlled.

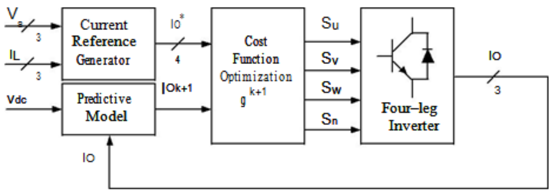


Figure 2: Proposed predictive current control block diagram

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 (V).

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 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
$[k + 1]T_s$.

$$\mathbf{i_o}[k+1] = \frac{T_s}{L_{eq}}\left(v_{xN}[k] - \mathbf{v_o}[k]\right) + \left(1 - \frac{R_{eq}T_s}{L_{eq}}\right)\mathbf{i_o}[k].$$

in order to predict the output current io at the instant (k+1), the input voltage value vo and the converter output voltage vxN, are required. The algorithm calculates all 16 values associated with the possible combinations that the state variables can achieve.

2) Cost Function Optimization: In order to select the optimal switching state that must be applied to the power converter, the predicted values obtained for io[k + 1] are compared with the reference using a cost function

$$\begin{aligned} g[k+1] = {} & (i^*_{ou}[k+1] - i_{ou}[k+1])^2 \\ & + (i^*_{ov}[k+1] - i_{ov}[k+1])^2 \\ & + (i^*_{ow}[k+1] - i_{ow}[k+1])^2 \\ & + (i^*_{on}[k+1] - i_{on}[k+1])^2 \end{aligned}$$

4. Current Reference Generator

A dq-based current reference generator scheme is used to obtain the active power filter current reference signals. The scheme presents a fast and accurate signal tracking capability. The dq-based scheme operates in a rotating reference frame; therefore, the measured currents must be multiplied by the sin(wt) and cos(wt) 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°. The sin(wt) and cos(wt) synchronized reference signals are obtained from a Synchronous Reference Frame (SRF) PLL.

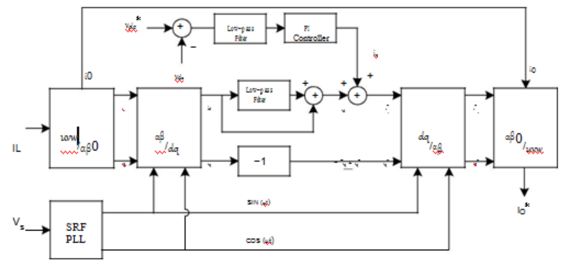


Figure 3: dq-based Current Reference Generator Block Diagram

V DC-voltage Control

The dc-voltage converter is controlled with a traditional PI controller.

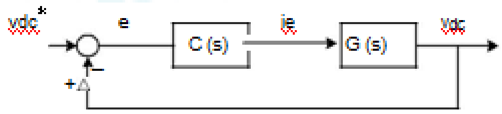


Figure 4: DC-voltage control block diagram.

$$\begin{bmatrix} u_\propto \\ u_\beta \\ u_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}$$

For converting $\boldsymbol{\alpha\beta}0$ to abc by using inverse clark's transformation.

5. Classification Based on Fuzzy Logic Method

Now we have to extend the above paper by using the fuzzy rules and in the below I have detail wrote the rules and we have to absorb the corresponding current output waveforms and waveform for the THD calculation

Fuzzy rules

Rule. No	*Error(e)*	*Change in error(Δe)*	*Output*
1	NB	NB	NB
2	NB	NM	NB
3	NB	NS	NB
4	NB	ZE	NB
5	NB	PS	NM
6	NB	PM	NS
7	NB	PB	ZE
8	NM	NB	NB
9	NM	NM	NB

10	NM	NS	NB
11	NM	ZE	NM
12	NM	PS	NS
13	NM	PM	ZE
14	NM	PB	PS
15	NS	NB	NB
16	NS	NM	NM
17	NS	NS	NS
18	NS	ZE	NS
19	NS	PS	ZE
20	NS	PM	PS
21	NS	PB	PM
22	ZE	NB	NB
23	ZE	NM	NM
24	ZE	NS	NS
25	ZE	ZE	ZE
26	ZE	PS	PS
27	ZE	PM	PM
28	ZE	PB	PB
29	PS	NB	NM
30	PS	NM	NS
31	PS	NS	ZE
32	PS	ZE	PS
33	PS	PS	PS
34	PS	PB	PB
35	PS	PM	PM
36	PM	NB	NS
37	PM	NM	ZE
38	PM	NS	PS
39	PM	ZE	PM
40	PM	PS	PM
41	PM	PM	PB
42	PM	PB	PB
43	PB	NB	ZE
44	PB	NM	PS
45	PB	NS	PM
46	PB	ZE	PB
47	PB	PS	PB
48	PB	PM	PB
49	PB	PB	PB

6. Results

The Grid Voltage, Grid Current, Load current and inverter current.

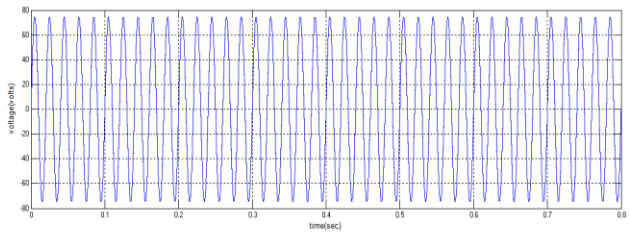


Figure A

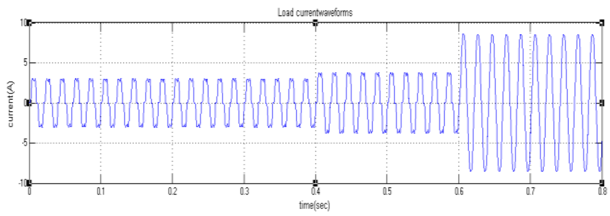


Figure B

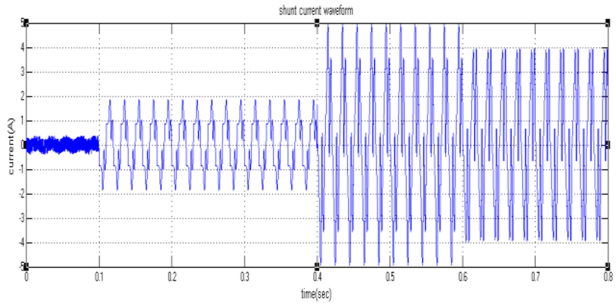


Figure C

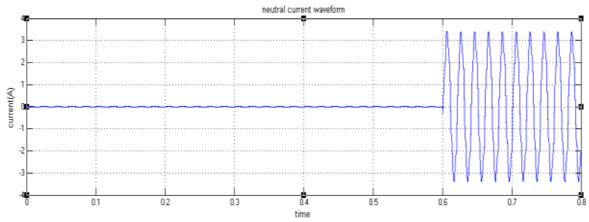


Figure D

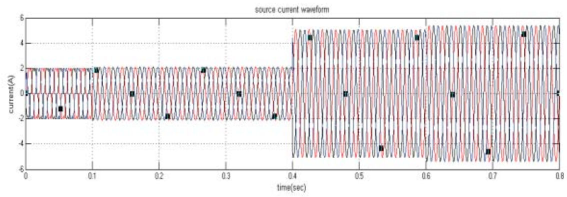


Figure E

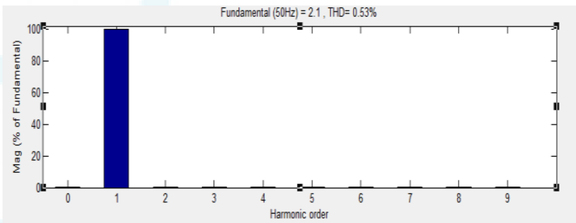


Figure F

Figure: Simulated waveforms of the Predictive control scheme. (a) Phase to neutral source voltage. (b) Load Current. (c) Active power filter output current. (d) Load neutral current. (e) System neutral current (f) THD analysis of Is at predictive control method

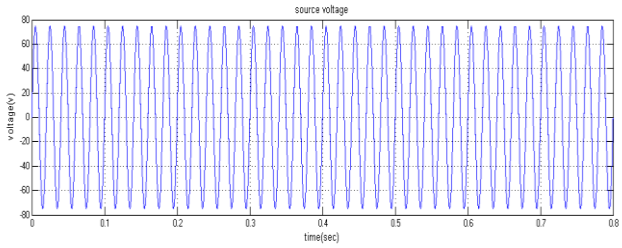
A Six pulse rectifier was selected as a non-linear load in order to verify the effectiveness of the current harmonic compensation. A step load change was applied to evaluate the stability of the dc-voltage. Finally, an unbalanced load was used to validate the performance of the neutral current compensation.

Table I
SPECIFICATION PARAMETERS

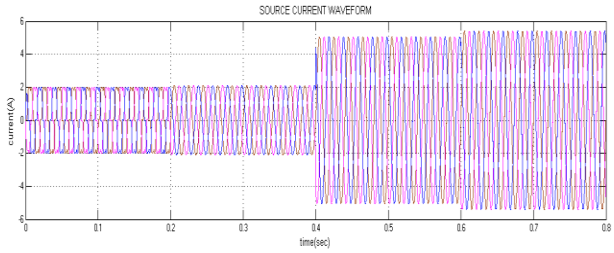
Variable	Description	Value [a]
v_s	Source voltage	55 $[V]$
f	System frequency	50 $[Hz]$
v_{dc}	dc-voltage	162 $[V]$
C_{dc}	dc capacitor	2200 $[\mu F]$ (2.0 pu)
L_f	Filter inductor	5.0 $[mH]$ (0.5 pu)
R_f	Internal resistance within L_f	0.6 $[\Omega]$
T_s	Sampling time	20 $[\mu s]$
T_e	Execution time	16 $[\mu s]$

[a] Note: V_{base} = 55 V and S_{base} = 1 kVA.

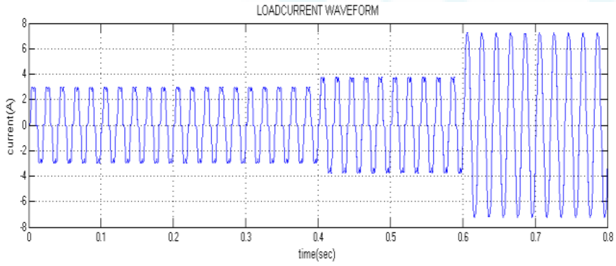
System response for fuzzy controller



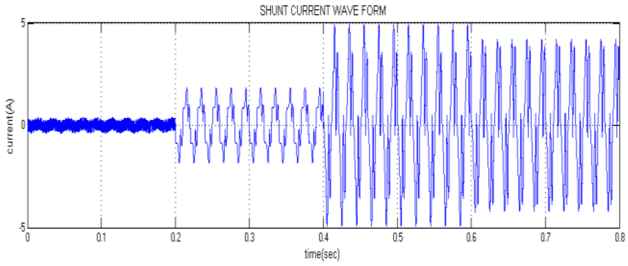
(a)



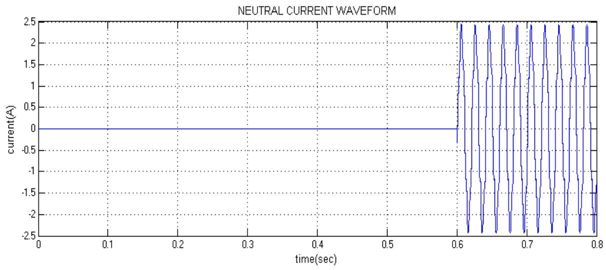
(b)



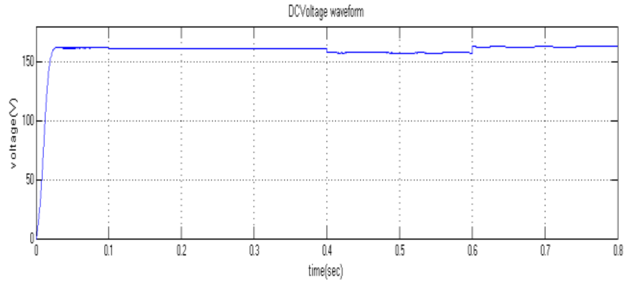
(c)



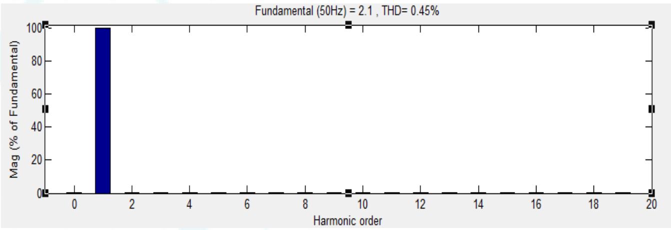
(d)



(e)



(f)



(g)

Figure: Simulated waveforms of the proposed (Fuzzy) control scheme. (a) Phase to neutral source voltage. (b) Source current. (c) Load current (d) Active power filter output current. (e) Load neutral current. (f) System neutral current. (g) THD analysis of Is at Fuzzy control method.

7. 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, modeling and implementation. The use of a Fuzzy logic controller 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 Fuzzy control method is a good alternative to classical linear control methods. Simulated results have shown the compensation effectiveness of the proposed active power filter.

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Author Profile

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