Source Current Harmonics Reduction with Intelligent controlled Multiple RES based SAPF

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Abstract:
Now a day’s due to increase in the power demand, generation has to be increased. Due to which the fossil fuels are using out which creates the pollution too. Hence we are using the Renewable energy sources which neither creates pollution problems nor energy conservation problems. Renewable energy resources (RES) are being increasingly connected in distribution systems utilizing power electronic converters. In recent years, the number and variety of applications of Hybrid Fuzzy Logic (HFL) have increased significantly. Among the Renewable energy resources most abundantly available throughout the earth is Sun radiation. This paper presents a novel control strategy for achieving maximum benefits from these grid-interfacing inverters when installed in 3-phase 4-wire distribution systems. The inverter is controlled to perform as a multi-function device by incorporating active power filter functionality. 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. This new intelligent (HFLC) controller based concept is demonstrated with extensive MATLAB/Simulink simulation studies.

Keywords: Hybrid FLC; Active power filter; current control; four-leg converters; predictive control.

I. INTRODUCTION
Electric utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. Seventy five percent of total global energy demand is supplied by the burning of fossil fuels. But increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it necessary to look towards renewable sources as a future energy solution. Since the past decade, there has been an enormous interest in many countries on renewable energy for power generation. The market liberalization and government’s incentives have further accelerated the renewable energy sector growth. Renewable energy source (RES) integrated at distribution level is termed as distributed generation (DG). The utility is concerned due to the high penetration level of intermittent RES in distribution systems as it may pose a threat to network in terms of stability, voltage regulation and power-quality (PQ) issues. Therefore, the DG systems are required to comply with strict technical and regulatory frameworks to ensure safe, reliable and efficient operation of overall network. With the advancement in power electronics and digital control technology, the DG systems can now be actively controlled to enhance the system operation with improved PQ at PCC. However, the extensive use of power electronics based equipment and non-linear loads at PCC generate
harmonic currents, which may deteriorate the quality of power [1], [2]. Generally, current controlled voltage source inverters are used to interface the intermittent RES in distributed system. Recently, a few control strategies for grid connected inverters incorporating PQ solution have been proposed. In [3] an inverter operates as active inductor at a certain frequency to absorb the harmonic current. But the exact calculation of network inductance in real-time is difficult and may deteriorate the control performance. A similar approach in which a shunt active filter acts as active conductance to damp out the harmonics in distribution network is proposed in [4]. In [5], a control strategy for renewable interfacing inverter based on – theory is proposed. In this strategy both load and inverter current sensing is required to compensate the load current harmonics.

The non-linear load current harmonics may result in voltage harmonics and can create a serious PQ problem in the power system network. Active power filters (APF) are extensively used to compensate the load current harmonics and load unbalance at distribution level. This results in an additional hardware cost. However, in this paper authors have incorporated the features of APF in the, conventional inverter interfacing renewable with the grid, without any additional hardware cost. Here, the main idea is the maximum utilization of inverter rating which is most of the time underutilized due to intermittent nature of RES. It is shown in this paper that the grid-interfacing inverter can effectively be utilized to perform following important functions: 1) transfer of active power harvested from the renewable resources (wind, solar, etc.); 2) load reactive power demand support; 3) current harmonics compensation at PCC; and 4) current unbalance and neutral current compensation in case of 3-phase 4-wire system.

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 and validated with experimental results obtained in a 2 kVA system.

II. FOUR-LEG CONVERTER MODEL

Figure 1 shows the configuration of a typical power distribution system with renewable power generation. It consists of various types of power generation units and different types of loads. Renewable sources, such as wind and sunlight, are typically used to generate electricity for residential users and small industries. 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 behavior is random and unpredictable, and therefore, it may be single- or three-phase, balanced or unbalanced, and linear or nonlinear. 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 Figure 2. This circuit considers the power system equivalent impedance Zs, the converter output ripple filter impedance Zf, and the load impedance ZL.
The four-leg PWM converter topology is shown in Figure 3. 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.

![Figure 3: Two-level four-leg PWM-VSI topology.](image)

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:

$$v_{xR} = S_x - S_n \ v_d, \quad x = u, v, w, n.$$  

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

$$v_o = v_{2n} - R_{eq} \ i_0 - L_{eq} \ \frac{di_0}{dt}$$

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 $Z_L$.

$$Z_{eq} = \frac{Z_s \ Z_f}{Z_s + Z_f} + Z_f \approx Z_s + Z_f.$$  

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)

$$R_{eq} = R_f \text{ and } L_{eq} = L_s + L_f.$$  

### III. DIGITAL PREDICTIVE CURRENT CONTROL

The block diagram of the proposed digital predictive current control scheme is shown in Figure 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.
generates a pure sinusoidal waveform even when the system voltage is severely 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 (8) shows the relationship between the real currents iLx(t) (x=u,v,w) and the associated dq components (id and iq)

\[
\begin{bmatrix}
  i_d \\
  i_q
\end{bmatrix} = \frac{2}{3} \begin{bmatrix}
  \sin \omega t & \cos \omega t \\
  -\cos \omega t & \sin \omega t
\end{bmatrix} \begin{bmatrix}
  \frac{1}{3} & -\frac{1}{2} & -\frac{1}{2} \\
  \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} & 0
\end{bmatrix} \begin{bmatrix}
  i_{L1} \\
  i_{L2} \\
  i_{L3}
\end{bmatrix}.
\]

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

\[
i_{0n}^* = -\left( i_{L1} + i_{L2} + i_{L3} \right).
\]

One of the major advantages of the dq-based current reference generator scheme is that it allows the implementation of a linear controller in the dc-voltage control loop. However, one important disadvantage of the dq-based current reference frame algorithm used to generate the current reference is that a second order harmonic component is generated in id and iq under unbalanced operating conditions. The amplitude of this harmonic depends on the percent of unbalanced load current (expressed as the relationship between the negative sequence current iL,2 and the positive sequence current iL,1). The second-order harmonic cannot be removed from id and iq, and therefore generates a third harmonic in the reference current when it is converted back to abc frame. Figure 6 shows the percent of system current imbalance and the percent of third harmonic system current, in function of the percent of load current imbalance. Since the load current does not have a third harmonic, the one generated by the active power filter flows to the power system.

The dc-voltage converter is controlled with a traditional PI 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. For this reason, the PI controller represents a simple and effective alternative for the dc-voltage control. The dc-voltage remains constant (with a minimum value of \( \sqrt{6} \) vs (rms)) until the active power absorbed by the converter decreases to a level where it is unable to compensate for its losses.

V. INTRODUCTION TO INTELLIGENT CONTROLLER

A new language was developed to describe the intelligent properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. PI with Fuzzy set theory has been widely used in the control area with some application to dc-to-dc converter system. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of dc-to-dc converters. The basic scheme of a fuzzy logic controller is shown in Figure 5 and consists of four principal components such as: a fuzzy fication interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

![Figure 6: DC-voltage control block diagram.](image)

![Figure 7: General Structure of the Fuzzy Logic Controller on Closed-Loop System.](image)
The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10]. Simulation is performed in buck converter to verify the proposed fuzzy logic controllers.

A. Fuzzy Logic Membership Functions
The dc-dc converter is a nonlinear function of the duty cycle because of the small signal model and its control method was applied to the control of boost converters. Fuzzy controllers do not require an exact mathematical model. Instead, they are designed based on general knowledge of the plant. Fuzzy controllers are designed to adapt to varying operating points. Fuzzy Logic Controller is designed to control the output of boost dc-dc converter using Mamdani style fuzzy inference system. Two input variables, error (e) and change of error (de) are used in this fuzzy logic system. The single output variable (u) is duty cycle of PWM output.

B. Fuzzy Logic Rules
The objective of this dissertation is to control the output voltage of the boost converter. The error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided into five groups; NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big and its parameter [10]. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table II as per below:

<table>
<thead>
<tr>
<th>Error (e)</th>
<th>NB</th>
<th>NS</th>
<th>ZO</th>
<th>PS</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC-DC Converter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NB</td>
<td>NB</td>
<td>NB</td>
<td>ZO</td>
<td>NS</td>
<td>ZO</td>
</tr>
<tr>
<td>NS</td>
<td>NB</td>
<td>NB</td>
<td>NS</td>
<td>ZO</td>
<td>PS</td>
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<td>ZO</td>
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<tr>
<td>PB</td>
<td>ZO</td>
<td>PS</td>
<td>PB</td>
<td>PB</td>
<td>PB</td>
</tr>
</tbody>
</table>

VI. SIMULATION RESULTS

Case 1: Predictive control Scheme for 4-Leg APF

Figure 12: Shows The MATLAB/SIMULINK Model Of Predictive Control Scheme For Fuzzy Controller.

Figure 13: Simulated waveforms of the proposed control scheme (a) Phase to neutral source voltage (b) Load Current (c) Load neutral current. (d) Three phase source current. (e) Compensating currents. (f) DC voltage converter.
Figure 14: Simulated waveforms of single phase source load compensating currents.

Figure 15: Simulated waveforms of 3-phase source load current neutral line current compensating current source voltage.

Figure 16: Shows the Power factor.

Figure 17: Shows The Total Harmonic Distortion 29.98%.

Case 2: Intelligent controller based APF

Figure 18: Matlab/simulink model of fuzzy controller based APF.

Figure 19: Shows the source current Power factor with fuzzy controller.

Figure 20: Simulated waveforms of the proposed intelligent control scheme (a) Phase to neutral source voltage (b) Load Current. (c) Compensating currents (d) Load neutral current. (e) Source neutral current (f) Three phase source current. (f) Constant DC voltage converter.
VII. CONCLUSION

In this concept fuzzy controlled active power filter for renewable energy source is 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. PI is replaced with the fuzzy controller to perform the speed operation of the converter. Advantages of the proposed scheme are related to its simplicity, modeling, and implementation. The use of a predictive control for the converter current loop proved to be an effective solution for active power filter applications. Finally this concept proposed the intelligent controller is better controller compare to the PI controller is obtained by the simulation results.

REFERENCES


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