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Output LC Filter Design for the PWM Inverters

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Abstract
Inverters are widely used in almost every aspect of life. These devices are implemented on pulse width modulation with a significant frequency to produce the desired voltage form. Inverters are used in power converters, such as variable speed drive systems, Dynamic Voltage Restorers (DVRs) or UPSs, etc. The LC filter is an essential component in inverters. It helps that the output voltage remains the desired fundamental element and eliminates the converter's high-order harmonic feature. This research proposes a method to estimate the current through the capacitor of an LC filter from which it can be accurately determined to control.

Keywords: LC Filter, Neural Network, Estimate

1. Introduction

A passive filter is used to retain the selected fundamental harmonic component. In [1-6], the method analyzed and proposed the filter configurations to improve voltage quality, including losses and harmonics. The control strategy for stand-alone inverters used for USP [7-9] or grid-connected inverters [10-13] is mainly based on the principle of inductive current control. After filtering, the output voltage is different from the voltage at the output of the converter because the LC filter is a second-order element of the form. The difficulty in implementing this solution is that the harmonic component in the capacitor current is quite large compared to the fundamental current. The use of low-pass filters causes phase delay and is therefore of little use. Several solutions to improve the efficiency of low-pass filters described in [14-19] have proven effective. The paper proposes a method to estimate the current value through the capacitor i_c with the input is the reference voltage applied to the inverter and the error calculated based on the output of the voltage across the capacitor.

2. Mathematical Model

The basic structure of a single-phase inverter with an output LC filter is shown in Fig 1.

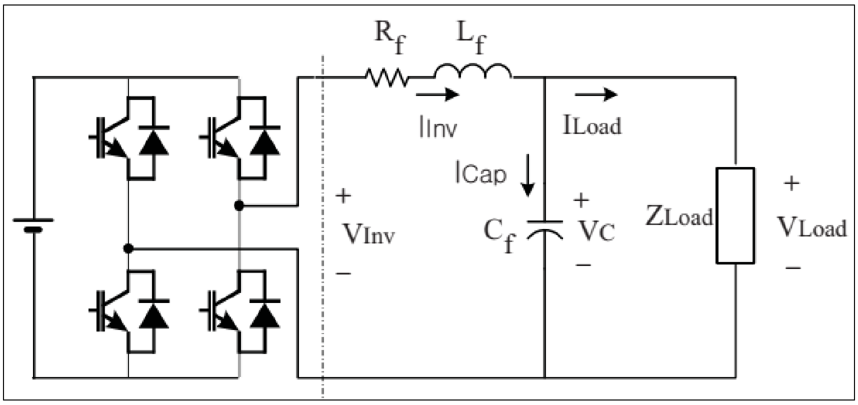

Fig 1: Principle diagram of single-phase inverter with output LC filter

The relationship between the input and the output is described as follows:

$$\begin{cases} u_{out} = u_{inv} - u_L = u_{inv} - L\frac{di_L}{dt} \\ I_L = I_{out} + I_c \end{cases} \quad (1)$$

From (1), it is easy to see the dependence of the output voltage u_{out} on the output current, which causes difficulties in control problems in dynamic mode (i.e., variable load current). Therefore, the output voltage control of the filter is to control the voltage across the capacitor C is an efficient solution. Controlling the output voltage can be accomplished by rapidly controlling the current through the capacitor without regard to the load current.

$$U_{out} = U_C = \frac{1}{C}\int i_C dt \quad (2)$$

3. Estimating Model

A proposed neural network structure is given. The input is a vector of known variables, and the output is a vector of the values to be estimated.

The input vector of the network is

$$X = [x_1 \quad x_2 \quad \cdots\cdots \quad x_{N_x}]^T \in (N_x \times 1) \quad (3)$$

The output of the network

$$\hat{y} = w_1^{(2)}a_1 + w_2^{(2)}a_2 + \ldots + w_{N_1}^{(2)}a_{N_1} + b^{(2)}$$

$$\hat{y} = \begin{bmatrix} w_1^{(2)} & w_2^{(2)} & \ldots & w_{N_1}^{(2)} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \ldots \\ a_{N_1} \end{bmatrix} + b^{(2)} \quad (4)$$

The weight update rules of the network are presented in (5) and (6)

$$w_{c_{ij}}^{(1)}(k+1) = w_{c_{ij}}^{(1)}(k) - l_c \frac{\partial L_c(k)}{\partial w_{c_{ij}}^{(1)}(k)} \quad (5)$$

$$b_{c_{ij}}^{(1)}(k+1) = b_{c_{ij}}^{(1)}(k) - l_c \frac{\partial L_c(k)}{\partial b_{c_{ij}}^{(1)}(k)} \quad (6)$$

Where

$$\frac{\partial L_c}{\partial w_{c_{ij}}^{(1)}} = e_c w_i^{(2)} x_j \left(1 - \sigma_i^2\left(\sum_{l=1}^{N_x}\left(w_{c_{ij}}^{(1)} x_l\right) + b_{c_i}^{(1)}\right)\right)$$

$$\frac{\partial L_c}{\partial b_{c_i}^{(1)}} = e_c \times w_{c_i}^{(2)}\left(1 - \sigma_i^2\left(\sum_{l=1}^{N_x}\left(w_{c_{il}}^{(1)} x_l\right) + b_{c_i}^{(1)}\right)\right)$$

The equation that describes the LC filter is rewritten as the following:

$$u_{inv} = u_L + u_C \quad (7)$$

Where:

$$u_L = L\frac{di_L}{dt} \quad (8)$$

$$u_c = \frac{1}{C}\int i_c dt \quad (9)$$

From (7) and (8) we have:

$$u_C = u_L - u_{inv} = L\frac{di_L}{dt} - u_{inv} \quad (10)$$

$$i_o = i_L - i_c \Leftrightarrow i_L = i_o + i_c \quad (11)$$

The value $u_C = f(u_{inv}, i_o)$ is a function of the u_L and i_o values. Therefore, the i_c current will be calculated by derivation of the network output estimated value as follows

$$\hat{i}_c = C\frac{d\hat{u}_c}{dt} \quad (12)$$

4. Numerical Simulation

The estimated results are compared with the equivalent current generated by the ideal voltage source replacing the inverter

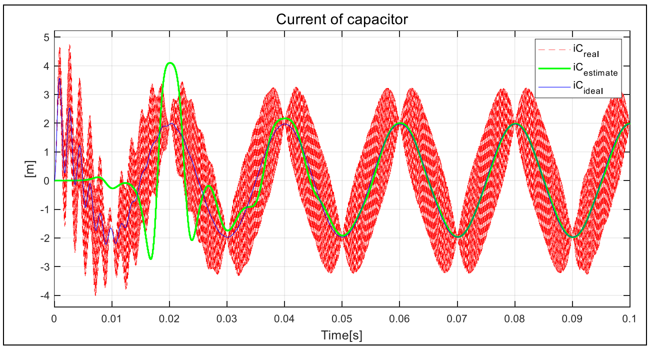

Fig 2: The current through the capacitor C

The current i_c is calculated as the product of the capacitor value with the voltage derivative across the capacitor in Fig 2. shows the ability to accurately approximate the i_c current without the phase delay that often occurs in conventional filter. Therefore, this estimator is suitable for voltage regulators for other control problems.

5. Conclusion

The simulation results have proved the effectiveness of the implemented process. The learning time required for the neural network to approximate the model is three cycles of grid voltage. The learning coefficient l_c will determine the learning speed of the network. The larger the learning coefficient, the faster the learning speed. However, if the learning coefficient is too large, it can cause the network to be unstable. These filters are designed in the same way so that the estimated value is not out of phase with the actual value.

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