Application of BP Neural Network in Power Grid Inverter Control

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Abstract

In the new energy power generation operation, grid-connected inverter is an important part of the power transmission grid. At the same time, due to the nonlinear and time-varying uncertainty of the system, it is difficult to establish the mathematical model of the system, and the traditional control method is sometimes ineffective or even ineffective. However, the neural network control strategy does not need to establish an accurate mathematical model, it has strong ability to approach nonlinearity and to control effectively nonlinear and uncertain systems. In this work, to reduce the harmonic current caused by the switching frequency, a hybrid filter is introduced into the grid-connected inverter and a hybrid filter, the inverter's electrical model is put forward. The compound intelligent control scheme based on BP neural network PID control is proposed for the output current of grid-connected inverter. The simulation results show that the control scheme can effectively realize the stable operation of grid-connected inverter, meanwhile the harmonic content of inverter output current is low and the waveform quality is good.

Keywords: Power Grid, Inverter Control, hybrid filter, Grid-connected inverter.

1. INTRODUCTION

In recent years, with the development and utilization of wind energy, especially in the wind power generation system using variable-speed and constant-frequency generator sets, grid-connected inverters are widely used as the core devices for the connection of a motor to a power grid (Lu et al., 2013). The decrease of the switching frequency leads to the increase of the high frequency harmonic component in the output current of the inverter network side, while the power grid has a strict requirement for the harmonic content of the input current. Therefore, how to ensure the stable operation of the system, reduce the output current harmonic content and to meet the requirements of grid connection has become the focus of the study (Eltawil and Zhao, 2010).

The main characteristics of neural network control algorithm adapt to the basic requirements of the development of control theory and control engineering, and can solve the problems encountered. Therefore, neural network must be widely used in this field (Miao et al., 2012). For the uncertainty of the model parameters of the controlled system and the perturbation of the model structure itself, the learning and adaptive ability of the neural network makes it possible to simulate the change of the characteristics of the controlled object in real time. At the same time, even when the output of the controlled plant is in error with the output of the model, the fault-tolerant performance of the control system will also make the control system have some robust performance. In addition, the standard structure and simulation accuracy of neural network provide a standard framework for solving the adaptive control of nonlinear systems. Therefore, for those control problems which are hard to be realized or work by traditional control methods, neural network control technology can often be solved. Grid-connected inverter is such a system, which has its own strong nonlinear and time-varying uncertainties to make it difficult to establish accurate mathematical model of the system, the traditional control methods can not achieve the desired results. Therefore, this work explores the neural network control instead of traditional control, applied to grid connected inverter control, and analyzes its effectiveness and rationality (Chavarria et al., 2013).

2. MATHEMATIC MODEL OF GRID-CONNECTED INVERTER

The grid connected inverter converts the DC power into sinusoidal alternating current and sends it to the power grid after filtering. The grid connected inverter usually adopts the input voltage type, and the output control adopts the full bridge inverter circuit with current control mode. The frequency and phase of the grid voltage are
tracked by controlling the frequency and phase of the inductance current, and the sinusoidal output is maintained, so as to achieve the purpose of grid connected operation. In this work, the grid-connected inverter is filtered by the three-phase PWM inverter and to the grid. Among them, the passive filter circuit used to filter out the 5th, 7th harmonic, the active filter is used to suppress the passive filter circuit can not eliminate the harmonics, the output filter using LC low-pass filter to filter out the voltage Inverter high-frequency operation of switching devices generated high-frequency glitches.

To simplify the model, the voltage inverter was a voltage source. Assuming that the isolation transformer is an ideal transformer, the voltage conversion ratio is 1: n, and the voltage inverter and output filter are converted to the isolation transformer network side. According to Kirchhoff's current and voltage theorem, there are (Park et al., 2014):

$$\begin{align*}
U_s &= U_L + I_s * Z_s \\
I_s &= I_L + I_F \\
\frac{U_F}{n} + I_{L0} * \frac{Z_{L0}}{n^2} + I_F * Z_{PF} &= U_L \\
I_{co} * (Z_{L0} / n^2) &= \frac{U_F}{n} + I_{L0}(\frac{Z_{L0}}{n^2})
\end{align*}$$

(1)

In order to simplify the above formula, remove the variable $U_L$, $I_{L0}$, $I_F$, $I_{co}$, simplified to draw:

$$K_1 * \frac{U_F}{n} + (K_2 + Z_s + Z_{PF}) * I_s - (K_2 + Z_{PF}) * I_L - U_s = 0$$

(2)

$$\begin{align*}
K_1 &= \frac{Z_{C0}}{Z_{L0} + Z_{C0}} \\
K_2 &= \frac{Z_{L0} * Z_{C0}}{(Z_{L0} + Z_{C0}) * n^2}
\end{align*}$$

(3)

As can be seen from the formula (3), $K_1$ and $K_2$ are respectively the series voltage division ratio and parallel impedance of $L_0$ and $C_0$. From the formula (2) shows, in addition to filtering the switching glitch of the grid connected inverter, the output filter has partial pressure on the output voltage of the inverter (Mariéthoz and Morari, 2009).

Grid inverter control rate by the formula (2) can be drawn:

$$I_s = \frac{(K_2 + Z_{PF}) * I_L + U_s - K_1 \frac{U_F}{n}}{K_2 + Z_s + V}$$

(4)

Control of grid-connected inverter which considers the power supply harmonic current and the grid harmonic voltage, the control law can be expressed as:

$$U_F = K_I U_s + KI_s$$

(5)

When the grid voltage is in ideal condition, equation (5) can be expressed as:

$$U_F = KI_s$$

(6)
$K_I$ in the formula is used to suppress the influence of harmonic currents. At this point, the grid inverter output harmonic current can be well controlled.

3. BP NEURAL NETWORK CONTROL ALGORITHM

BP neural network is generally set to three or more layers of the neural network, the middle of the hidden layer is set to one or more layers, the network structure is shown in Figure 1:

![Network structure of BP neural network](image)

In the three-layer feed forward network, the weight between the input layer and the hidden layer is $m \times n$, and the output value of the output layer is often modeled by the three-layer BP neural network. As a result of the prediction, if the output value is two gray numbers, the whitening number is also whitened. Therefore, the weight matrix between the input layer and the hidden layer is set to the gray number, and the weight matrix between the hidden layer and the output layer should be white. When the error is propagated back to the input layer, the weight $W_{kj}$ between output layer and hidden layer and the weight $V_{\oplus ji}$ between hidden layer and input layer are adjusted according to the adjustment formula, and the value adjustment formula between output layer and hidden layer is as follows (Li and Wolfs, 2008):

$$w_{kj}(t+1) = w_{kj}(t) - \Delta w_{kj} = w_{kj}(t) - \eta o_k(d_k - o_k)(1 - o_k)y'_{\oplus j}$$  \hspace{1cm} (7)

And the weight $V_{\oplus}$ between the hidden layer and the input layer is the number of gray, the adjustment should be of its interval. Since the value range of this work is $[-1,1]$, the number of intervals gradually reduce the approximation of the optimal value, should be based on the weight adjustment of the positive and negative to determine the adjustment of the gray interval, namely (Dali et al., 2010):

$$v_{\oplus ji}(t+1) \in \left[ v_{\oplus ji}(t+1), \quad v_{\oplus ji}(t+1) \right]$$  \hspace{1cm} (8)

When $\Delta v_{\oplus ji} > 0$

$$v_{\oplus ji}(t+1) = v_{\oplus ji}(t) + \Delta v_{\oplus ji}$$  \hspace{1cm} (9)

$$v_{\oplus ji}(t+1) = v_{\oplus ji}(t) - \Delta v_{\oplus ji}$$  \hspace{1cm} (10)
4. GRID-CONNECTED INVERTER PID CONTROL BASED ON BP NEURAL NETWORK

In this work, the structure of the neural network PID control system used in the control of grid connected inverter is shown in Figure 2, the controller consists of two parts: the classic PID controller and neural network, the neural network adopts the structure of BP network. According to the error between the input ideal signal (rin) and the output of the grid-connected inverter (yout), the BP network automatically adjusts the system performance self-learning and the weighting coefficient to make the neural network output corresponding to the best combination of PID controller parameters, so as to achieve the optimal control of the grid-connected inverter output current (Qiao and Smedley, 2001).

As the control objective of the control system is to make the harmonic current of the inverter output zero, the harmonic current produced by the inverter can be taken as the deviation signal. Since the harmonic current produced by the inverter is the cross variable, it must be converted to the d-q coordinate system to control the corresponding DC component. Take deviation signal as (Muller et al., 2002):

\[ error(k) = i^*_{sp2} \]  

(13)

The required state quantities of BP network are as follows:

\[
\begin{align*}
    x_1(k) &= error(k) \\
    x_2(k) &= error(k) - error(k-1) \\
    x_3(k) &= error(k) - 2error(k-1) + error(k-2)
\end{align*}
\]  

(14)

Network hidden layer input and output are as follows:

\[ net^{(2)}_i(k) = \sum_{j=0}^{3} w^2_{i,j} o^{(1)}_j, O_i^2(k) = f(net^{(2)}_i(k)) \]  

(15)
Network output layer input and output are as follows:

\[ \text{net}^{(3)}_i(k) = \sum w^{(3)}_{il} o^{(2)}_l(k), O^3_i(k) = g(\text{net}^{(2)}_i(k)) \] (16)

The output layer of network learning algorithm is as follows:

\[ \Delta w^{(3)}_{li}(k) = a \Delta w^{(3)}_{li}(k-1) + \eta \delta_i^{(3)} O^{(2)}_i(k) \] (17)

\[ \delta_i^{(3)} = \text{error}(k) \text{sgn}(\frac{\partial y(k)}{\partial u(k)}) \frac{\partial u(k)}{\partial o_i^{(3)}(k)} g'(\text{net}^{(3)}_i(k)) \] (18)

Through neural network learning, online adjustment of weighting coefficients, adaptive adjustment of PID control parameters is achieved.

5. SIMULATION AND VERIFICATION

A BP neural network PID intelligent control scheme is proposed for the output current of the grid connected inverter with a hybrid filter, the simulation model is established to verify the correctness of the proposed scheme. To verify the correctness of this scheme, in which the grid voltage of single-phase grid-connected inverter is 220V, the switching frequency of 10kHz, using MATLAB software for simulation. Figure 3 is the error curve of improved BP neural network, it can be seen from the Figure 3, when the number of training reaches 50 times, the mean square error of the neural network estimation model has dropped to 0.0000997, reaching the set error range of 0.0001, and the training is stopped. In order to improve the performance of BP neural network for intuitive analysis, the training model is trained by standard neural network model.

![Figure 3. Error curve of improved BP neural network](image)

As shown in Figure 4, it is the single-phase grid inverter in the BP neural network and PI control of a combination of control strategy of the grid current, grid voltage waveform. In order to compare the waveforms of the two, one-seventh of the grid-connected voltage is taken as the output. The control strategy proposed in this work can make the grid-connected current better track the grid voltage and achieve the same Frequency in phase. Compared with the traditional PI control of current inner loop to reduce the waveform distortion rate of grid current, the unity power factor can be achieved.
5. CONCLUSIONS

The harmonic component of grid current fed by grid connected inverter will seriously affect the power grid, it is necessary to control the output current waveform effectively so as to reduce the harm of harmonics injected into the grid. The proposed neural network PID control scheme of output current of grid-connected inverter can theoretically completely suppress the harmonic components of the output current. Simulation results show that this control scheme can effectively improve the waveform quality of inverter output current.

REFERENCES


