The Research of Active Disturbance Rejection Control on Shunt Hybrid Active Power Filter

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Abstract

This paper thoroughly analysis the principles and structures of active disturbance rejection control (ADRC), and applied it to shunt hybrid active power filter (SHAPF). Based on the principles of ADRC, this paper regards the uncertainties both within and external of the system model as unknown interference of system, then estimating through extended state observer (ESO), and compensating by nonlinear feedback control (NLSEF), which makes the control law of the system is only related to specified input / output, and reduces detections in control process, i.e. simplifies complex control process. Excellent results can be achieved in system simulation by selecting Parameter, which proves the possibility of control strategy.

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Keyword: Shunt hybrid active power filter; active disturbance rejection control (ADRC); extended state observer

1. Introduction

With the rapid development of power electronics technology, all kinds of power electronic devices have been widely used, and also caused serious harmonic pollution to the power system. APF has become a very viable developing orientation of power electronic applications. Compared with traditional passive power filter (PPF), it has the following features: quick response and real time dynamic sequential compensation. In power circuit, SHAPF serves as controlled current, mainly used to compensate the load

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reactive power and active power, absorb current harmonics and negative sequence and zero sequence components of industrial frequency current et al.[1]

It regards the model perturbation as internal disturbance, and compensate together with the external system disturbance as a system disturbance [2]. With further applications of modern control technology in power electronics [6], this article applied ADRC control technology to the new object -APF in power electronics technology, and conducted a simulation study.

2. ADRC

ADRC consists of three parts: nonlinear tracking differentiator (TD) extended state observer (ESO) and nonlinear feedback control (NLSEF).

2.1. TD

TD is a device which can: input signal $v(t)$, it will output two signals, $z_1$ and $z_2$. $z_1$ tracks $v(t)$, while $z_2 = \dot{z}_1$, thus regards $z_2$ as a ‘differential approximation’ [7]. The role is arranging the transition process based on the reference input $v(t)$ and the constraints of controlled object, and then get smooth input signal, and propose the dynamic link of this transition process’ derivative.

Discrete form of TD:

$$
\begin{align*}
\dot{z}_{11}(t + h) &= z_{11}(t) + h z_{22}(t) \\
\dot{z}_{22}(t + h) &= z_{22}(t) + h f_{st}(z_{11}(t) - v(t), z_{22}(t), r, h)
\end{align*}
$$

Where $v(t)$ is the input signal, $h$ is the integration step, $f_{st}(z_{11}, z_{12}, r, h)$ is a nonlinear function.

2.2. Extended state observer (ESO).

ESO is core part of ADRC. The system controller requires only input and output as a source of information, it can not only get all estimates of states, but also estimate the uncertainty model and the amount of real-time role in outside interference by ESO, so that the uncertainty of the object could be compensated in the feedback, in order to achieve the purpose of reconstructing the object.

The form ESO is as follows:

$$
\begin{align*}
\dot{z}_{21} &= z_{22} - \beta_{21} g_1(e) \\
\vdots \\
\dot{z}_{2n} &= z_{2n+1} - \beta_{2n} g_n(e) + b_n u \\
\dot{z}_{2n+1} &= -\beta_{2n+1} g_{n+1}(e) \\
e &= z_{21} - x(t)
\end{align*}
$$

So $z_{2n+1}$ is Real-time estimation of total disturbance $f(x, \dot{x}, ..., x^{(n-1)}, t) + w(t) + (b - b_0)u$, $b_0$ is estimate value of $b$. ESO has good tracking capabilities for output states of the observed system; its dynamic quality depends on the gain $\beta$, and the faster the response is, the higher accuracy of estimates is, however, the real-time estimates of the total disturbance are restricted to certain conditions. For example, when frequency of outside interference is high, the capacity of ESO to track the total disturbance is limited.
2.3. NLSEF.

Nonlinear state error feedback control law is the non-linear combination of the errors between state-estimates generated from tracking-differentiator and ESO, it forms control amount together with total disturbance compensation amount with ESO.

\[ u_0 = k_1 f_{a1}(\varepsilon_1, \alpha, \delta) + \cdots + k_n f_{an}(\varepsilon_n, \alpha, \delta) \]  

(3)

According to the characteristics of the function and field operating experience, select non-linear factor \( \alpha \) appropriately, this will obviously change control effects, and make the ratio and the differential play their efficacies respectively.

3. Active disturbance rejection control of SHAPF

3.1. Principle and Modeling of SHAPF.

From the point of view of working principles, upper and subjacent arms of SHAPF can be regarded as ideal switch, the equivalent circuit is showed in Figure 1(a). Since the action of switches could control the size of the AC side voltage, the SHAPF can be considered as a controllable voltage source and a parallel impedance to compensate harmonic current and reactive current in circuit, as showed in Figure 1(b).

![Figure 1. Equivalent circuit of the Single-phase SHAPF](image)

Analyze from Figure (1), mathematical model of single-phase parallel hybrid active power filter can be expressed as:

\[ L_s \frac{di_s}{dt} = -R_s i_s + \bar{u}_s + \overline{\omega} \overline{r} \]  

(4)

Here \( \overline{\omega} \overline{r} \) is the unknown disturbance of system.

It can be calculated as follows:

\[ \dot{i}_s = f(i_s, t) + bu + a(t) \]  

(5)

From (5) we can get that if a comprehensive disturbance \( a(t) \) can be observed and feed forward compensation is available, APF can be transformed into a first-order linear model.

4. Design of ADRC.

- The control of system is showed in Figure 2. Since the response of the inner ring is much faster than the speed of the outer ring, the DC voltage is constant when the inner current control is achieved.
Expression of TD:
\[
\begin{align*}
\varepsilon_0 &= S_{11} - i_t \\
\dot{S}_{11} &= -r \cdot \text{fal}(\varepsilon_0, \alpha_0, \delta_0)
\end{align*}
\]  

Building ESO as the following equations:
\[
\begin{align*}
e &= S_{21} - i_s \\
\dot{S}_{21} &= S_{22} - \beta_{\alpha_1} \text{fal}(\varepsilon, \alpha_1, \delta_1) + u(t) \\
\dot{S}_{22} &= -\beta_{\delta_2} \text{fal}(\varepsilon, \alpha_1, \delta_1)
\end{align*}
\]  

The disturbance rejection control law can be obtained through nonlinear function which feedbacks by the system of state error:
\[
\begin{align*}
\varepsilon_1 &= S_{11} - S_{21} \\
u_b &= \beta \text{fal}(\varepsilon_1, \alpha, \delta)
\end{align*}
\]  

Total output of ADRC is:
\[
u = \frac{u_b - S_{22}}{b}
\]  

Equation (9) illustrates that system control law is only related to system output and a given input, and not related to the parameters of the system and unknown disturbance.

5. Simulation results

Genetic optimization process uses real number coding, after a 100-generation evolution, the optimal parameters obtained are as follows: Optimized parameter in nonlinear tracking-differentiator are \( r = 9487 \), \( a_0 = 0.4 \), \( \delta_0 = 0.001 \) in ESO are \( \beta_{01} = 47962, \beta_{02} = 76931, a = 0.5, \delta = 0.00015 \), and in NLSEF are \( \beta_1 = 13, a_1 = 1, \delta_1 = 0.0001 \).
6. Conclusions

ADRC controller can resolve control problems of a kind of uncertain objects, and has strong adaptability and robustness. ADRC control regards system model and the role of outside interference as the system disturbances, and then automatically estimates and compensates. This compensation specifically realizes linearization of uncertain system feedback and deterministic feedback. Applying ADRC into APF could reduce the signal to be collected, only need to sample supply current and the DC side capacitor voltage, and to compensate the load current and supply voltage as unknown interference in a system. Meanwhile, Parameter selection of control system has nothing to do with the parameters in the system, parameters can be selected within a relatively large range, therefore, the structure of control system is simple and easy to implement.

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