Small-signal Stability Analysis of Paralleled Converter System under Power Quality Control Strategy for Microgrid

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Abstract—In order to enhance the output voltage stability of converter system under non-linear and unbalanced load conditions, the power quality control strategy based on fault-tolerant control architecture is adopted. By analyzing the principle of power quality control strategy, a mathematical model of parallel converter system is established. The mathematical model of the paralleled converter system is linearized at the steady-state operating point, and the corresponding small-signal mathematical model is established. The small-signal stability of the paralleled converter system under the power quality control strategy is analyzed. The results show that under the power quality control strategy, the output voltage stability of the converter system is improved, and the small interference stability of the parallel converter system is guaranteed.

1. INTRODUCTION

In recent years, distributed power generation and energy storage technologies have received increasing attention from scholars, and distributed energy generation systems with three-phase converters in parallel play an important role in electrical energy conversion. Distributed power generation and energy storage devices are connected to the microgrid through converters to realize plug-and-play of renewable energy supply devices \cite{1-2}. However, the fast response speed, small inertia, and poor overload capacity of the converter affect the stable operation of the microgrid \cite{3-6}, and it is necessary to study the improved converter control strategy and its feasibility and stability in order to improve the reliability of the distributed microsource power supply, increase the stability of the supply voltage, and improve the microgrid power quality \cite{7-10}.

For the small-signal stability analysis of the parallel converter system, the power differential link is introduced on the basis of droop control in \cite{11}, which solves the problem of disturbance oscillation, analyzes the small-signal stability of the system, and summarizes the selection of control parameters. In \cite{12}, a parallel inverter system with synchronous generator characteristics is studied and a small-signal model is established, and the small-signal stability analysis is used as a reference basis for the configuration of system parameters. In \cite{13-14}, a full-order small-signal model of a three-phase AC microgrid was established to determine the effects of each control parameter on the dynamic
characteristics and stability of the system, and to improve the quality of the voltage waveform during islanded operation of the microgrid by controlling the inverter output impedance. In [15-16], virtual impedance is introduced and its small-signal stability is investigated for the problem that the microgrid system is prone to oscillation instability due to the reduced inertia caused by the increase of microgrid penetration. In [17], the mathematical model of direct-drive permanent magnet wind turbine grid-connected system with double pulse width modulation control strategy was established by analyzing the working principle of wind power generation system, based on which, the corresponding small signal mathematical model was established and the key factors affecting the small disturbance stability of the system were screened by using the eigenvalue sensitivity analysis.

Based on the above research, this paper introduces a power quality compensation link based on fault-tolerant control architecture in the converter double closed-loop control, and uses a model matching approach to design the parameters. The full-order small-signal mathematical model of the converter parallel system under the power quality control strategy is established, and the small-signal stability analysis of the designed system is carried out by using eigenvalue analysis. The feasibility of the control method is verified by simulation, which effectively improves the stability and reliability of the converter parallel system.

2. POWER QUALITY CONTROL STRATEGY AND ITS MATHEMATICAL MODEL\textsuperscript{[18]}

The converter system under the power quality control strategy mainly includes: the control object LC filter, the voltage and current double closed loop, the residual generator based on the observer, and the compensation matrix Q. The schematic diagram of the topological structure of the parallel connection of two converters under the power quality control strategy is shown in Figure.

Among them: \( L_f \) is the filter inductance, \( H \); \( R_f \) is the parasitic resistance of the filter inductance, \( \Omega \); \( C_f \) is the filter capacitor, \( F \); \( R_{\text{line}} \) and \( L_{\text{line}} \) are the line inductance and resistance, respectively; \( I_{\text{dq}} \) is inductive current; \( v_{\text{dq}} \) and \( I_{\text{dq}} \) are the converter output current and voltage, respectively; \( u_{\text{fodq}} \) and \( u_{\text{foq}} \) are compensation signals superimposed on d and q axes respectively.

![Fig. 1 Paralleled Converter under Power Quality Control Strategy](image)

2.1. Observer Based Residual Generator

For the LC filter of the control object, considering only the output voltage \( v_{\text{dq}} \) of the three-phase
inverter as the input, without considering the effect of the load current $I_{\text{load}}$, the Luenberger observer is established, and the discrete state space mathematical model of the observer based residual generator can be obtained as follows:

$$
\hat{z}_k = Az_k + B_1 u_k + L r_k
$$

$$
\hat{y}_k = C z_k
$$

$$
r_k = y_k - \hat{y}_k
$$

state variable $z_k$, Input variable $u_k$, Output variable $\hat{r}_k$, $\hat{y}_k$. The expressions are:

$$
z_k = [\hat{i}_{d,k}, \hat{i}_{q,k}, \hat{v}_{d,k}, \hat{v}_{q,k}]^T
$$

$$
u_k = [v_{d,k}, v_{q,k}]^T
$$

$$
\hat{r}_k = [r_{d,k}, r_{q,k}, r_{d,k}, r_{q,k}]^T
$$

$$
\hat{y}_k = [\hat{i}_{d,k}, \hat{i}_{q,k}, \hat{v}_{d,k}, \hat{v}_{q,k}]^T
$$

Where, is the unit matrix of $4 \times 4$, and $A$ and $B_1$ are:

$$
A = \begin{bmatrix}
\frac{R_f}{L_f} & \omega & 0 & 0 \\
-\omega & \frac{R_f}{L_f} & 0 & 0 \\
\frac{1}{C_f} & 0 & 0 & \omega \\
0 & \frac{1}{C_f} & -\omega & 0 \\
\end{bmatrix}, B_1 = \begin{bmatrix}
\frac{1}{L_f} & 0 \\
0 & \frac{1}{L_f} \\
0 & 0 \\
0 & 0 \\
\end{bmatrix}
$$

2.2. Compensation Matrix $Q$

The corresponding mathematical description of the structure of the design parameter matrix $Q$ is:

$$
u_{\text{rod}} = \frac{k_1}{s + T} r_{\text{rod}} + \frac{k_2}{s + T} r_{\text{rod}} + k_6 r_{\text{rod}}
$$

$$
u_{\text{rvoq}} = \frac{k_1}{s + T} r_{\text{rvoq}} + \frac{k_2}{s + T} r_{\text{rvoq}} + k_6 r_{\text{rvoq}}
$$

Where: $r_{\text{ld}}, r_{\text{ld}}, r_{\text{vd}}, r_{\text{vq}}$ are the residual signals of current and voltage on the D and Q axes generated by the observer based residual generator respectively; $u_{\text{rod}}$ and $u_{\text{rvoq}}$ are the output signals of the parameter matrix $Q$ on the D and Q axes respectively; $k_1, k_2, k_3, k_4, k_5, k_6, k_7$ and $k_8$ are unknown parameters to be designed, and $T$ represents a time constant.

The state space mathematical model of parametric matrix $Q$ matrix in discrete state can be obtained as follows:

$$
x_{\text{rk},l+1} = A x_{\text{rk},l} + B r_k
$$

$$
u_{\text{rk},l} = C x_{\text{rk},l} + D r_k
$$

Where $A$ is $4 \times 4$ matrix, $B$ is $4 \times 4$ identity matrix. $C, D$ is the coefficient matrix with unknown parameters to be designed in the parameter matrix $Q$. $A, B, C, D$, The expression is as follows:

$$
A_l = \begin{bmatrix}
-T & 0 & 0 & 0 \\
0 & -T & 0 & 0 \\
0 & 0 & -T & 0 \\
0 & 0 & 0 & -T \\
\end{bmatrix}, B_r = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix}
$$

$$
C_r = \begin{bmatrix}
k_1 & 0 & k_2 & 0 \\
k_1 & 0 & k_2 & 0 \\
0 & k_1 & 0 & k_3 \\
0 & k_1 & 0 & k_3 \\
\end{bmatrix}, D_r = \begin{bmatrix}
k_4 & 0 & k_5 & 0 \\
k_4 & 0 & k_5 & 0 \\
0 & k_6 & 0 & k_7 \\
0 & k_6 & 0 & k_7 \\
\end{bmatrix}
$$

state variable $x_{\text{rk}},$ Input variable $r_k, u_{\text{rk}}$, The output variables are;
2.3. Parameter Design

In order to obtain the appropriate parameters of the Q matrix of the compensation link, the model matching method is chosen. The schematic diagram of model matching is shown in Fig. 2.

![Fig. 2 Schematic diagram of model matching](image)

According to the linear superposition principle, the effect $y_{p,d}$ produced by the perturbation acting alone on the LC filter of the control object in the converter system can be superimposed with the compensation signal $y_{p,q}$ produced by the Q matrix, and if the calculation makes $y_{p,d} + y_{p,q} = 0$, then the theoretical compensation matrix can eliminate any disturbance signal acting on the converter system, from the purpose of eliminating the disturbance and improving the output voltage stability of the converter.

Where the load current $I_{odq}$ is the disturbance input, $r$ is the residual signal output by the observer, and $u_r$ is the compensation signal obtained by matrix calculation. $G_y$ is the transfer function corresponding to the observer, and $G_p$ is the transfer function of the disturbance signal acting on the LC filter, the corresponding state space mathematical expression is:

$$
G_{yd}(s) = \begin{bmatrix}
A & B_p \\
C & D_p
\end{bmatrix}
$$

(4)

$G_y$ is the transfer function of the control signal acting on the LC filter alone when there is no disturbance, and the corresponding state space mathematical expression is:

$$
G_y(s) = \begin{bmatrix}
A & B_c \\
C & D_c
\end{bmatrix}
$$

(5)

Then the expression for calculating the matrix parameters is:

$$
G_q(s) = -G^{-1}_p(s)G_{yd}(s)G_y^{-1}(s)
$$

(6)

3. SMALL SIGNAL MODELING

3.1. Single Converter Small Signal Model

In operation, due to the variation of various parameters, small disturbance is common. If the disturbance is sufficiently small, the nonlinear equation describing the system is linearized at the steady-state operating point, and the stability of the actual nonlinear system can be studied according to the stability of the linearized system.

The state space equation of voltage loop and current loop is linearized, and the voltage loop small
signal model is:

$$
\begin{align*}
\begin{bmatrix}
\Delta \phi_{iq} \\
\Delta \phi_{od}
\end{bmatrix} &= [0]
\begin{bmatrix}
\Delta \phi_{iq} \\
\Delta \phi_{od}
\end{bmatrix} + B_{11} \begin{bmatrix}
\Delta v'_{iq} \\
\Delta v'_{od}
\end{bmatrix} + B_{12} \begin{bmatrix}
\Delta \omega_{od}
\end{bmatrix} \\
\Delta I_{iq} &= C_{1} \begin{bmatrix}
\Delta \phi_{iq} \\
\Delta \phi_{od}
\end{bmatrix} + D_{11} \begin{bmatrix}
\Delta v'_{iq} \\
\Delta v'_{od}
\end{bmatrix} + D_{12} \begin{bmatrix}
\Delta \omega_{od}
\end{bmatrix}
\end{align*}
$$

(7)

The small signal model of the current loop is:

$$
\begin{align*}
\begin{bmatrix}
\Delta y_{iq} \\
\Delta y_{od}
\end{bmatrix} &= [0]
\begin{bmatrix}
\Delta y_{iq} \\
\Delta y_{od}
\end{bmatrix} + B_{11} \begin{bmatrix}
\Delta v'_{iq} \\
\Delta v'_{od}
\end{bmatrix} + B_{12} \begin{bmatrix}
\Delta \omega_{od}
\end{bmatrix} \\
\Delta V_{iq} &= C_{1} \begin{bmatrix}
\Delta y_{iq} \\
\Delta y_{od}
\end{bmatrix} + D_{11} \begin{bmatrix}
\Delta v'_{iq} \\
\Delta v'_{od}
\end{bmatrix} + D_{12} \begin{bmatrix}
\Delta \omega_{od}
\end{bmatrix}
\end{align*}
$$

(8)

The state space equation of the observer-based residual generator is linearized, and the small signal model of the observer-based residual generator is:

$$
\begin{align*}
\begin{bmatrix}
\Delta I_{ud,e} \\
\Delta I_{od,e}
\end{bmatrix} &= \left((A - LC) - \frac{\Delta I_{ud,e}}{\Delta \omega_{od}} \right) + B_{11} \begin{bmatrix}
\Delta y_{iq} \\
\Delta y_{od}
\end{bmatrix} + L \begin{bmatrix}
\Delta I_{ud,e} \\
\Delta I_{od,e}
\end{bmatrix} + B_{12} \begin{bmatrix}
\Delta \omega_{od}
\end{bmatrix} \\
\Delta I_{ud,e} &= C_{1} \begin{bmatrix}
\Delta I_{ud,e} \\
\Delta I_{od,e}
\end{bmatrix} + D_{11} \begin{bmatrix}
\Delta y_{iq} \\
\Delta y_{od}
\end{bmatrix} + D_{12} \begin{bmatrix}
\Delta \omega_{od}
\end{bmatrix} + D_{12} \begin{bmatrix}
\Delta \omega_{od}
\end{bmatrix}
\end{align*}
$$

(9)

Linearized the state space equation of parameter matrix Q in the fault-tolerant control architecture, and obtained the small signal model of parameter matrix Q:

$$
\begin{bmatrix}
\Delta v_{ad} \\
\Delta v_{bd} \\
\Delta v_{cd}
\end{bmatrix} = \begin{bmatrix}
L_{ad} & L_{bd} & L_{cd} \\
L_{da} & L_{db} & L_{dc}
\end{bmatrix} \begin{bmatrix}
\Delta I_{ad,e} \\
\Delta I_{bd,e} \\
\Delta I_{cd,e}
\end{bmatrix}
$$

(10)

Superposition the control signals $v_{ad}$, $v_{bd}$, and $v_{cd}$ output by the double closed-loop and the fault-tolerant control signals $u_{vad}$ as the control signal input $v_{adp}$ of the LC filter, and the expression is as follows:

$$
\begin{align*}
\begin{bmatrix}
v_{adp} \\
v_{bdp} \\
v_{cdp}
\end{bmatrix} &= \begin{bmatrix}
v_{ad} \\
v_{bd} \\
v_{cd}
\end{bmatrix} + \begin{bmatrix}
u_{adp} \\
u_{bdp} \\
u_{cdp}
\end{bmatrix}
\end{align*}
$$

(11)

The corresponding small signal equation is:

$$
\begin{bmatrix}
\Delta v_{adp} \\
\Delta v_{bdp} \\
\Delta v_{cdp}
\end{bmatrix} = \begin{bmatrix}
\Delta v_{ad} \\
\Delta v_{bd} \\
\Delta v_{cd}
\end{bmatrix} + \begin{bmatrix}
\Delta u_{adp} \\
\Delta u_{bdp} \\
\Delta u_{cdp}
\end{bmatrix}
$$

(12)

Linearized the state space equation of LC filter, which is a control object considering coupling resistance and inductance, and obtained the corresponding small signal model:

$$
\begin{bmatrix}
\Delta I_{ad,e} \\
\Delta I_{bd,e} \\
\Delta I_{cd,e}
\end{bmatrix} = \begin{bmatrix}
L_{ad} & L_{bd} & L_{cd} \\
L_{da} & L_{db} & L_{dc}
\end{bmatrix} \begin{bmatrix}
\Delta I_{ad,e} \\
\Delta I_{bd,e} \\
\Delta I_{cd,e}
\end{bmatrix} + B_{11} \begin{bmatrix}
\Delta v_{ad} \\
\Delta v_{bd} \\
\Delta v_{cd}
\end{bmatrix} + B_{12} \begin{bmatrix}
\Delta \omega_{od}
\end{bmatrix} + B_{12} \begin{bmatrix}
\Delta \omega_{od}
\end{bmatrix}
$$

(13)

The small signal model of the converter under the power quality control strategy of a single unit is:

$$
\begin{bmatrix}
\Delta \omega_{syn} \\
\Delta \omega_{sym}
\end{bmatrix} = \begin{bmatrix}
A_{syn} & A_{syn} \\
B_{syn1} & B_{syn2}
\end{bmatrix} \begin{bmatrix}
\Delta v_{600} \\
\Delta v_{600}
\end{bmatrix} + B_{syn1} \begin{bmatrix}
\Delta \omega_{com}
\end{bmatrix} + B_{syn2} \begin{bmatrix}
\Delta \omega_{com}
\end{bmatrix}
$$

(14)

Where, the state variable is:
3.2. Parallel Small Signal Model with Two Converters

Single converter in each part of the small signal model is built on their rotation coordinate system, when two parallel inverters, need to choose a reference coordinate to global coordinates of the converter, the other a small signal model of current transformer transformation to the global coordinate system, the definition of $\delta$ for the second stage converter and the phase Angle difference of the global coordinate system.

The output current $I_{adj}$ of the second inverter is converted to the global reference coordinate system and expressed as $I_{adj}$:

$$[I_{adj}] = [T][I_{adj}] = \begin{bmatrix} \cos \delta & -\sin \delta \\ \sin \delta & \cos \delta \end{bmatrix} [I_{adj}]$$

(15)

After linearization, the following equation can be obtained:

$$[\Delta I_{adj}] = \begin{bmatrix} \cos \delta_0 & -\sin \delta_0 \\ \sin \delta_0 & \cos \delta_0 \end{bmatrix} [\Delta I_{adj}]$$

$$+ \begin{bmatrix} -I_0 \sin \delta_0 & -I_0 \cos \delta_0 \\ I_0 \cos \delta_0 & -I_0 \sin \delta_0 \end{bmatrix} [\Delta \delta]$$

(16)

The bus voltage $v_{adj}$ in the global reference coordinate system is transformed to the rotating coordinate system of the second inverter as follows:

$$[v_{adj}] = [T^{-1}][v_{adj}] = \begin{bmatrix} \cos \delta & \sin \delta \\ -\sin \delta & \cos \delta \end{bmatrix} [v_{adj}]$$

(17)

After linearization, the following equation can be obtained:

$$[\Delta v_{adj}] = \begin{bmatrix} \cos \delta_0 & \sin \delta_0 \\ -\sin \delta_0 & \cos \delta_0 \end{bmatrix} [\Delta v_{adj}]$$

$$+ \begin{bmatrix} -v_0 \sin \delta_0 + v_0 \cos \delta_0 \\ -v_0 \cos \delta_0 + v_0 \sin \delta_0 \end{bmatrix} [\Delta \delta]$$

(18)

The parallel circuit model of two converters is shown in Fig. 4.
Fig. 4 Modelling of the network

The mathematical model of the corresponding line is:

\[
\begin{align*}
\frac{dI_{\text{load}}}{dt} &= -\frac{R_{\text{load}}}{L_{\text{load}}} I_{\text{load}} + \frac{\omega}{L_{\text{load}}} (v_{\text{load}} - v_{\text{bus}}) + \frac{1}{L_{\text{load}}} v_{\text{bus}} \\
\frac{dI_{\text{bus}}}{dt} &= -\frac{R_{\text{bus}}}{L_{\text{bus}}} I_{\text{bus}} - \frac{\omega}{L_{\text{bus}}} (v_{\text{load}} - v_{\text{bus}}) + \frac{1}{L_{\text{bus}}} v_{\text{bus}}
\end{align*}
\]  

(19)

The small signal equation of the line obtained by linearization is:

\[
\begin{bmatrix} \Delta I_{\text{load,q}} \end{bmatrix} = A_{\text{line}} \begin{bmatrix} \Delta I_{\text{load,q}} \end{bmatrix} + B_{\text{line}} \begin{bmatrix} \Delta I_{\text{bus,q}} \end{bmatrix} + B_{\text{line2}} [\Delta \omega]
\]  

(20)

The mathematical model of resistive load is as follows:

\[
\begin{align*}
\frac{dI_{\text{load}}}{dt} &= -\frac{R_{\text{load}}}{L_{\text{load}}} I_{\text{load}} + \frac{\omega}{L_{\text{load}}} (v_{\text{load}} - v_{\text{bus}}) + \frac{1}{L_{\text{load}}} v_{\text{bus}} \\
\frac{dI_{\text{bus}}}{dt} &= -\frac{R_{\text{bus}}}{L_{\text{bus}}} I_{\text{bus}} - \frac{\omega}{L_{\text{bus}}} (v_{\text{load}} - v_{\text{bus}}) + \frac{1}{L_{\text{bus}}} v_{\text{bus}}
\end{align*}
\]  

(21)

The small signal equation of load obtained by linearization is:

\[
\begin{bmatrix} \Delta I_{\text{load,q}} \end{bmatrix} = A_{\text{load}} \begin{bmatrix} \Delta I_{\text{load,q}} \end{bmatrix} + B_{\text{load1}} \begin{bmatrix} \Delta I_{\text{bus,q}} \end{bmatrix} + B_{\text{load2}} [\Delta \omega]
\]  

(22)

To eliminate ac bus node voltage, virtual impedance \( r_n \) is introduced between each node and ground.

\[
\begin{align*}
v_{\text{sd}} &= r_n (i_{\text{sd}} - i_{\text{load}}) \\
v_{\text{sq}} &= r_n (i_{\text{sq}} - i_{\text{load}})
\end{align*}
\]

The parallel small signal model of two converters is as follows:

\[
\begin{bmatrix} \Delta i_{\text{sys}} \end{bmatrix} = A_{\text{sys}} \begin{bmatrix} \Delta x_{\text{sys}} \end{bmatrix}
\]  

(23)

Where, \( x_{\text{sys}} \) is the state variable of the microgrid system with two converters, \( A_{\text{sys}} \) is the coefficient matrix of the state variable of the overall microgrid small signal model, and the stability of small signal can be systematically analyzed by analyzing the coefficient matrix \( A_{\text{sys}} \). The state variable is:

\[
\begin{align*}
\Delta x_{\text{sys}} &= \begin{bmatrix} \Delta \delta_1 & \Delta \phi_{\text{d1}} & \Delta \phi_{\text{q1}} & \Delta \gamma_{\text{d1}} & \Delta \gamma_{\text{q1}} & \Delta I_{\text{d1}} & \Delta I_{\text{q1}} & \Delta I_{\text{d2}} & \Delta I_{\text{q2}} & \Delta I_{\text{d3}} & \Delta I_{\text{q3}} & \Delta I_{\text{d4}} & \Delta I_{\text{q4}} & \Delta \phi_{\text{d2}} & \Delta \phi_{\text{q2}} & \Delta \phi_{\text{d3}} & \Delta \phi_{\text{q3}} & \Delta \phi_{\text{d4}} & \Delta \phi_{\text{q4}}
\end{bmatrix} \\
\Delta I_{\text{d1}} &= \Delta I_{\text{q1}} \\
\Delta I_{\text{d2}} &= \Delta I_{\text{q2}} \\
\Delta I_{\text{d3}} &= \Delta I_{\text{q3}} \\
\Delta I_{\text{d4}} &= \Delta I_{\text{q4}}
\end{align*}
\]

4. Simulation Experiment

Select the converter parameters as shown in Table I.
TABLE I. CONVERTER PARAMETERS

| Item                                      | Converter 1 | Converter 2 |
|-------------------------------------------|-------------|-------------|
| Parasitic Resistance $R_f/\Omega$        | 0.01        | 0.0001      |
| Filter Inductors $L_f/H$                  | 0.002       | 0.005       |
| Filter Capacitor $C_f/F$                  | 0.0015      | 0.001       |
| Voltage Loop Scaling Factor $K_{pv}$      | 10          | 0.2         |
| Voltage Loop Integration Factor $K_{pv}$  | 100         | 20          |
| Current Loop Scaling factor $K_{pc}$      | 10          | 0.2         |
| Current Loop Scaling Factor $K_{pv}$      | 100         | 0           |
| Matrix Parameters $T$                     | 8.0016      | 8.0016      |
| Matrix Parameters $k_1$                   | 0           | 0.85        |
| Matrix Parameters $k_2$                   | -5.72       | -3.94       |
| Matrix Parameters $k_3$                   | 0           | 1           |
| Matrix Parameters $k_4$                   | 0.642       | 0.94        |
| Matrix Parameters $k_5$                   | 0           | -504        |
| Matrix Parameters $k_6$                   | -512.6      | -410        |
| Matrix Parameters $k_7$                   | 0           | -500        |
| Matrix Parameters $k_8$                   | -403.8      | -402        |

The same microgrid transient simulation model of the simulation is also built in MATLAB/Simulink, and the steady-state operating point obtained from the simulation is brought into the state matrix as the initial value for the small-signal analysis. The small-signal stability of the system is analyzed at this equilibrium point, and the dynamic characteristics of the system under different operating conditions can be obtained, with the dynamic characteristics of the system during the parameter change. All the characteristic roots of the system are obtained, and it can be seen from Fig. 5 that all the characteristic roots of the system are distributed in the left half plane, which proves that the system is stable.

![Fig. 5 Characteristic root distribution of two paralleled converter system](image)

Analyze the effect of $Q$ matrix parameter variation on system stability under the electrical energy control strategy used in this paper.

![Fig. 6 Change of parameter $T$ in matrix $Q$](image)

When the parameter $T$ is changed from 100 to -10, the trend of the root trajectory of the converter is shown in Fig. 6. When $T$ changes from positive to negative, the characteristic root near the origin gradually moves to the right and the system stability is weakened. And it crosses the origin when $T$
becomes negative and the system is unstable. Therefore, when designing Q, it should ensure that the T parameter is positive.

When the parameter k changes, the trend of the root trajectory of the system is shown in Fig. 7.

When the parameter \( k_2 \) changes from 0 to 20, the root trajectory trend of the system is shown in Fig. 7(a), when \( k_2 \) gradually becomes larger, the left low-frequency characteristic root gradually approaches the imaginary axis; when the parameter \( k_4 \) changes from 10 to -10, the root trajectory trend of the system is shown in Fig. 7(b), when \( k_4 \) gradually becomes smaller, the left low-frequency characteristic root gradually moves away from the imaginary axis, and the system tends to be more stable, when the parameter \( k_6 \) changes from -125 to 125, the root trajectory trend of the system is shown in Fig. 7(c), when \( k_6 \) gradually becomes larger, the left low-frequency characteristic root gradually approaches the imaginary axis; when the parameter \( k_8 \) changes from -1000 to 0, the root trajectory trend of the system is shown in Fig. 7(d), it can be seen that when \( k_8 \) is negative to zero, the low-frequency characteristic root moves to the origin or even crosses the imaginary axis, positive root appears, and the system is easy to be unstable. From the above, the coefficient \( k_6 \) and \( k_8 \) changes of the residual signal have a large impact on the stability of the system.

5. CONCLUSION
In order to improve the stability of the output voltage of the converter, this paper proposes to adopt the power quality control strategy, and also takes the converter parallel system under this control strategy as the research object, establishes the full-order small-signal dynamic model, and uses MATLAB
simulation, by solving the characteristic roots of the small-signal model system at the static operating point and conducting analysis, it can be concluded that the adoption of the power strategy can ensure the small-signal stability of the system.

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