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Instability Analysis of Grid-Connected Inverters During Low-voltage-ride Through Process

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System Description

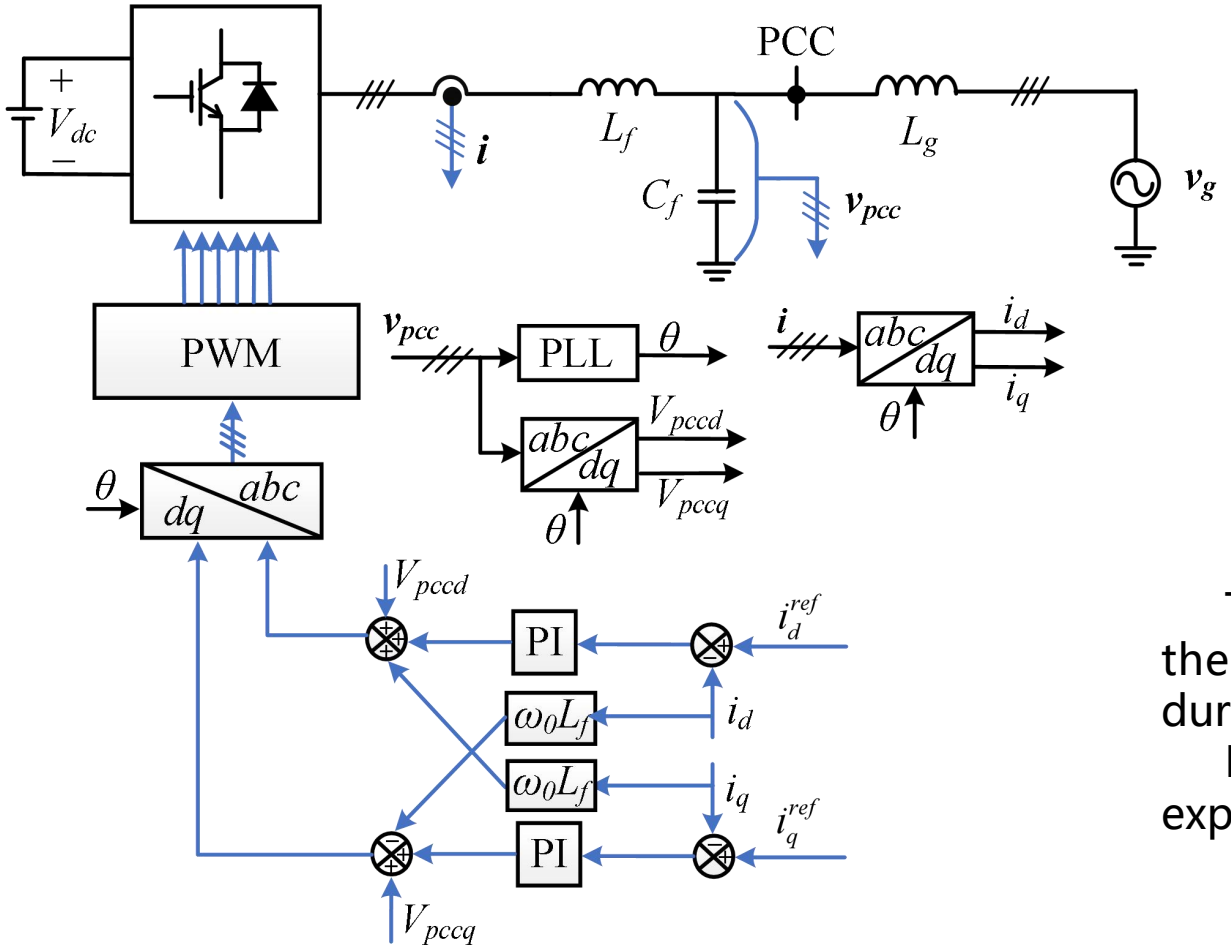

Fig.1 System diagram of grid-connected inverters.

$$I_d^{ref} = \begin{cases} I_{rate} & 0.9\text{p.u.} \le V_{pcc} \le 1.1\text{p.u} \\ (0.2 \sim 0.4) * I_{rate} & V_{pcc} < 0.9\text{p.u.} \end{cases} \quad (1)$$

$$I_q^{ref} = \begin{cases} 0 & 0.9\text{p.u.} \le V_{pcc} \le 1.1\text{p.u.} \\ k_{q\_adj} * (0.9 - V_{pcc}) * I_{rate} & V_{pcc} < 0.9\text{p.u.} \end{cases} \quad (2)$$

The grid code requires that the inverters need to raise the PCC voltage by injecting reactive current into the grid during LVRT process.

It is found that under this circumstance, the system may experience instability, especially under the weak grid.

Problem Description

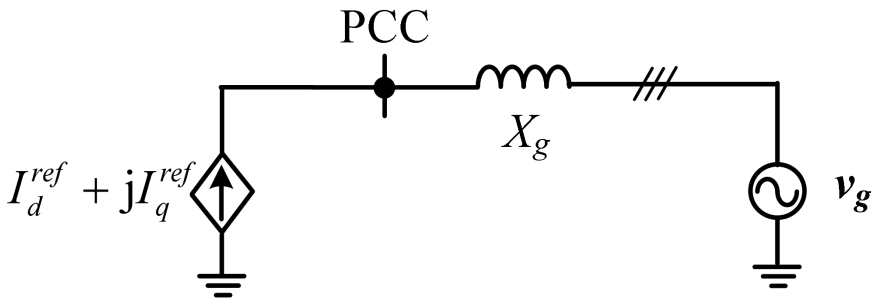

Fig. 2 Simplified diagram of the system.

$$V_{pcc} = V_g e^{-j\delta} + (I_d^{ref} + jI_q^{ref}) \cdot jX_g$$

$$\Downarrow$$

$$V_{pccd} = V_g \cos(\delta) - I_q^{ref} X_g$$

$$V_{pccq} = -V_g \sin(\delta) + I_d^{ref} X_g \tag{3}$$

$$V_{pcc} = V_{pccd} = \sqrt{V_g^{\,2} - (I_d^{ref} X_g)^2} - I_q^{ref} X_g \tag{4}$$

$$V_{pcc}(n+1) = \sqrt{V_g^{\,2} - (I_d^{ref} X_g)^2} + k_{q\_adj}(0.9 - V_{pcc}(n))X_g \tag{5}$$

Problem Description

$$V_{pcc}{}^{*} = \frac{\sqrt{V_g^2 - (I_d^{ref} X_g)^2} + 0.9 k_{q\_adj} X_g}{1 + k_{q\_adj} X_g} \qquad (6)$$

$$\begin{aligned} V_{pcc}^{*} &= f(V_{pcc}^{*}) \\ &= \sqrt{V_g{}^2 - (I_d^{ref} X_g)^2} + k_{q\_adj}(0.9 - V_{pcc}^{*}) X_g \end{aligned} \qquad (7)$$

Stability Condition:

$$\left| \frac{\mathrm{d}f(V_{pcc}^{*})}{\mathrm{d}V_{pcc}^{*}} \right| = k_{q\_adj} X_g < 1 \Rightarrow X_g < \frac{1}{k_{q\_adj}} \qquad (8)$$

The scheme with LPF (the proposed scheme):

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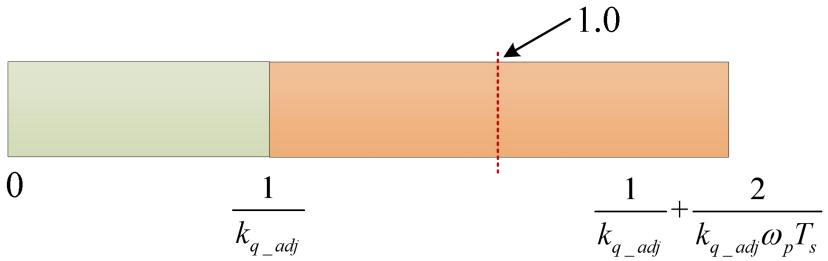
$$\begin{aligned} V_{pcc}(n+1) &= \sqrt{V_g{}^2 - (I_d^{ref} X_g)^2} \\ &\quad + k_{q\_adj}\left(0.9 - V_{pcc}(n) * \frac{\omega_p}{\frac{z-1}{zT_s} + \omega_p}\right) X_g \\ &= H - k_{q\_adj} X_g V_{pcc}(n) * \frac{\omega_p}{\frac{z-1}{zT_s} + \omega_p} \end{aligned} \qquad (9)$$

Stability Condition:

$$k_{q\_adj} X_g < \frac{2}{\omega_p T_s} + 1$$

$$\Downarrow$$

$$X_g < \frac{1}{k_{q\_adj}} + \frac{2}{k_{q\_adj} \omega_p T_s} \qquad (10)$$



Verification Results:

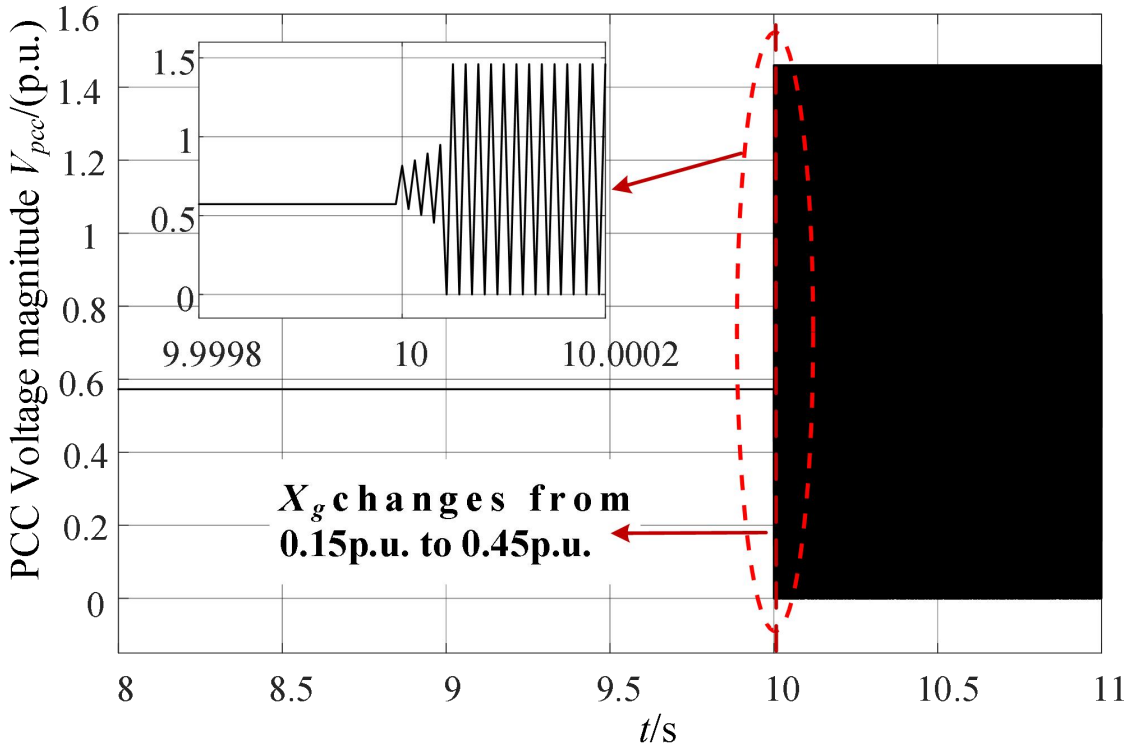


Fig. 7 The PCC voltage of grid-connected inverters during LVRT process when grid impedance changes from 0.15p.u. to 0.45p.u. and the adjustment coefficient of reactive current kqadj keeps as 2.5.

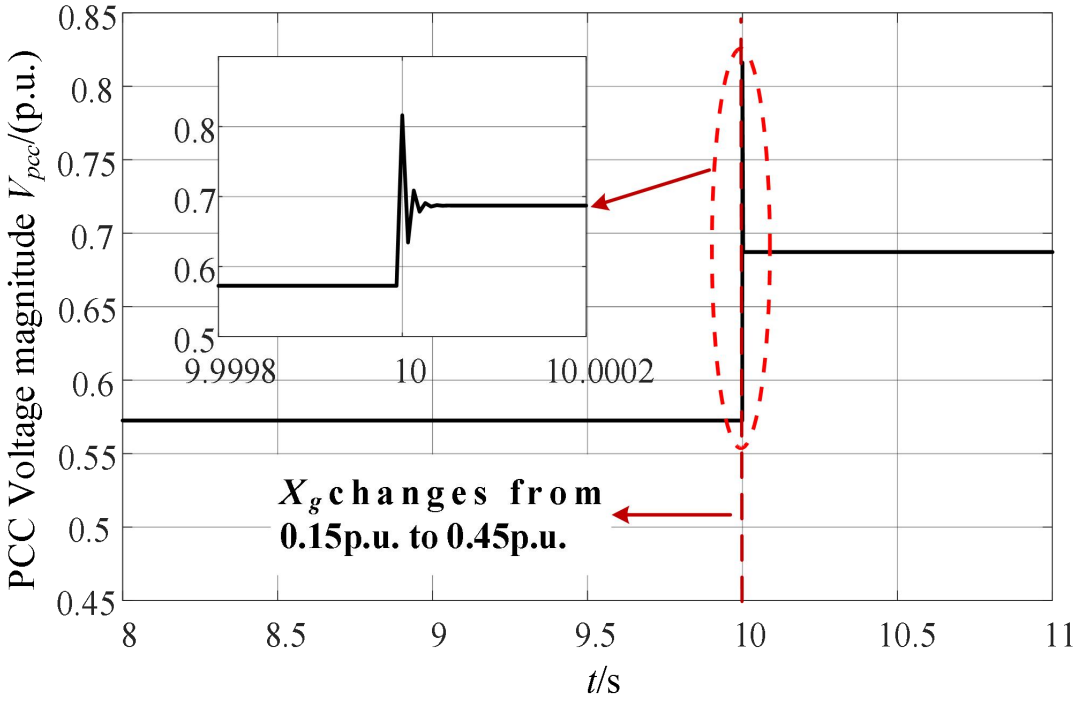


Fig. 10 The PCC voltage of grid-connected inverters during LVRT process when grid impedance changes from 0.15p.u. to 0.45p.u. and the adjustment coefficient of reactive current k_{qadj} keeps as 2.5 under the proposed scheme.

Verification Results:

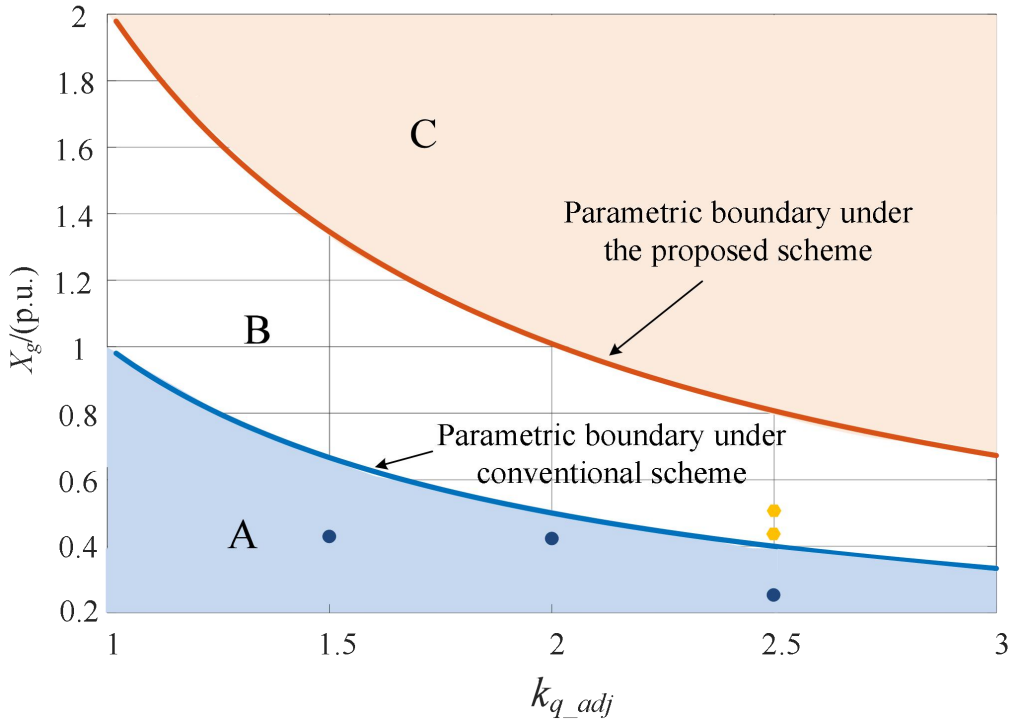


Fig. 11 The change of the parametric boundary under the conventional scheme and the proposed scheme(● represents the cases after verification).

A whole parametric boundary under the conventional scheme and the proposed scheme is shown in Fig. 11. The stable parametric range is area A under the conventional scheme. All the cases outside of A will be unstable. Under the proposed scheme, the stable parametric area will expand from A to A+B. All the cases inside this area will be stable. These results verify that the proposed scheme can enhance the stability of the inverters.

Conclusions:

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An instability phenomenon of grid-connected in-verters caused by the large grid impedance is re-vealed and analyzed. The obtained verification re-sults prove that the large impedance will make the characteristic roots move to the outside of the unit circle leading to instability. The proposed LPF used with the PCC voltage detection module can enlarge the configurable range of grid impedance leading to the enhancement of the stability performance.

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