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Investigation on the Mechanism and Influencing Factors of Subsynchronous Torsional Oscillations Induced by PMSG Wind Farms

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INTRODUCTION

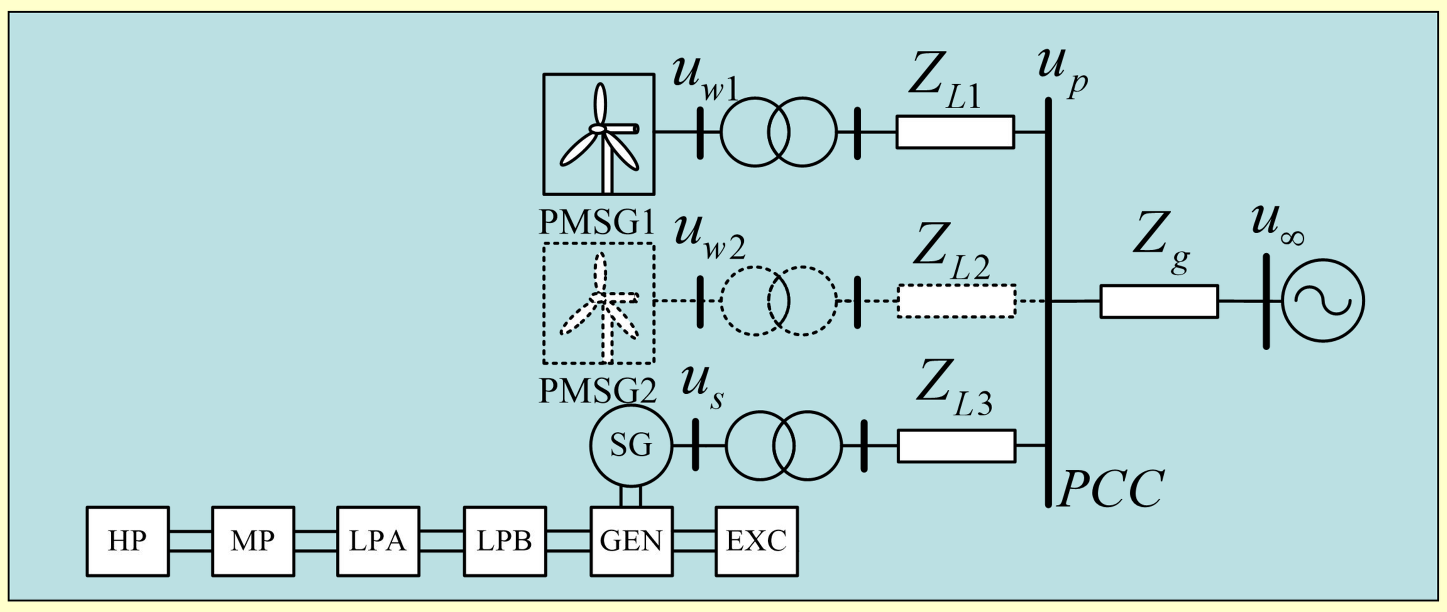


Fig.1 The studied system

The PMSG wind farms connected to the weak grid may induce the subsynchronous torsional oscillations (SSTOs). Different from the traditional subsynchrous resonance, there is no series compensated lines in the power grid and the power electronic equipment is the inducement of oscillation.

This paper studies the mechanism of the SSTOs induced by PLL-dominated mode and influencing factors of torsional mode stability.

THE SMALL-SIGNAL MODEL OF STUDIED SYSTEM

$$\begin{cases} \Delta\dot{\boldsymbol{x}}_s = \boldsymbol{A}_s\Delta\boldsymbol{x}_s + \boldsymbol{B}_s\Delta\boldsymbol{u}_s \\ \Delta\boldsymbol{i}_s = \boldsymbol{C}_s\Delta\boldsymbol{x}_s \end{cases} \quad (1)$$

The small-signal model of SG

$$\begin{cases} \Delta\dot{\boldsymbol{x}}_w = \boldsymbol{A}_w\Delta\boldsymbol{x}_w + \boldsymbol{B}_w\Delta\boldsymbol{u}_w \\ \Delta\boldsymbol{i}_w = \boldsymbol{C}_w\Delta\boldsymbol{x}_w \end{cases} \quad (2)$$

The small-signal model of PMSG

$$\begin{cases} \Delta u_{ix} = L_{ij}\dfrac{d\Delta i_{ijx}}{dt} - L_{ij}\Delta i_{ijy} + R_{ij}\Delta i_{ijx} + \Delta u_{jx} \\ \Delta u_{iy} = L_{ij}\dfrac{d\Delta i_{ijy}}{dt} + L_{ij}\Delta i_{ijx} + R_{ij}\Delta i_{ijy} + \Delta u_{jy} \end{cases} \quad (3)$$

The small-signal model of transmission line

$$\Delta\dot{\boldsymbol{x}} = \boldsymbol{A}_{sys}\Delta\boldsymbol{x}$$

The IEEE first benchmark model is adopted and only the grid-side controller of PMSG is considered. The A_{sys} is a 26×26 matrix.

THE MECHANISM AND INFLUENCING FACTORS of SSTOs

The single PMSG and single SG system

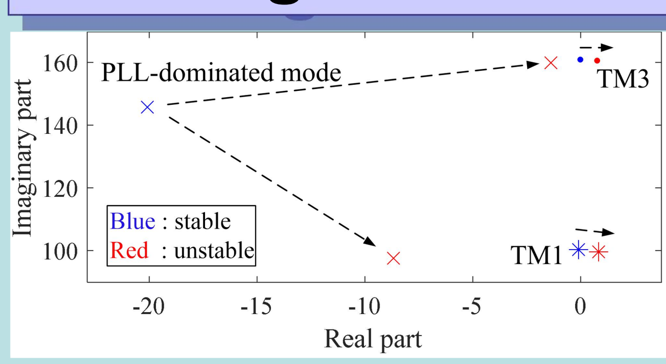


Fig.2 trajectory diagram of eigenvalues(Cross sign: PLL-dominated mode; Point: TM3; Asterisk:TM1）

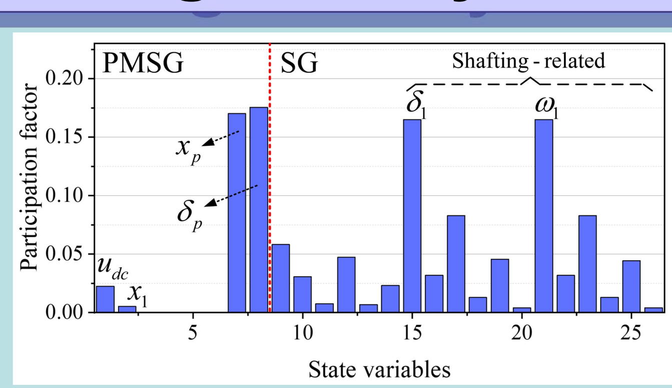


Fig.3 Participation factors of each state variable in unstable TM3

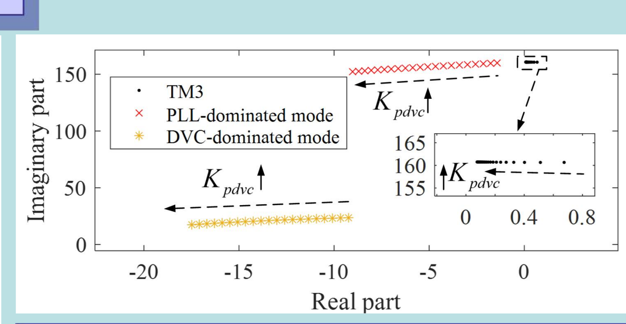
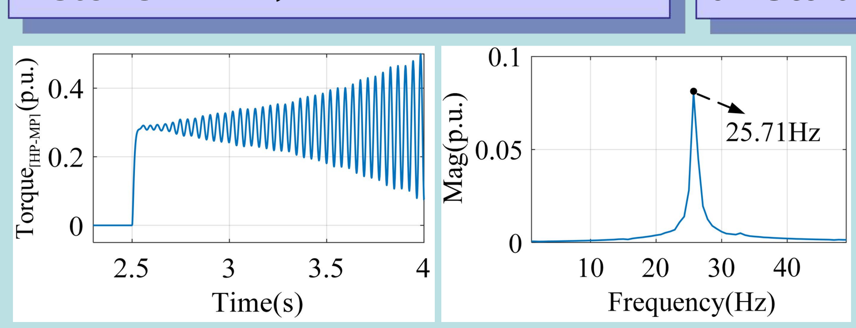


Fig.5 The trajectories of PLL-dominated mode, DVC-dominated mode and TM3



Decreasing the K_{pdvc} , the torsional mode become unstable, a similar conclusion can be drawn when K_{idvc} is decreasing.

Fig.4 The torque between HP and MP, and its FFT analysis

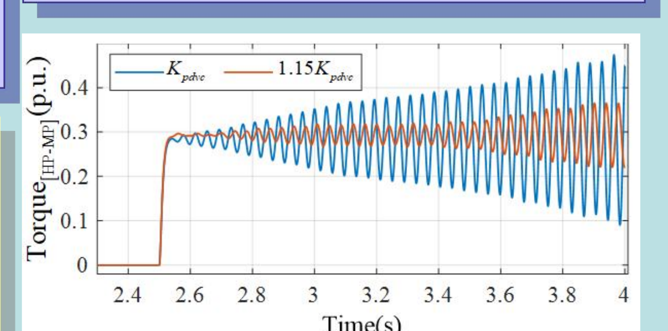


Fig.6 The HP-MP torque under different K_{pdvc}

The Multi-PMSGs and single SG system

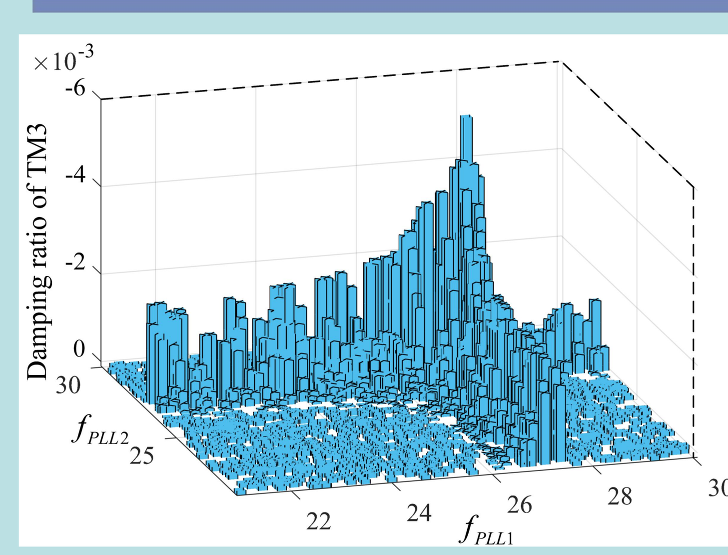


Fig.7 The damping ratio of TM3 when the Monte Carlo method is used to randomly generate PLL parameters

Case	Bandwidth of PLL1/Hz	Bandwidth of PLL2/Hz	Damping ratio of TM3
1	26.98	26.98	-0.0055
2	26.98	26.44	-0.0027
3	26.98	21.37	-0.0016
4	21.37	21.03	0.0004

Table.1 PLL parameters of PMSGS under different cases

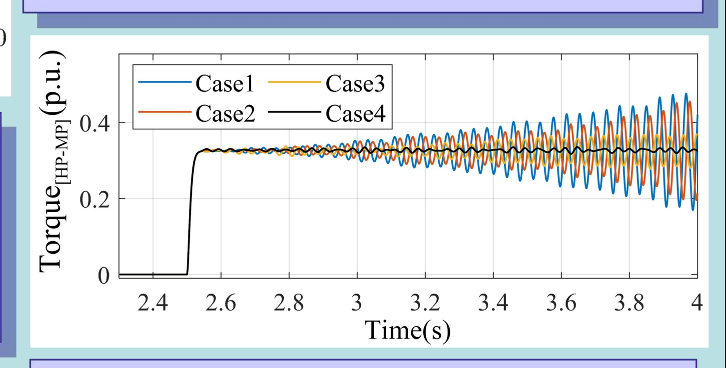


Fig.8 The HP-MP torque under different cases

Mechanism explanation: Fig. 2 shows that weakening the damping of PLL-dominated mode, make it approaches the imaginary axis, when its frequency is close to the frequency of the torsional modes, it will cause the torsional mode to enter the right side of the complex plane, the SSTOs will be induced. The time domain simulation in Fig.4 reproduces the SSTOs phenomenon.

Summary

When the PLL-dominated mode "approaches" to the torsional mode, the interaction between the PMSG and the SG will cause the torsional mode to enter the right side of the complex plane, and the SSTOs occur. At the same time, DVC parameters have a non-negligible influence on torsional mode stability.

In a multi-PMSGs grid-connected system, when the bandwidth of each PLL is close to the frequency of torsional mode, the risk of SSTOs in the system is high.