Transient Stability Improvement by Pre-fault and Post-fault modifications in Wind Power Plant Control

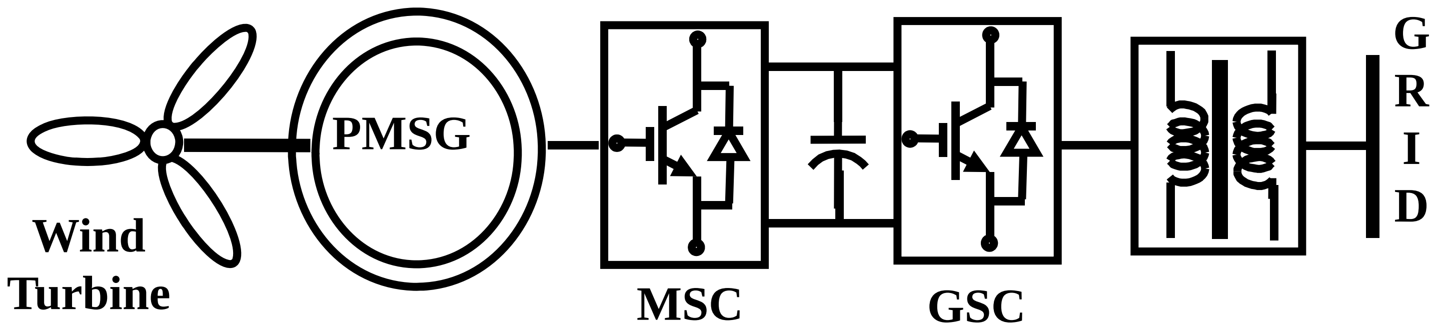
NILOY PATARI
DHEEMAN CHATTERJEE
TANMOY BHATTACHARYA

Department of Electrical Engineering
Indian Institute of Technology
Kharagpur
India

Introduction

- Out of the total installed capacity of 308 GW, 46 GW comes from renewables which includes 28 GW wind power.
- The plan is to add 175 GW of renewables including 60 GW of wind power by 2022
- In long term, the target is to increase the share of renewables to 40% by 2030.
- With such large share of wind power plants, controlling the injected power for impacting system stability looks to be a realistic goal

The Permanent Magnet Synchronous Generator and Variable Speed Wind Turbine Based Wind Power Plant



- ✓ Smaller size for a given MW.
- ✓ Less maintenance, gearless operation possible.
- ✓ It can provide reactive power support.

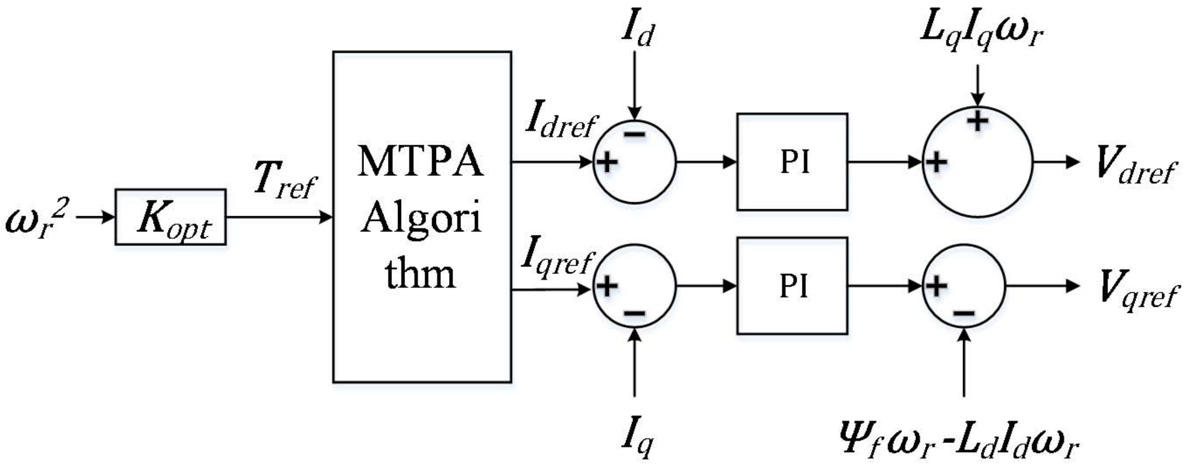
Machine side converter control

Reference torque for maximum power

$$T_{e_{ref}} = K_{opt}\,\omega_r^2 \quad if \;\; \omega_r < \omega_{r_{rated}}$$

$$= T_{e_{rated}} \quad if \;\; \omega_r \ge \omega_{r_{rated}}$$

$$K_{opt} = 0.5\rho\pi R^5 C_{p_{\max}}\,\omega_{tB}^2 \Big/ \left(\lambda_{opt}^3 S_B\right)$$



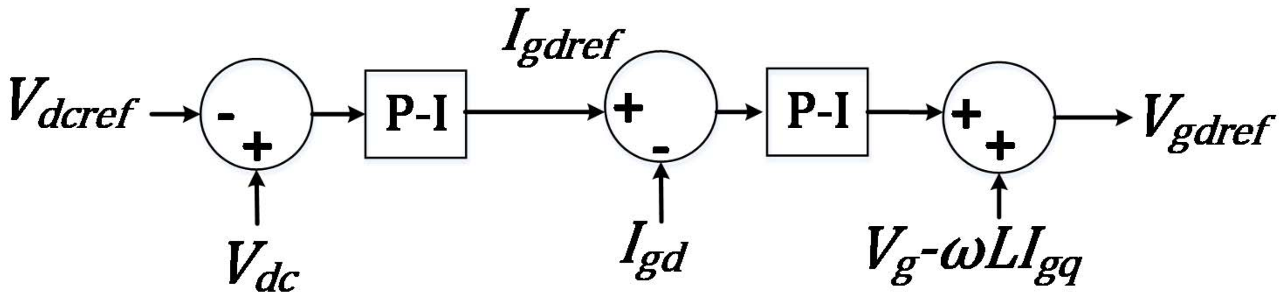
$$\frac{I_{dmref}}{I_b} = 0.01\frac{T_{ref}^2}{T_b^2} - 0.298\frac{T_{ref}}{T_b} + 0.0481$$

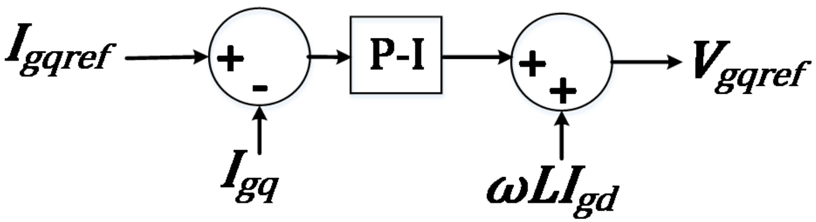
$$\frac{I_{qmref}}{I_b} = \frac{-2}{3\left(1 - \dfrac{I_{dref}}{I_b}\right)}\frac{T_{ref}}{T_b}$$

S. Huang, Z. Chen, K. Huang and J. Gao, “Maximum torque per ampere and flux-weakening control for PMSM based on curve fitting”, *Vehicular power and Propulsion Conference (VPPC)*, 2010, pp. 1-5

Grid side converter control

$$P_{dg} = \frac{3}{2} V_g i_{gd} \qquad Q_{dg} = -\frac{3}{2} V_g i_{gq} \qquad C\frac{dV_{dc}}{dt} = \frac{1}{V_{dc}}\left(P_m - P_{dg}\right)$$





Low Voltage Ride Through

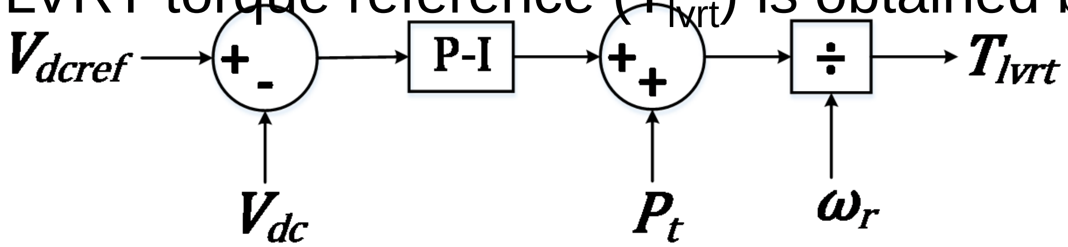
- During grid faults, the terminal bus voltage reduces
- As a result, active power injection by wind farm is limited
- Overvoltage of DC bus capacitor may take place

$$V_{dc}\left(C\frac{dV_{dc}}{dt}\right)=P_{cap}, \text{ where } P_{cap}=\text{stored capacitor power}$$

Considering variation of V_{dc} to be small, it can be approximated as

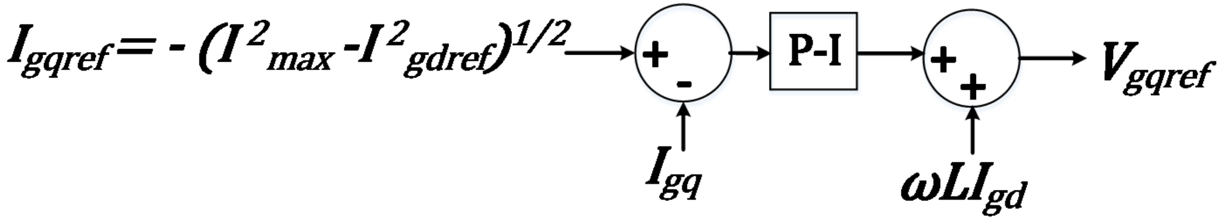
$$V_{dc0}\left(C\frac{dV_{dc}}{dt}\right)=P_{cap}\Rightarrow\frac{V_{dc}(s)}{P_{cap}(s)}=\frac{1}{V_{dc0}}\cdot\frac{1}{sC}$$

- A P-I controller is used to limit DC link overvoltage during faults
- P_{cap} is added with GSC terminal power to get P_{ref} for the MSC
- The LVRT torque reference (T_{lvrt}) is obtained by dividing P_{ref} by ω_r

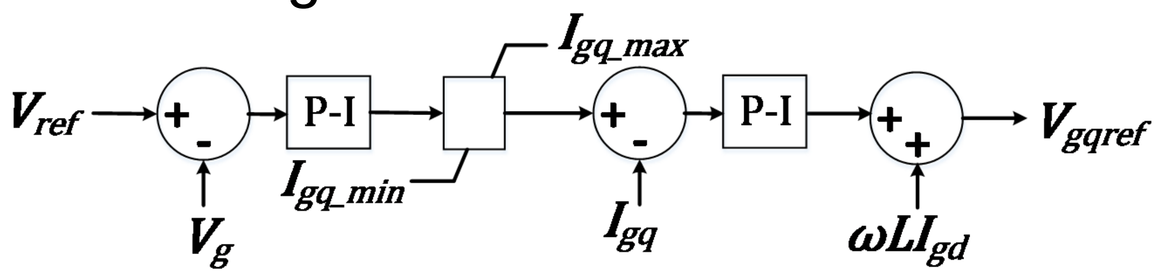


Proposed Modifications in Pre-fault and Post-fault Steady State

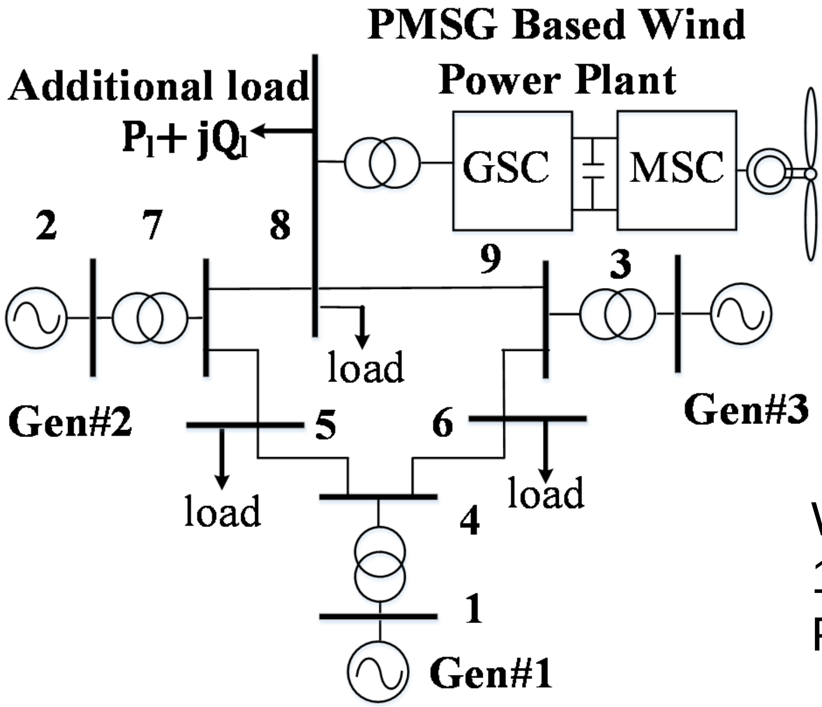
Case-I: Reactive Power Reference

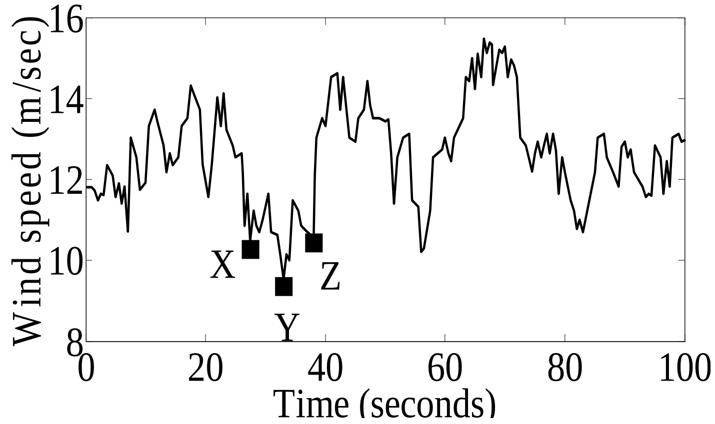


Case-II: Terminal Bus Voltage Control

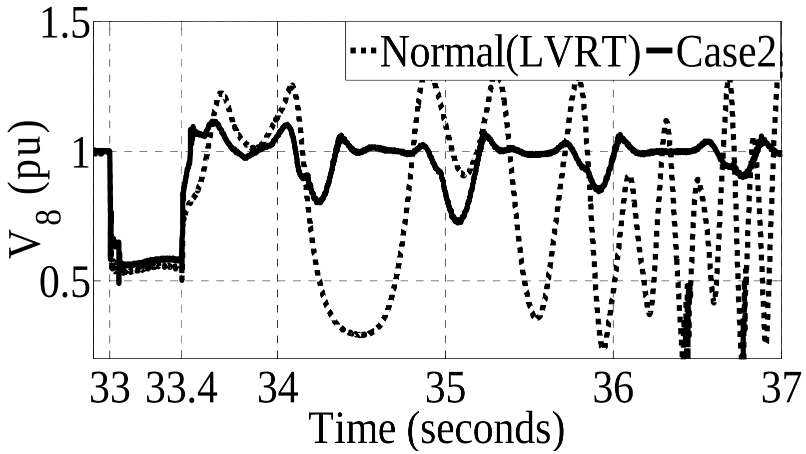


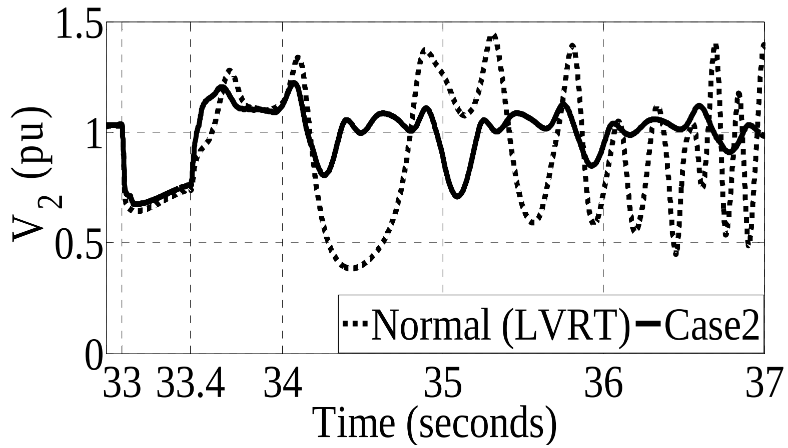
$$I_{gq\,max} = \sqrt{I_{max}^2 - I_{gdref}^2} \qquad I_{gq\,min} = -\sqrt{I_{max}^2 - I_{gdref}^2}$$



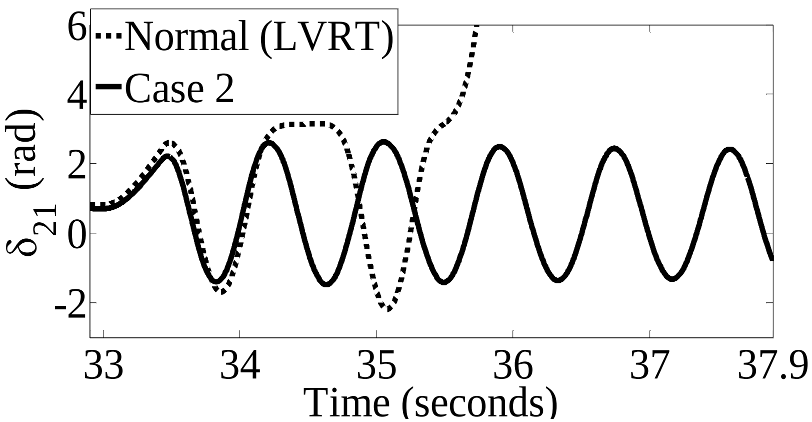


Wind speed varies between 9m/s & 15m/s
Power varies between 42% and 100%





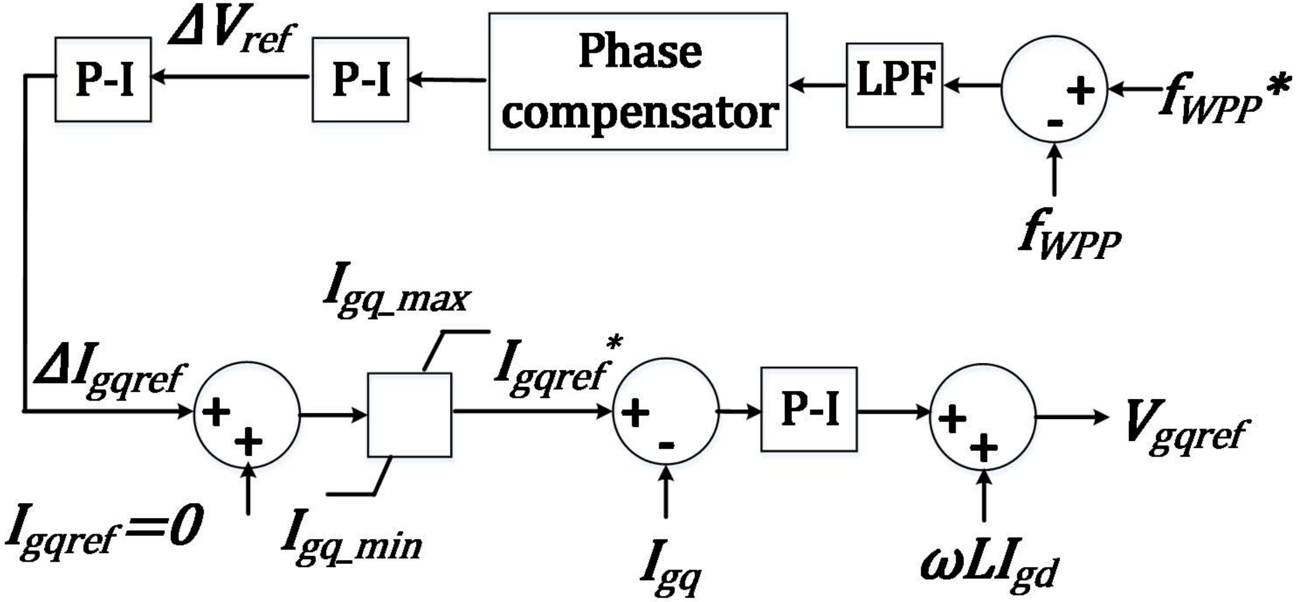
Effect of Modified Operation



Fault Location	Fault Instants	CCT (ms)				
		Normal	Case-1	Change	Case-2	Change
Bus 4	X	251	380	129	254	3
	Y	303	378	75	324	21
	Z	352	355	3	360	8
Bus 5	X	331	486	155	333	2
	Y	424	375	-49	492	68
	Z	521	470	-51	576	55

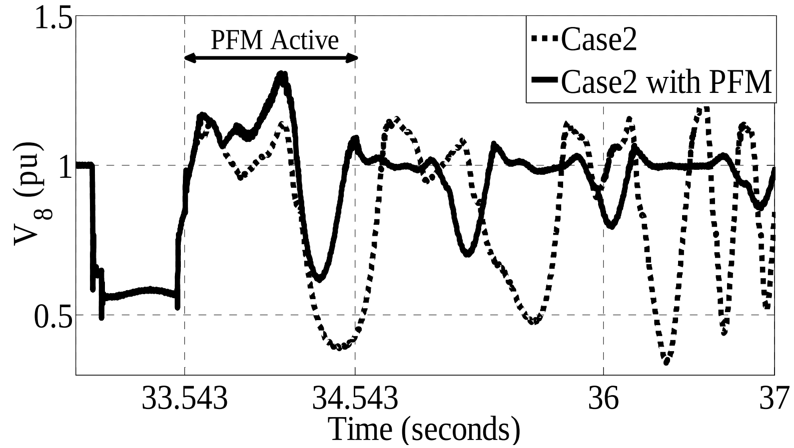
Case-II operation is preferred

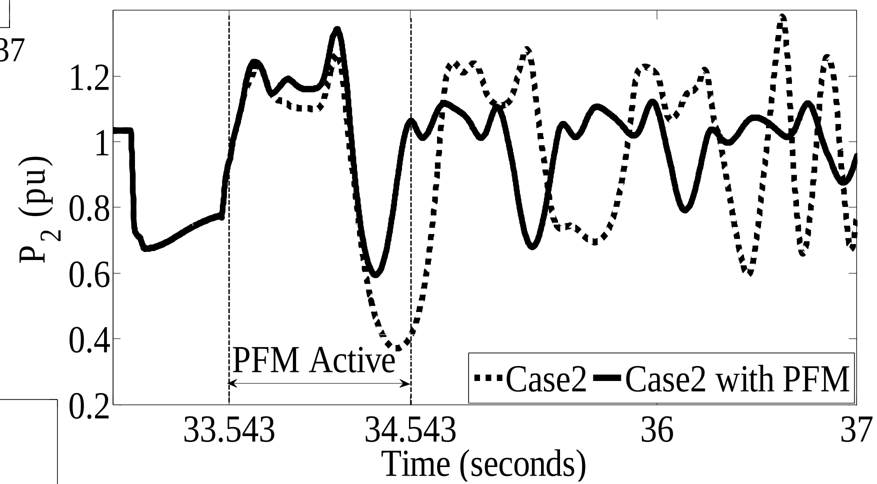
Proposed Modifications Just After Fault Clearance

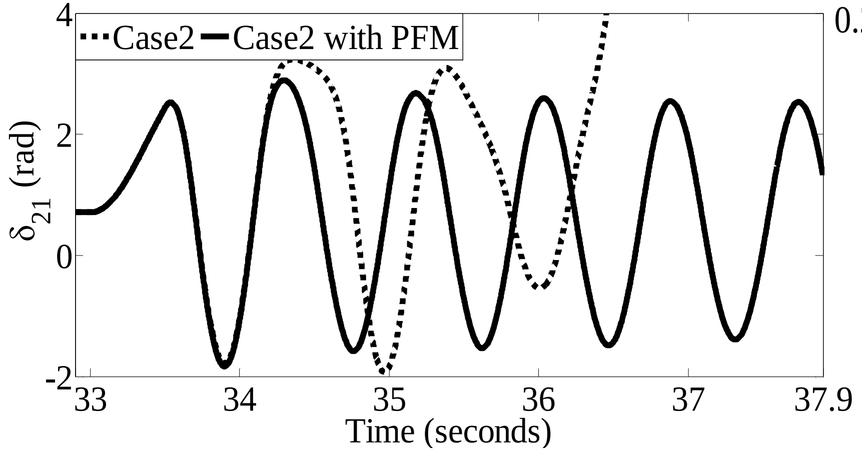


Applied for a small duration (1 s) after fault clearance

Effect of Modification Just after Fault Clearance







Effect of Overall Modifications In Terms of Change in CCT

Fault Bus	Fault Instants	Normal	Case 2 (ms)	Case2 with PFM (ms)	Overall Improvement (ms)
Bus 4	X	251	254	273	22
	Y	303	324	338	35
	Z	352	360	370	18
Bus 5	X	331	333	361	30
	Y	424	492	538	114
	Z	521	576	616	95

Conclusions

- ✓ This paper presents two possible modified operation of PMSG based wind power plant which may lead to enhanced transient stability margin of power systems.
- ✓ The first modification applicable during pre-fault and post-fault steady state, the GSC is controlled to maintain the power plant terminal voltage at a nominal value.
- ✓ In the second modification. which is applicable for a brief duration just after fault clearance, the reactive current reference of the GSC is modulated depending on the deviation in terminal bus frequency.
- ✓ Both the modifications are found to cause substantial improvement in transient stability condition.

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Thank You

Modelling of PMSG Based Wind Farm and Power Converters

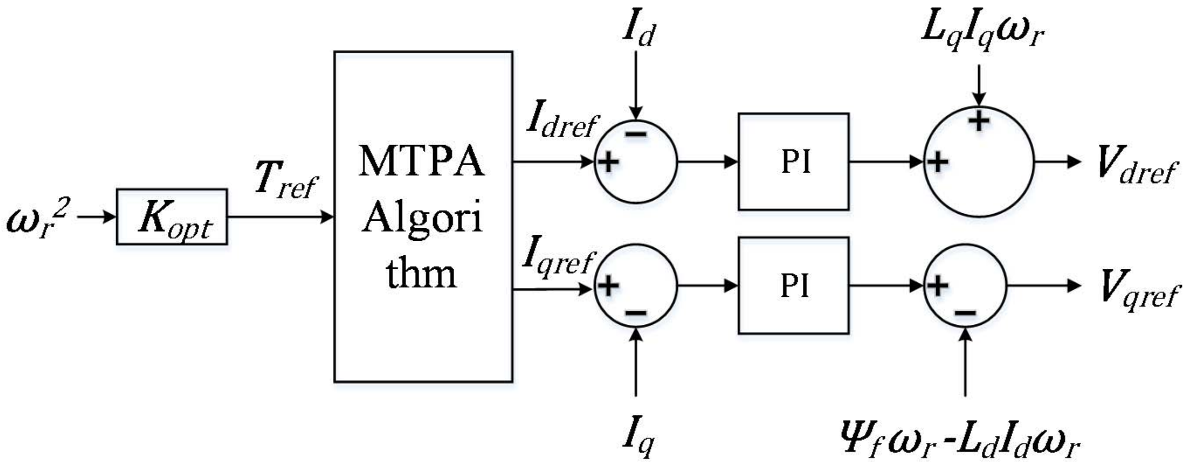
$$T_e = 1.5\frac{p}{2}\left[\left(L_q - L_d\right)I_d I_q + \psi_f I_q\right]$$

Under constant torque angle control, $I_d = 0$,

Torque controlled solely by I_q.

For IPMSM, $L_q \neq L_d$, So reluctance torque is used

to maximize total torque for lower stator current



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