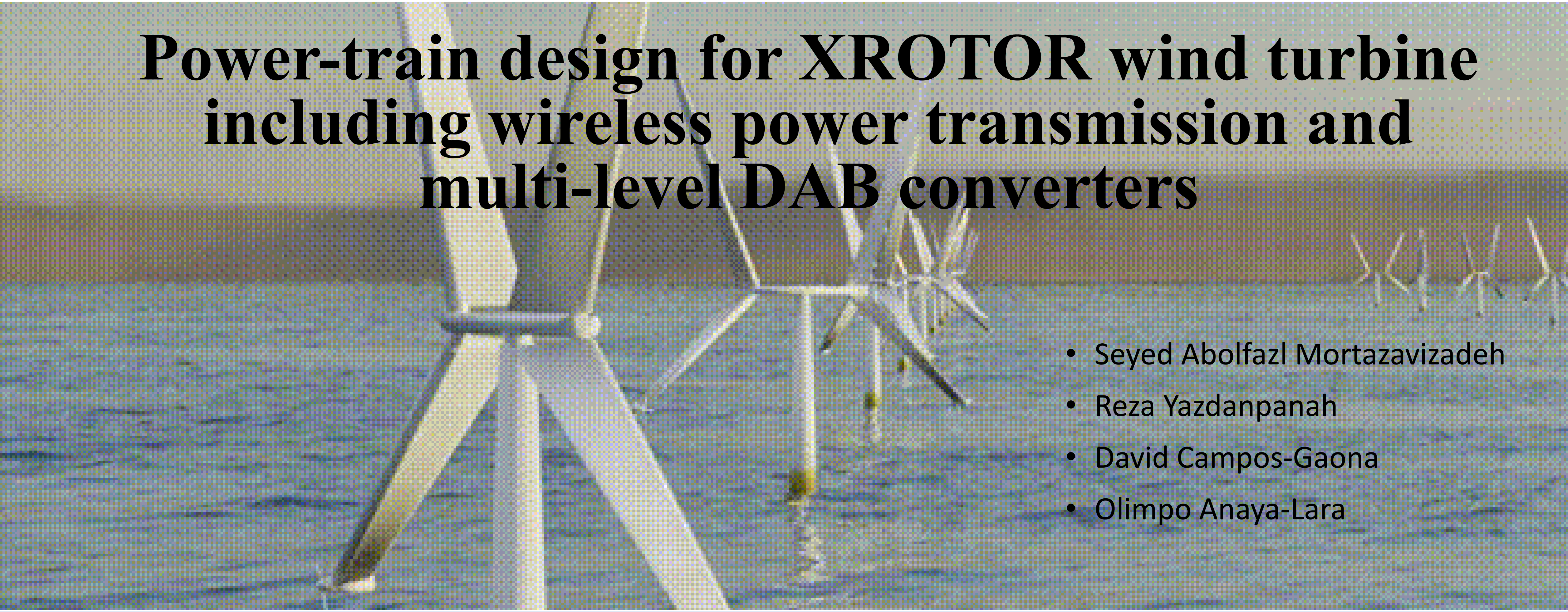
University of Strathclyde Glasgow

EERA DeepWind CONFERENCE 2024

XROTOR
X-shaped Radical Offshore Wind Turbine for Overall Cost of Energy Reduction



Power-train design for XROTOR wind turbine including wireless power transmission and multi-level DAB converters

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 101007135

https://xrotor-project.eu

X-shaped Radical Offshore Wind Turbine for Overall Cost of Energy Reduction

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XROTOR
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Introduction

- There is an increasing demand for renewable energy sources.
- X-shaped Radical Offshore wind Turbine for Overall cost of energy Reduction (XROTOR) project aims to decrease the O&M costs of offshore wind energy production up to 55% and capital costs up to 26%.
- A hybrid vertical-horizontal axis wind turbine using an X-shaped rotor
- in each tower of the XROTOR there are at least two generators
- In relation to each other, these generators experience load torques with phase shift
- With this phase shift between the generators, we are able to use controllers without overrating them to handle overload conditions

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System elements model

❑Generator

Three-phase permanent magnet synchronous machine

$$v_d = R_s i_d + L_d \frac{di_d}{dt} - \omega_e L_q i_q$$

$$v_q = R_s i_q + L_q \frac{di_q}{dt} + \omega_e L_d i_d + \lambda \omega_e$$

$$T_e = \frac{3}{2} p \left[\lambda i_q + \left(L_d - L_q \right) i_d i_q \right]$$

Table 1. PMSG parameters

Rated power	**2.5 MVA**	Pole pairs	**4**
Rated speed	**375 rpm**	Rated stator frequency	**25 Hz**
Rated voltage	**3300 V**	Ld	**13.9 mH**
Flux Linkage	**13 Wb**	Lq	**13.4 mH**
Inertia	**303.69 Kg.m^2**	Stator phase resistance	**0.049 ohm**
		Damping coefficient	**16.21 N.m**

With rotor flux-oriented control, the generator torque can be expressed as:

$$T_e = \frac{3}{2} p \left[\lambda i_q \right]$$

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System elements model

❑Overall system:

- Generators
- Machine-side converter and its controller
- Dual active bridge converter including rotary transformer
- Grid side converter

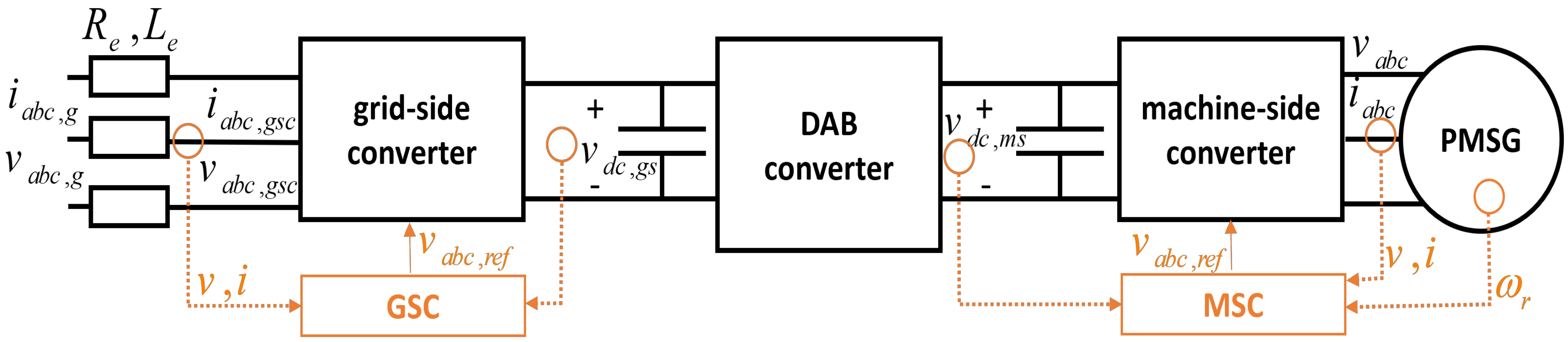

Fig. 0: Overall system and the control system block diagram

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System elements model

❑Generator

- The input to this block is the mechanical torque produced by the wind turbine
- Here two generators are being considered that experiencing nominal torque load. Furthermore, a sinusoidal load torque with 50% of nominal torque is added to this load.

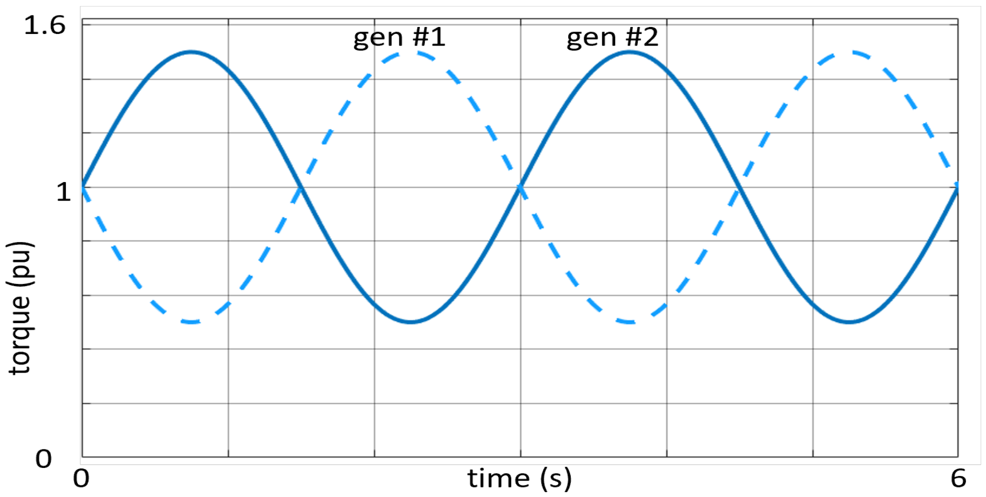

Fig. 1: input mechanical torque to the generators

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System elements model

❑ Machine-side converter controller

- Active power control and tracking its maximum available value are considered in control objectives of the machine-side converter

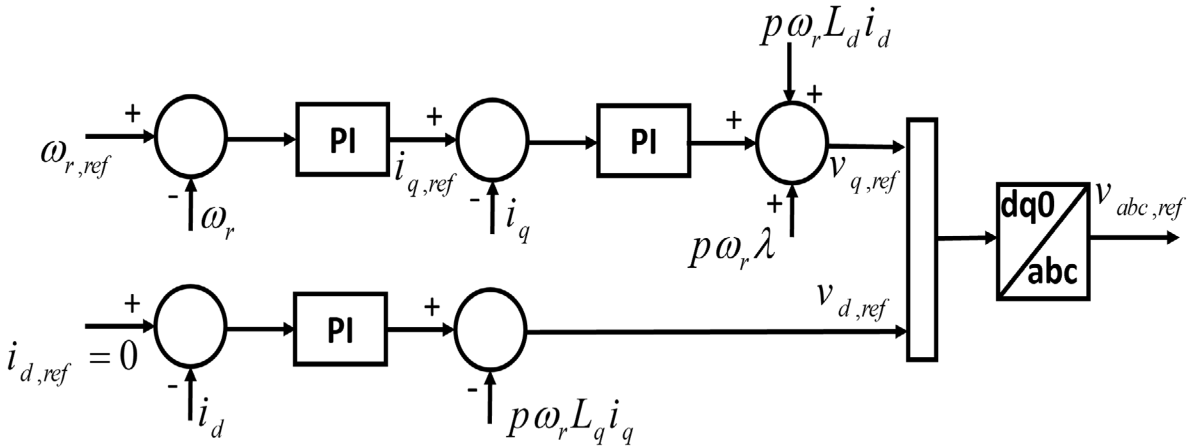

Fig. 2: machine-side converter's controller

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System elements model

❑ Grid-side converter controller

- At the grid-side, the inverter is responsible for regulating the dc-link voltage and transferring the active power generated from wind generator to the grid.
- The q axis loop is applied to control the reactive power injection, while the d axis loop is used for controlling the DC link voltage.
- The model of the grid-side converter in d-q frame is given as:

$$v_{d,gsc} = R_e i_{d,gsc} + L_e \frac{di_{d,gsc}}{dt} - \omega_0 L_e i_{q,gsc} + v_{d,g}$$

$$v_{q,gsc} = R_e i_{q,gsc} + L_e \frac{di_{q,gsc}}{dt} + \omega_0 L_e i_{d,gsc} + v_{q,g}$$

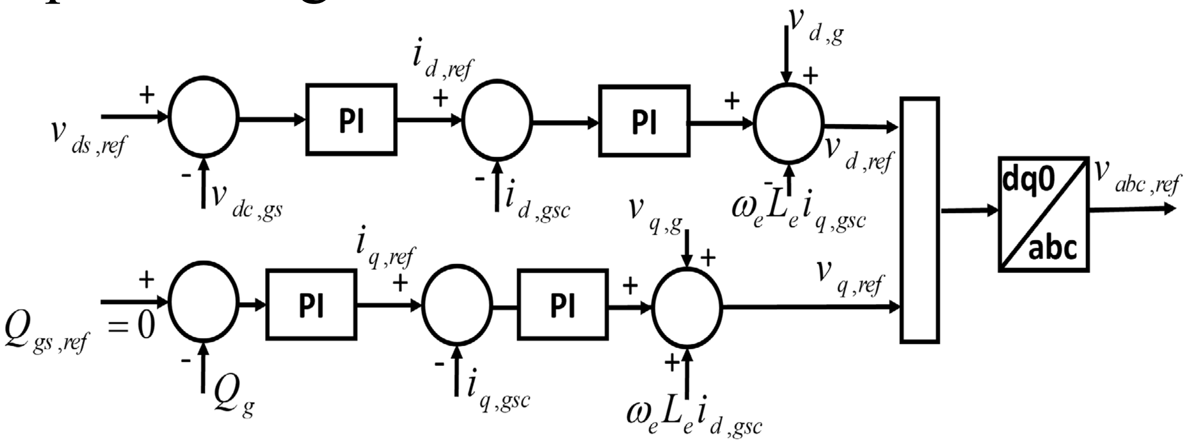

Fig. 3: Grid-side converter’s controller

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System elements model

❑ Dual active bridge

- The DAB topology can operate efficiently when the switching devices operate under zero voltage switching (ZVS) condition for the entire power range.
- The control parameter, ϕ is defined as the phase shift between the fundamental components of primary five level voltage and the secondary two-level voltage
- RT is used here to enable wireless power transfer

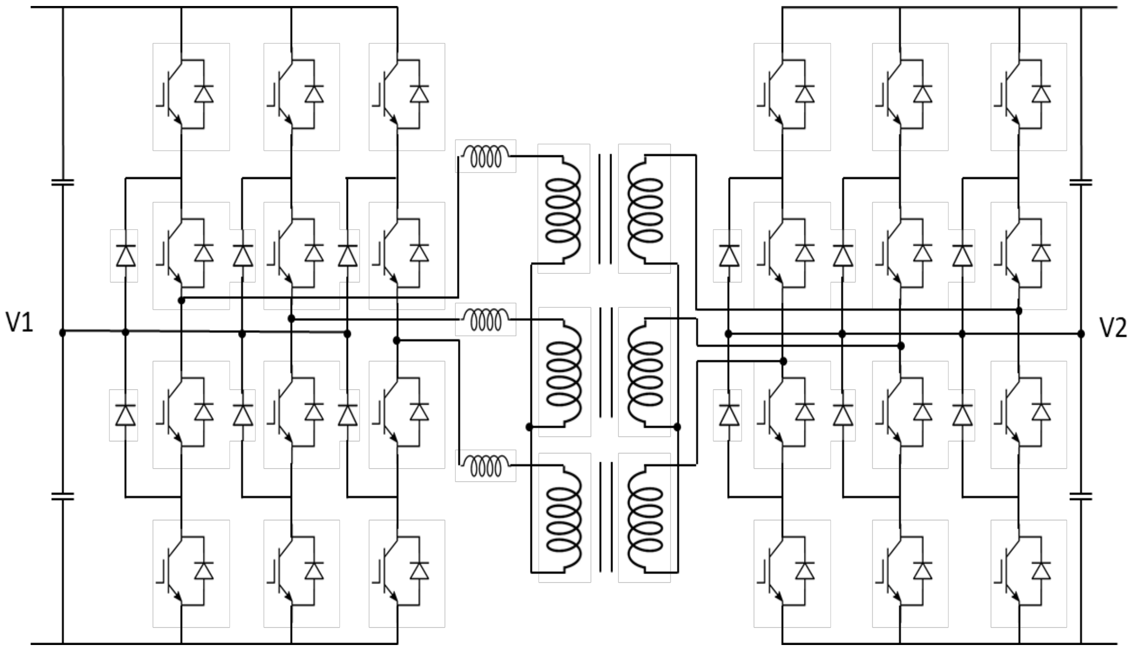

Fig. 4: Multi-level three phase DAB converter, 5-level NPC topology

Simulations

- Two scenarios are considered here. The first one is independent operation of the generators and their power train, assuming the rated mechanical input to the generator. In this method each DAB converter transfers the power of one generator and as the input mechanical power fluctuates over and under the rated power, DAB converter should be designed for higher power rating, here 50% higher

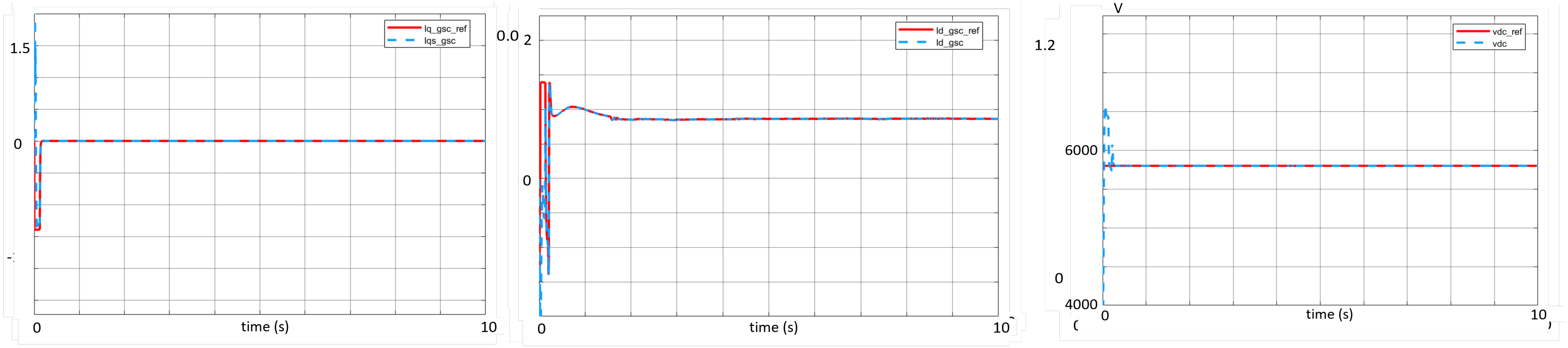

Fig 8. simulation results of independent generator operation, 2.5 MW input power

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Simulations

- The second scenario is the parallel configuration where two DAB converters share the input power. The average value of the accumulative mechanical load is 2pu for two generators but, there is no need to over rating of the DAB converters. Here, the machine-side dc-links are in parallel.

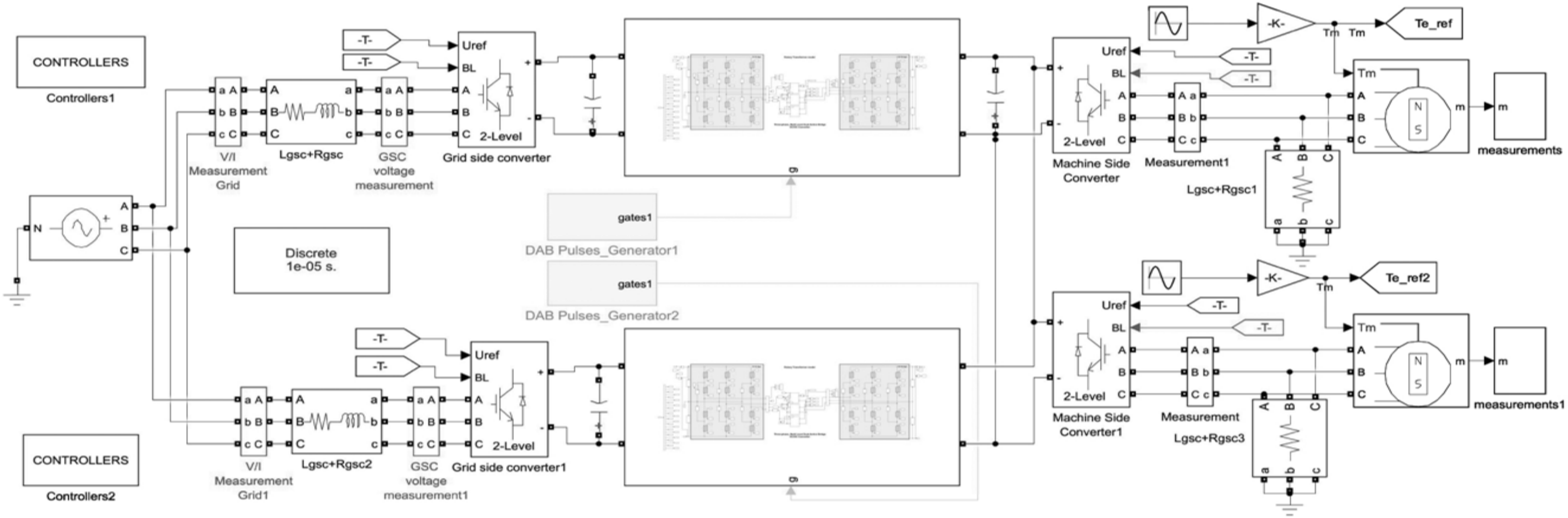

Fig 9. simulated power train for second scenario in MATLAB-Simulink

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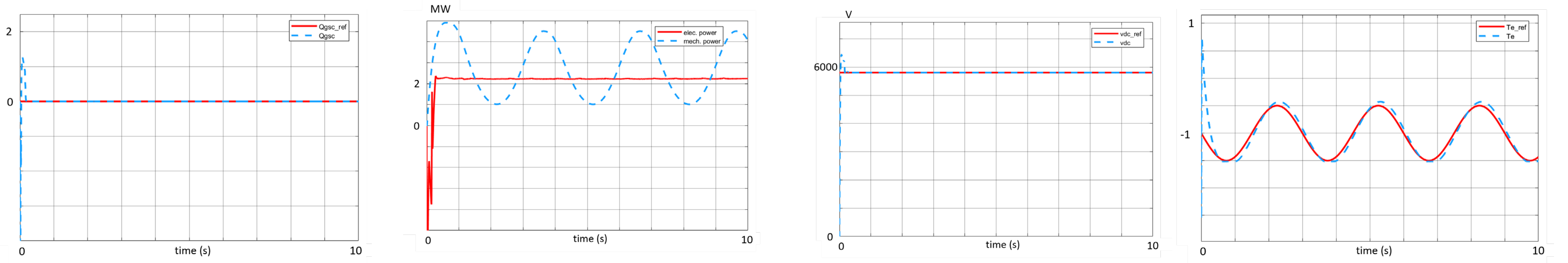
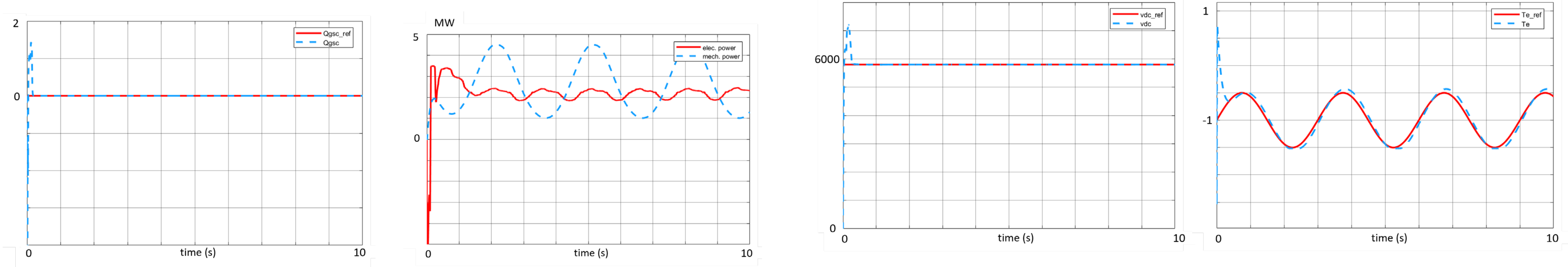
Simulations

❑Simulation results

- For generator 1:



- For generator 2:



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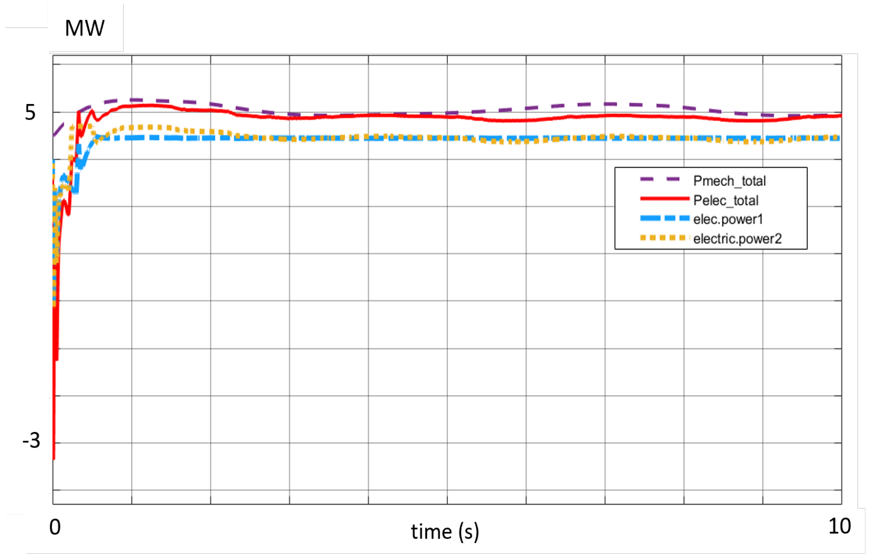
Simulations

❑Simulation results



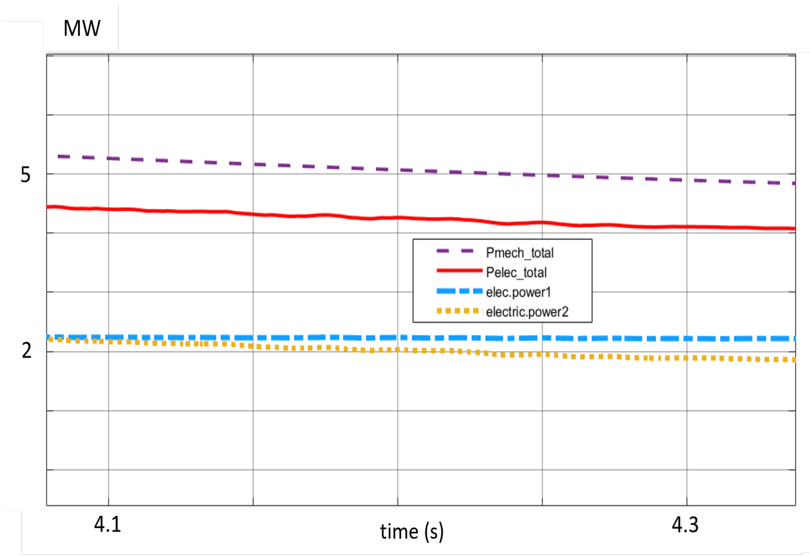


Fig. 10: simulation results of parallel generators operation, electrical and mechanical powers

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Conclusions

- For a novel wind turbine called XROTOR, multi-level 3-phase DAB converters with rotary transformers were developed. Two PMSGs are placed on lower tips of blades to capture wind energy in this structure.
- Since they experience torque shifts with respect to each other, paralleling the DAB converters allowed us to supply the load with overloading.
- The simulations first show the performance of the power train with 95% total efficiency from PMSGs to network while the mechanical slip rings are replaced with wireless power transfers to reduce maintenance costs.
- Two load torques with sinusoidal shapes and out of phase waveforms are considered, and DABs with parallel connections share the load properly. The DAB converters are controlled by two controllers, one of which supplies the network with the rated power and the other which supplies the rest available power. In this way, overloading up to 50% could be handled without overrating the converters, as shown by MATLAB/Simulink simulation results.

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Thanks for your attention.