Fast Frequency Response from Offshore Wind Farms Connected to HVDC via Diode Rectifiers

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Offshore Wind Farm Connection to HVDC

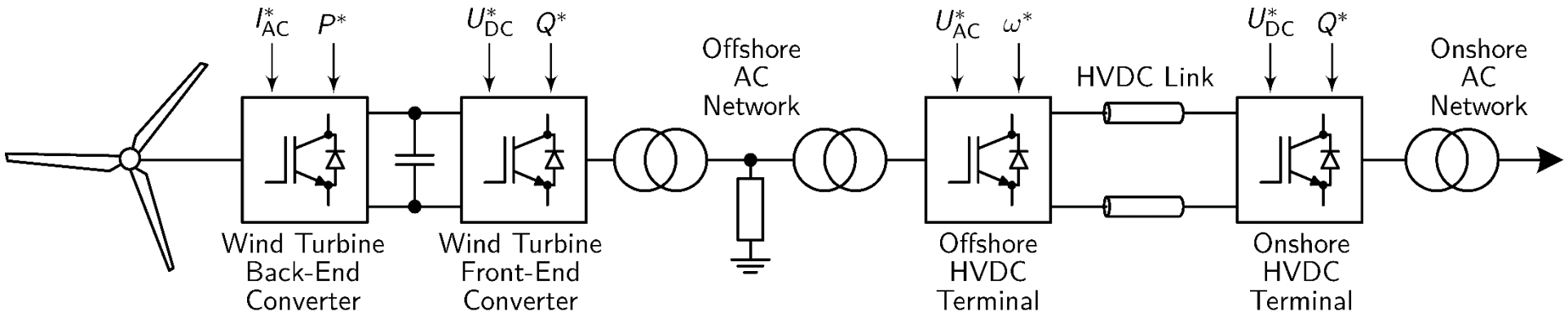
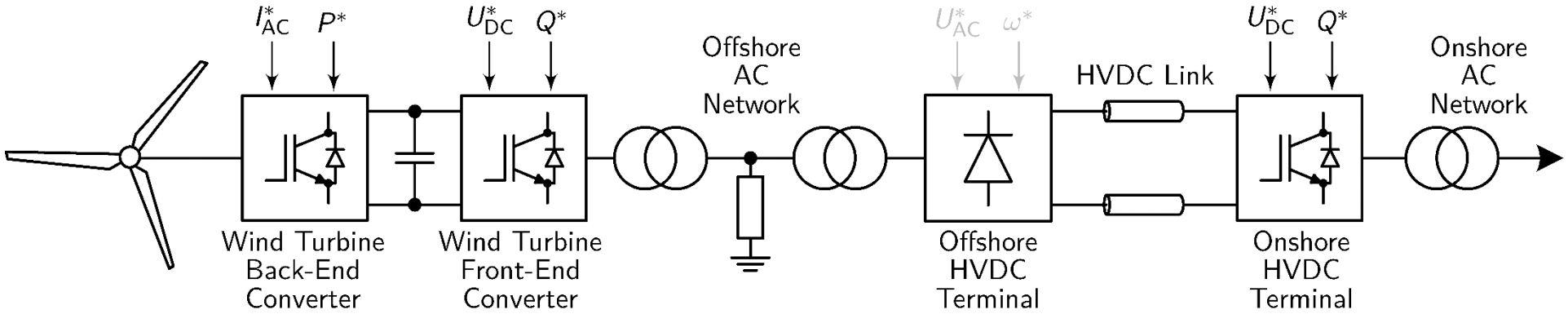


Figure: Offshore Wind Farm Connection to HVDC via Voltage Source Converters (VSCs)

Offshore Wind Farm Connection to HVDC



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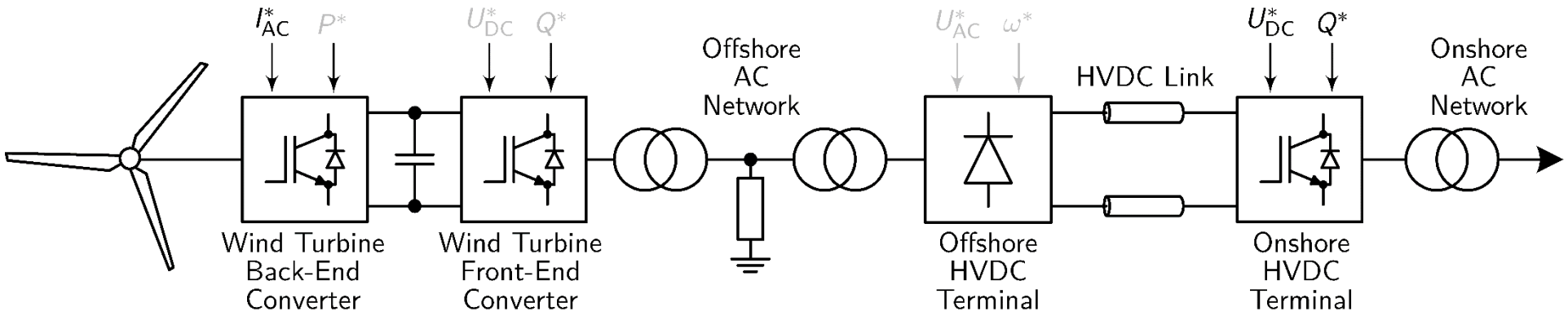

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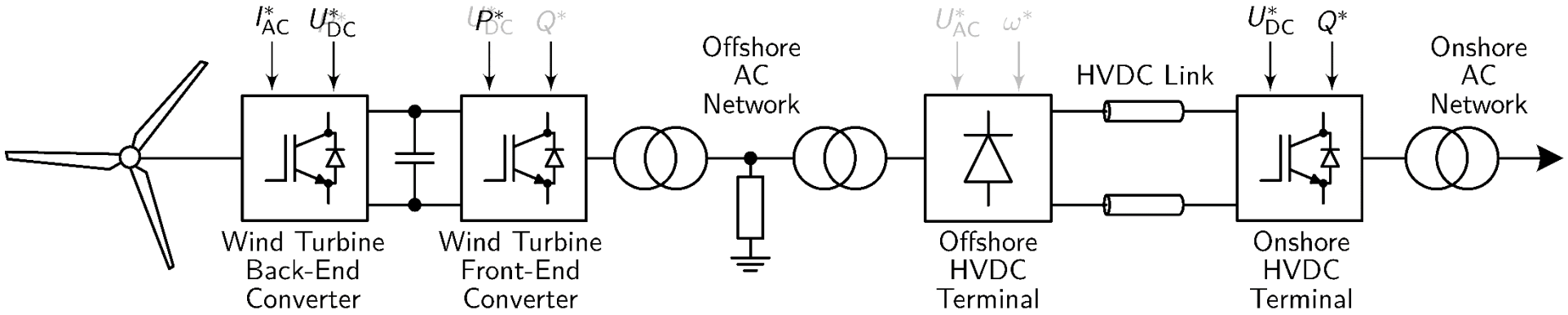

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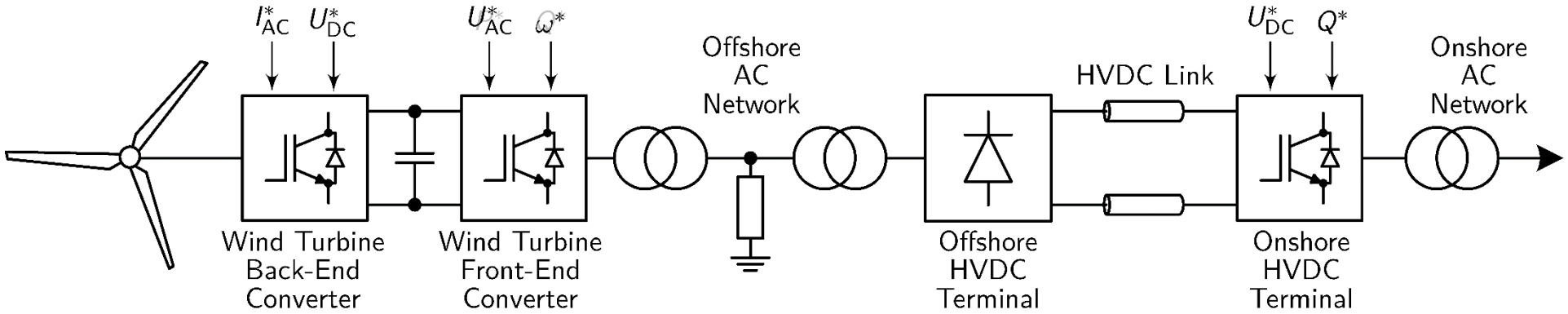

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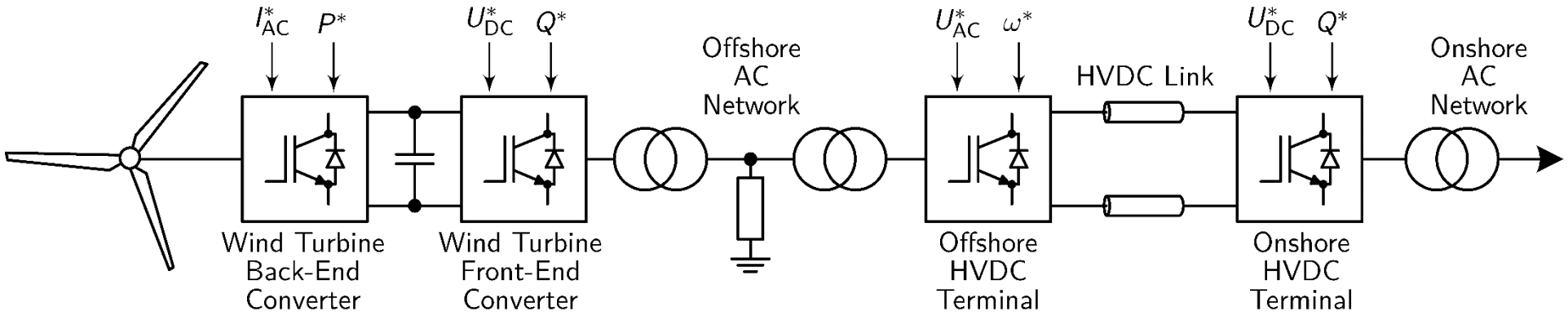

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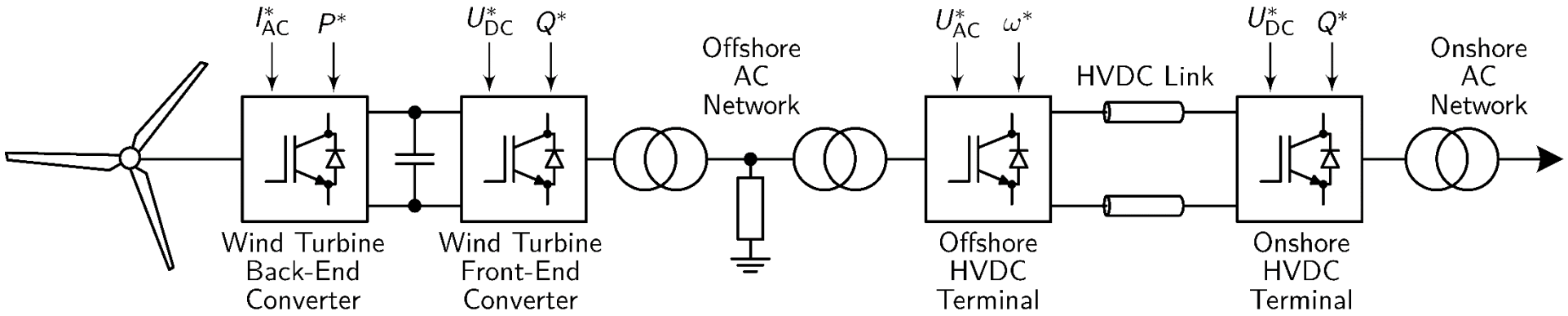

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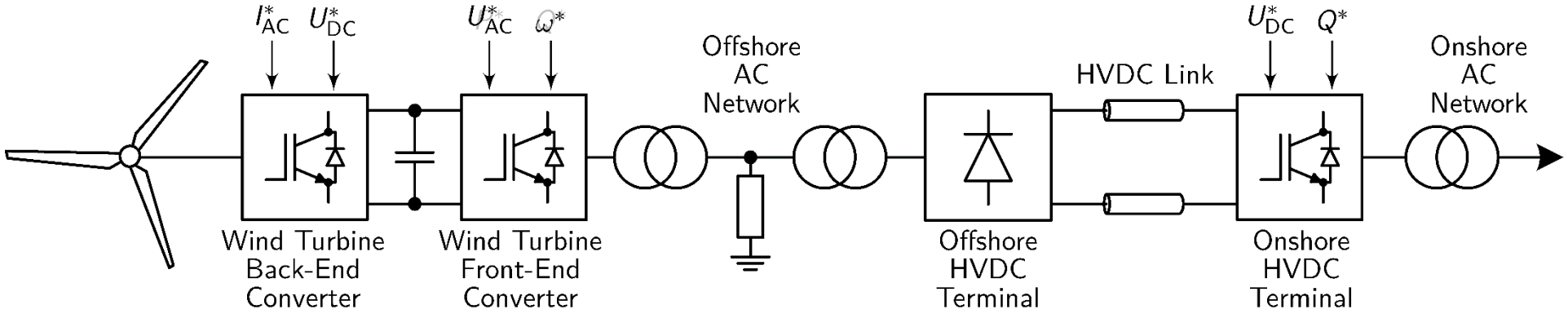

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Onshore Frequency Support

Onshore Frequency Support

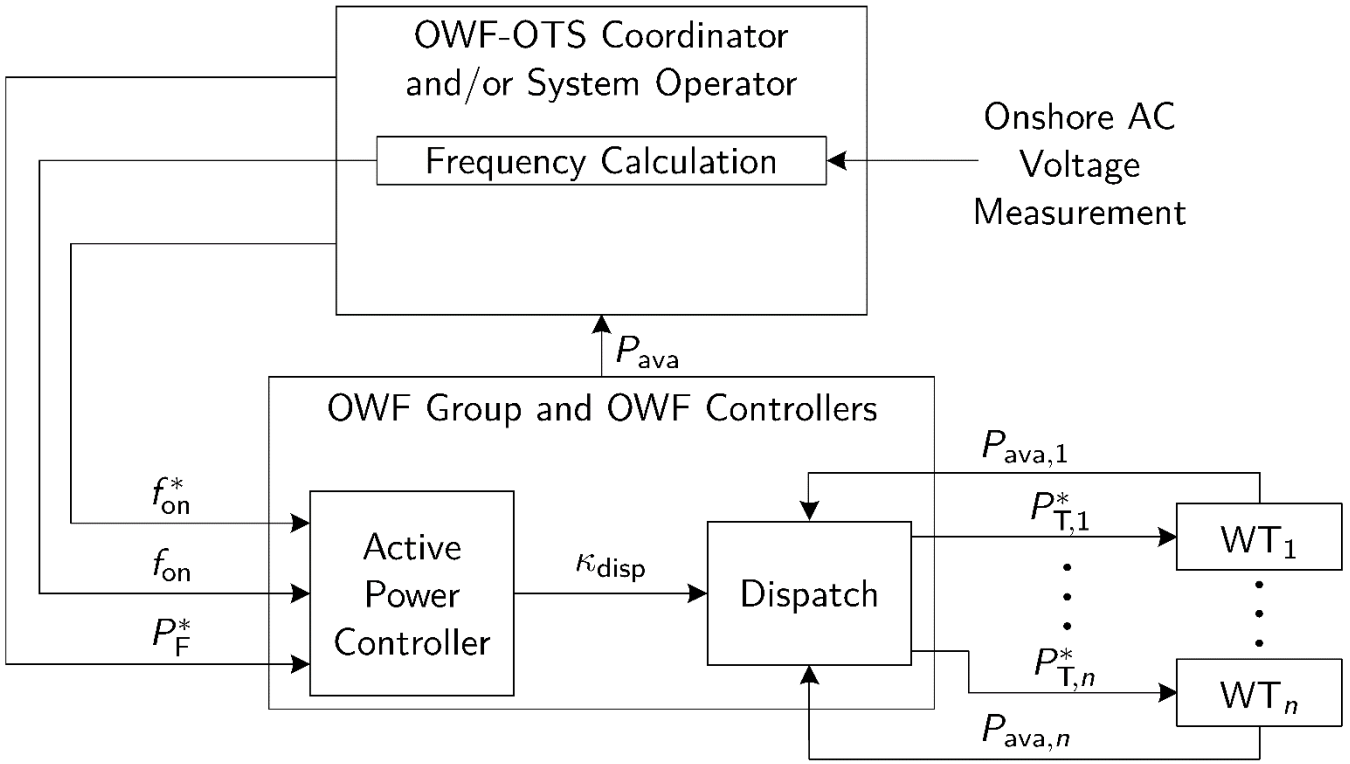
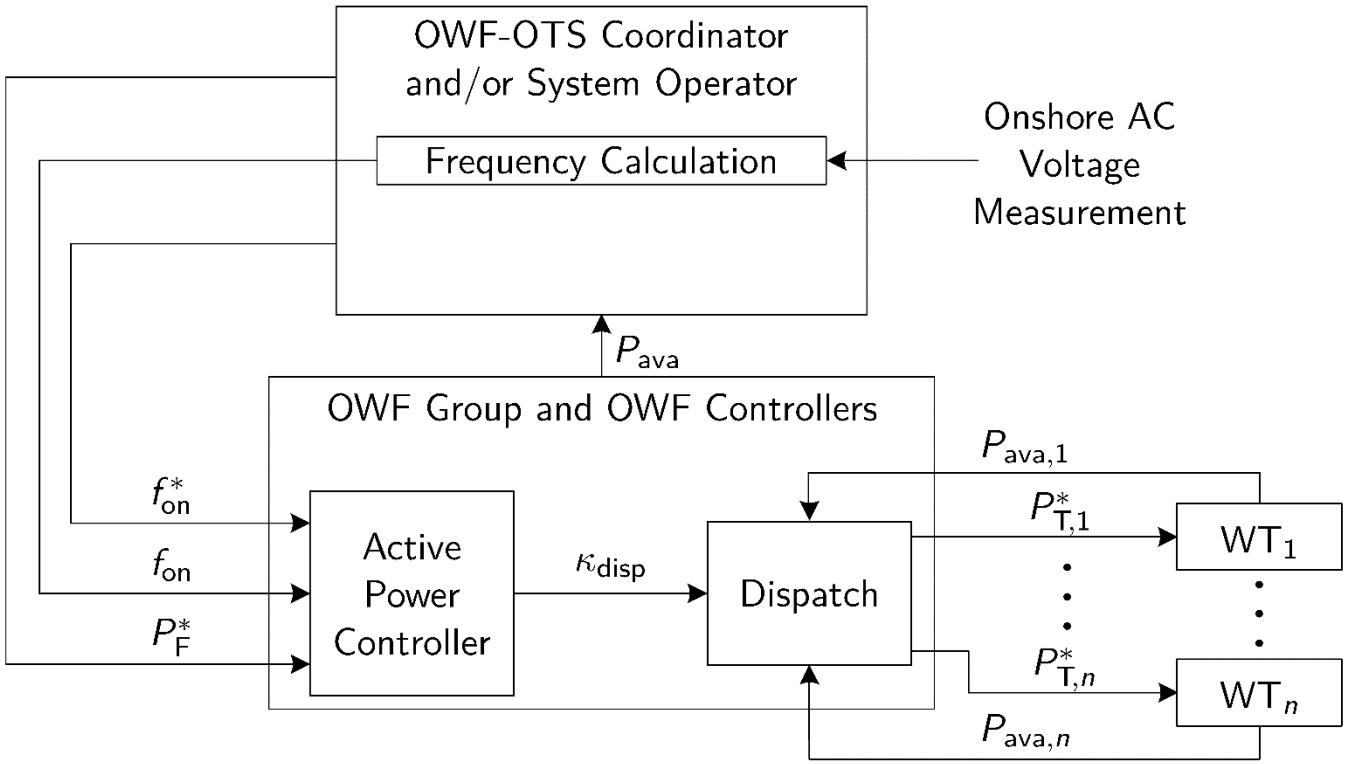


Figure: Simplified block diagram of the functionality for providing frequency support

Onshore Frequency Support



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- f_{on} communicated with a delay of 100 ms

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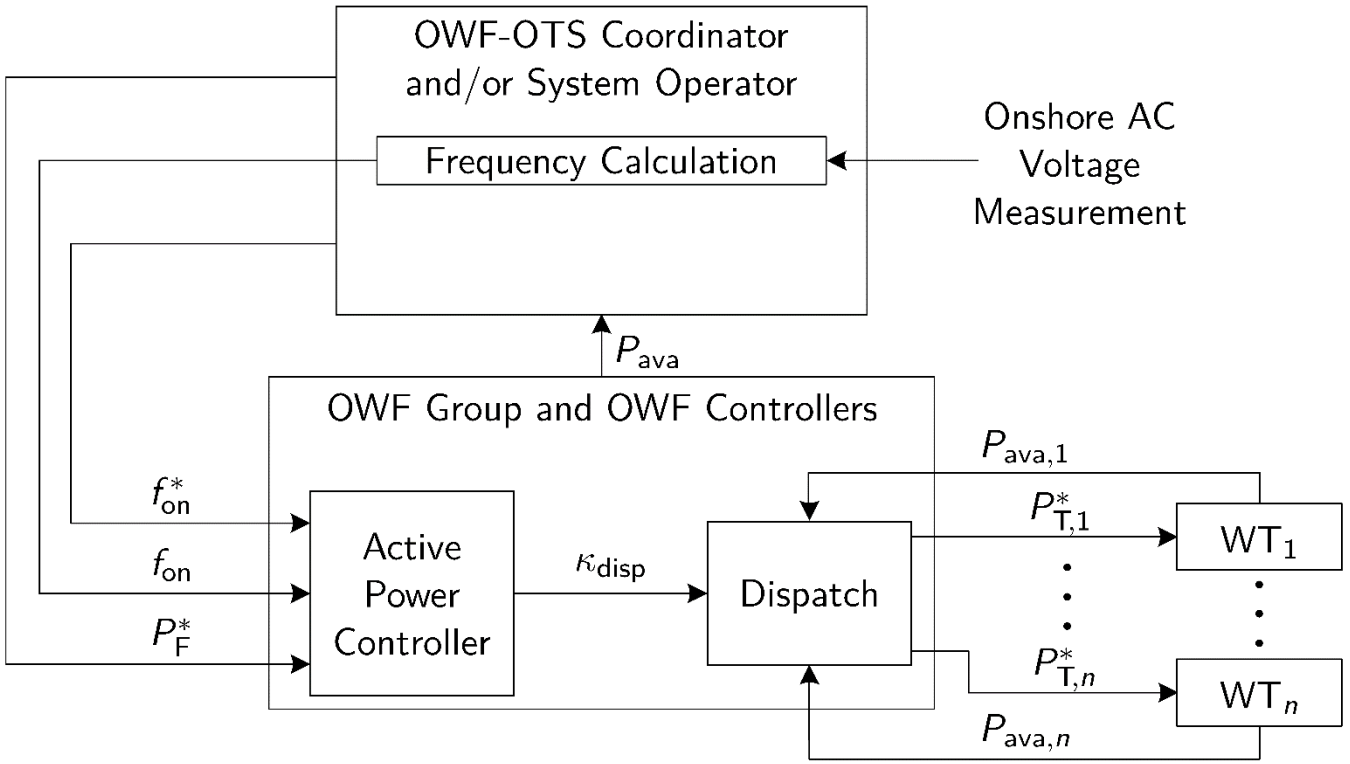

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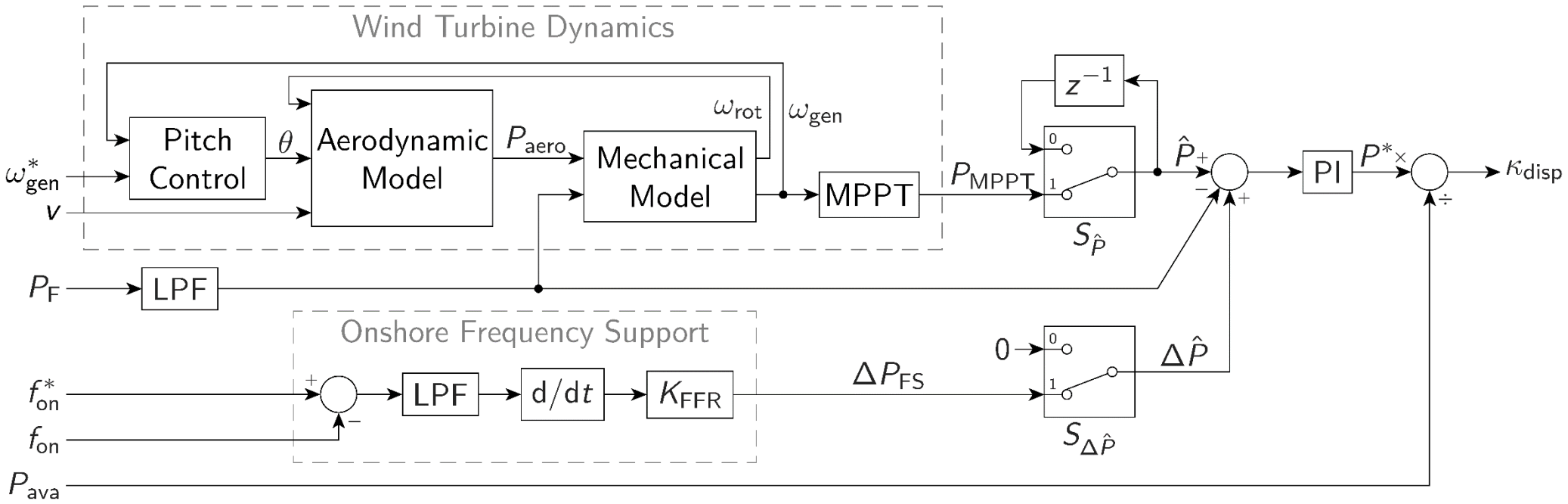
- f_{on} communicated with a delay of 100 ms
- Proportional dispatch: $P^*_{T,k} = \kappa_{disp} P_{ava,k}$

Wind Farm Active Power Control

Wind Farm Active Power Control



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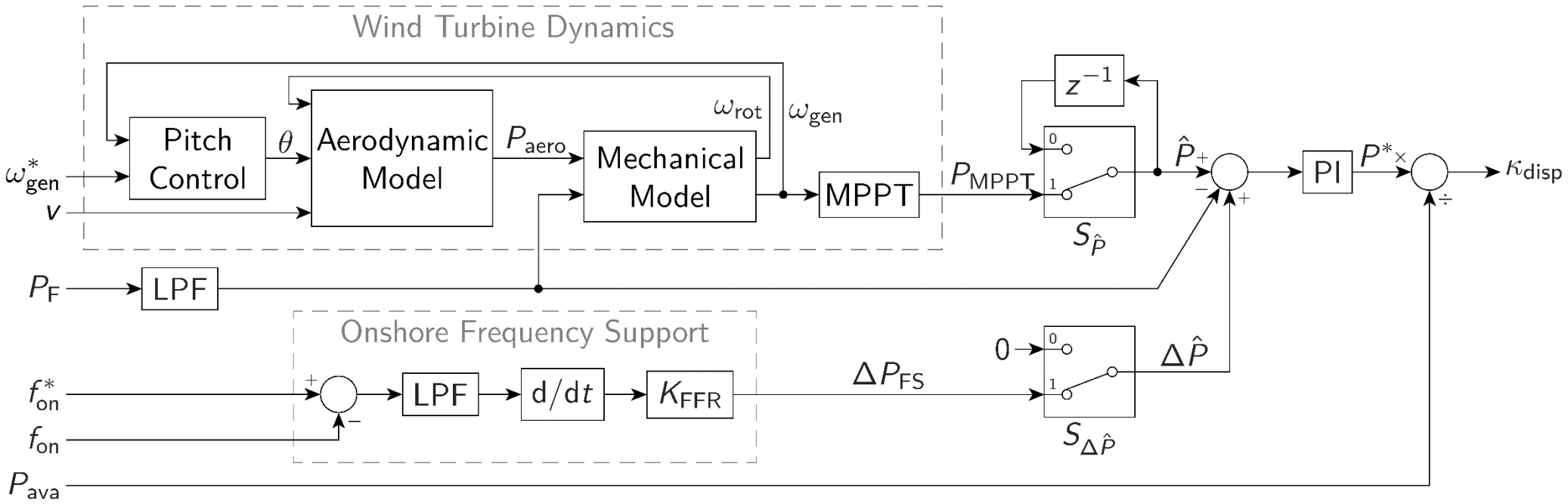

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- Wind turbines are overloaded to extract kinetic energy from their rotating masses

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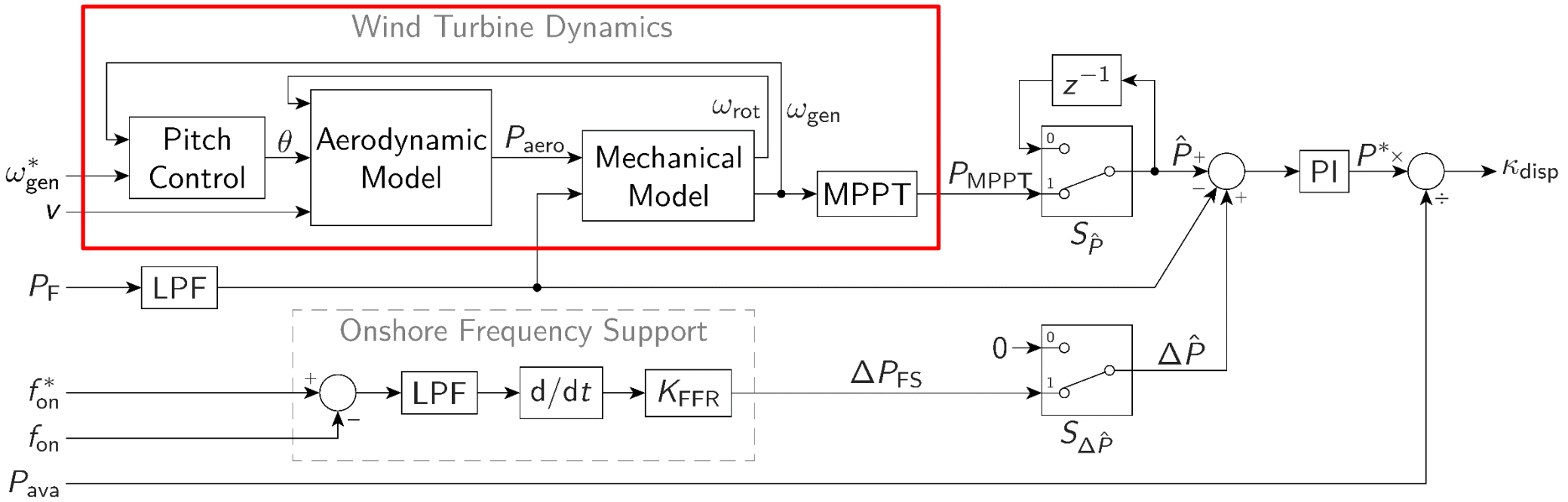
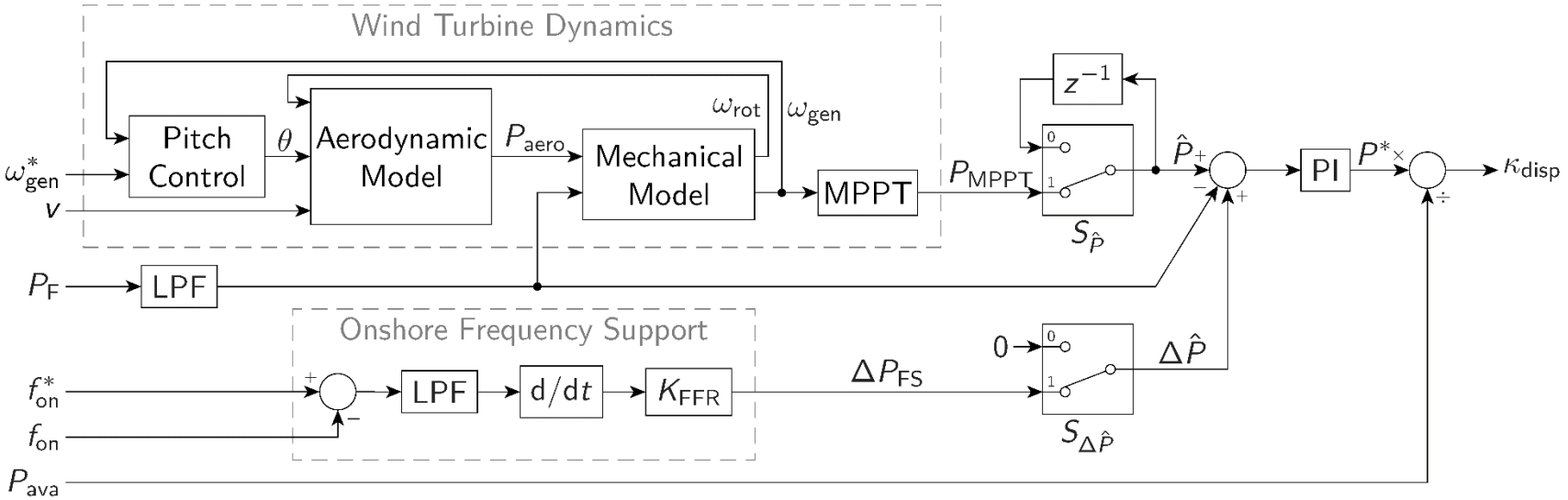


Figure: Wind farm active power control

- Wind turbines are overloaded to extract kinetic energy from their rotating masses
- Wind turbine dynamics → internal aggregated model

Wind Farm Active Power Control



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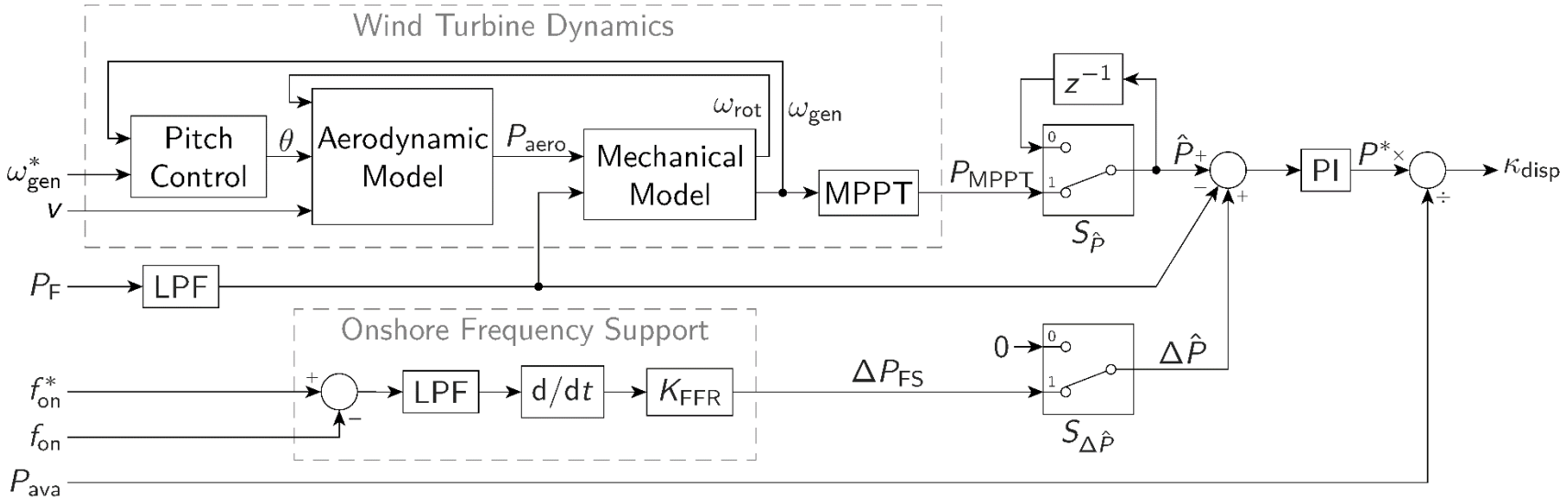
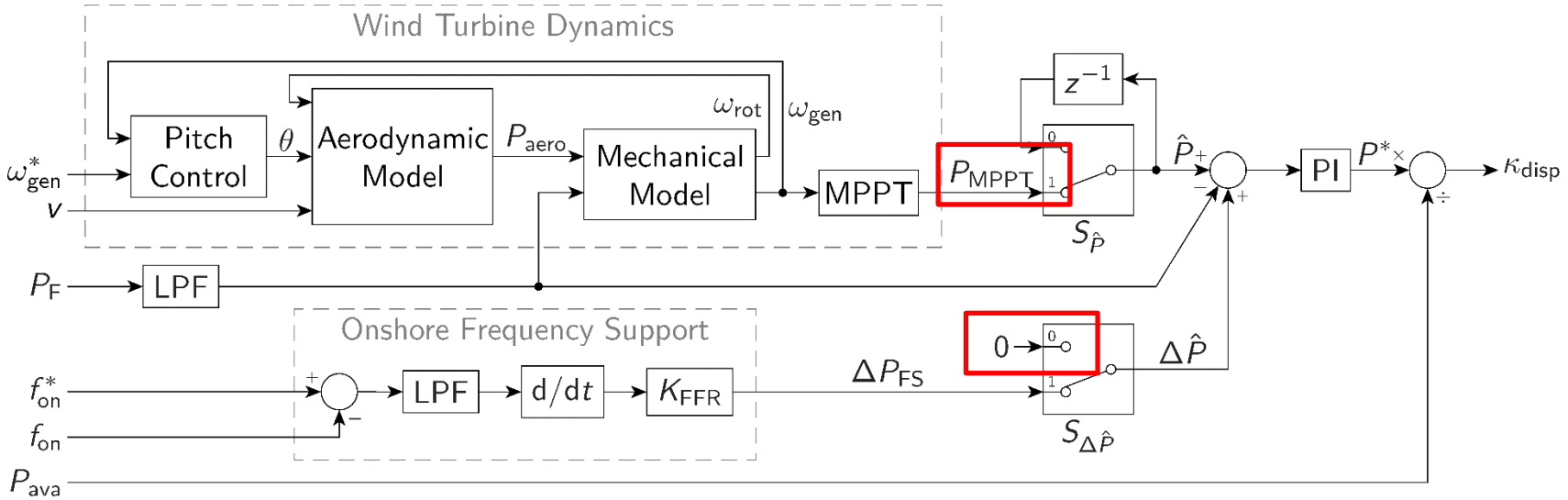


$S_{\Delta\hat{P}}$	$S_{\hat{P}}$	Case
0	1	No FS
1	0	Non-adaptive
	1	Adaptive

Wind Farm Active Power Control



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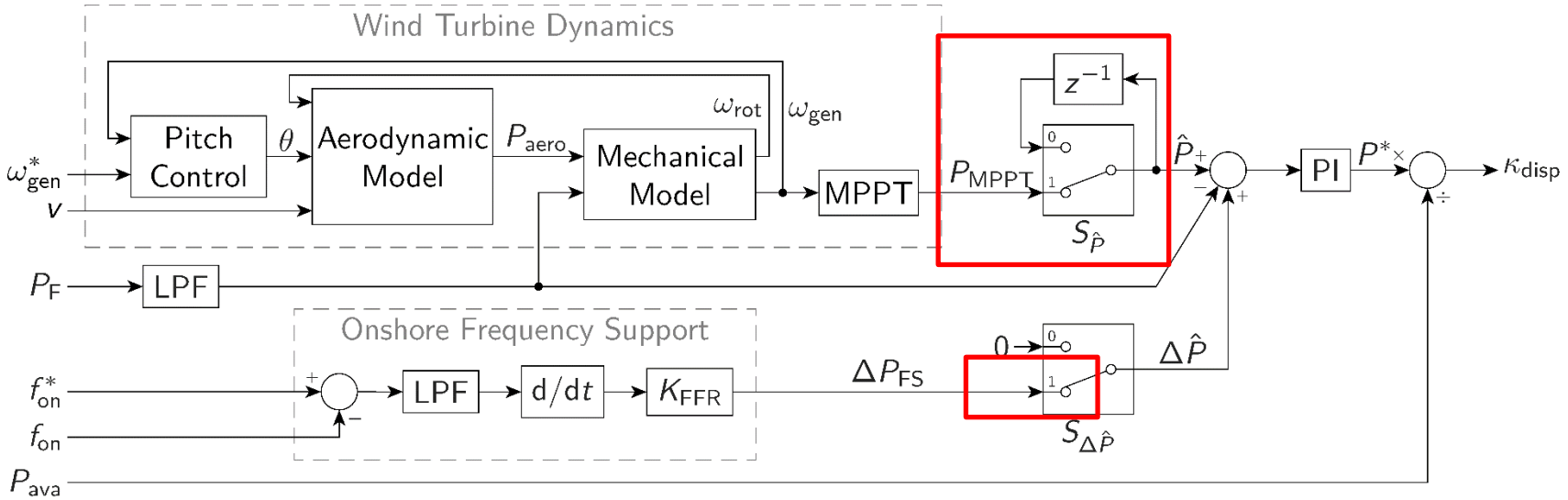
Wind Farm Active Power Control

- Two overloading methods: Non-adaptive, adaptive



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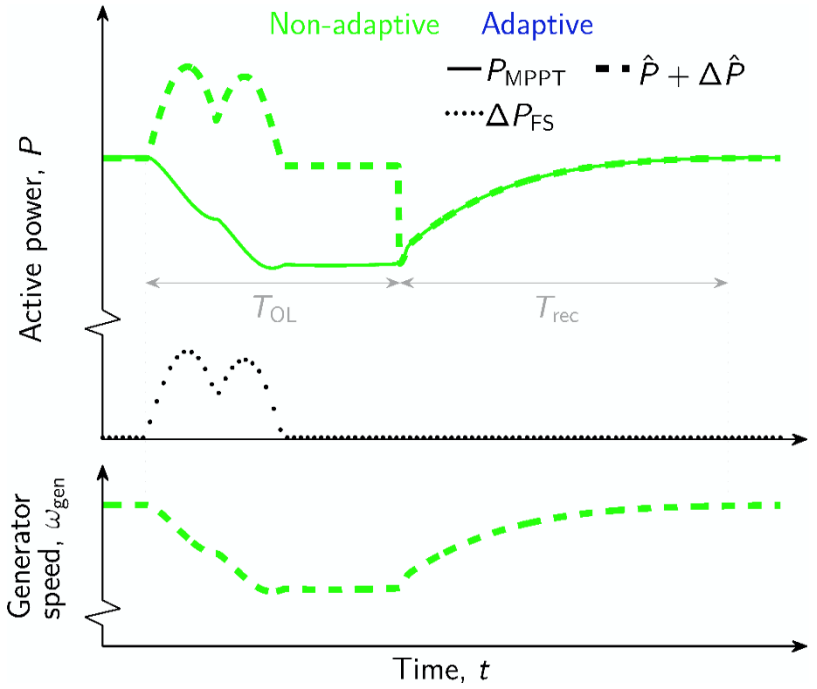

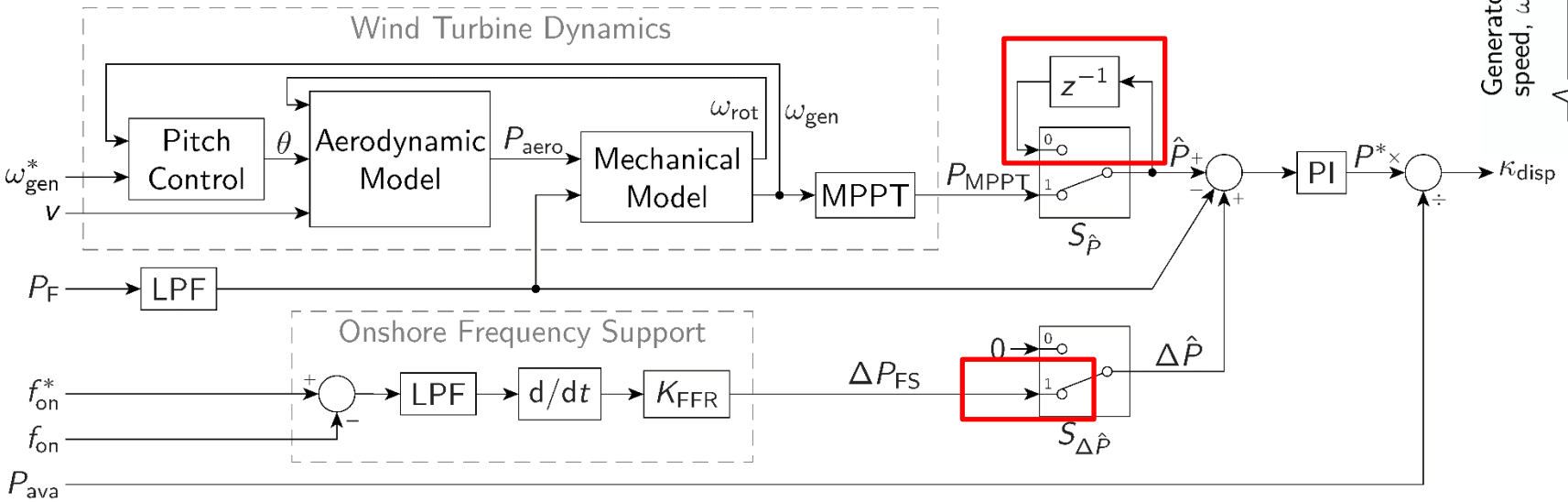

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Wind Farm Active Power Control

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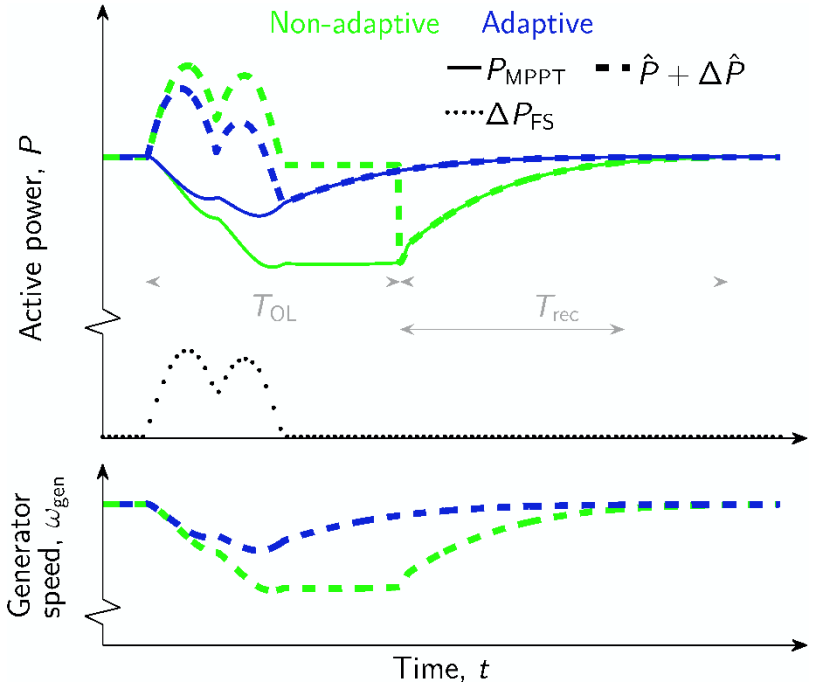
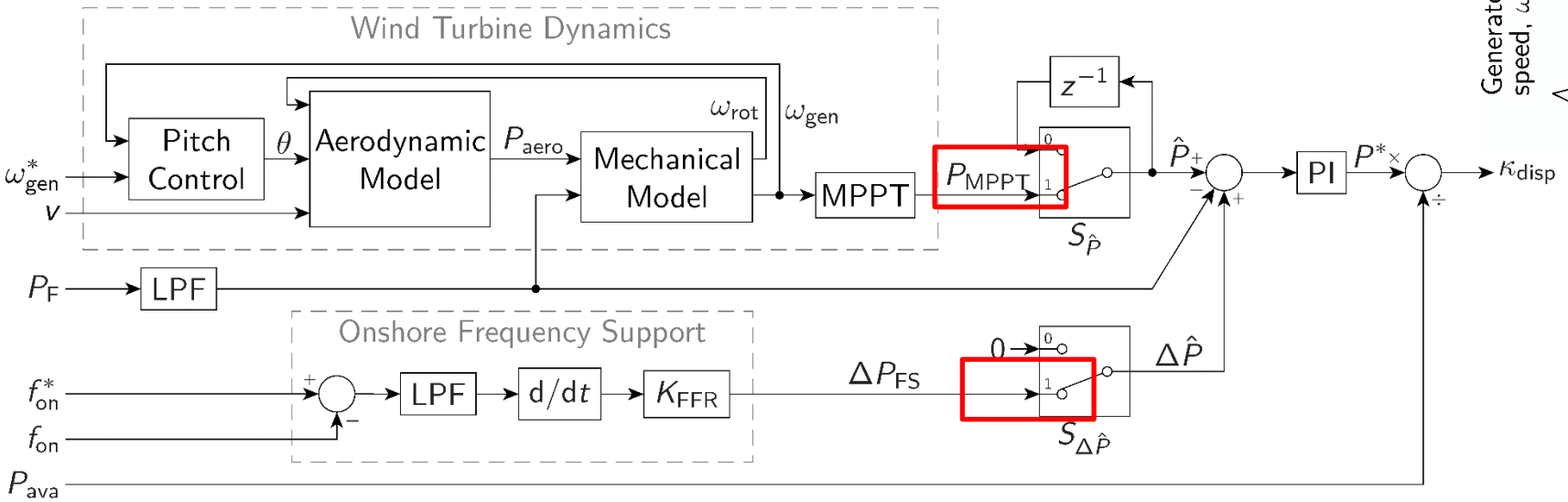
- Non-adaptive method: $\hat{P} = P_{\mathrm{MPPT}_0} \; \forall \, t \in T_{\mathrm{OL}}$
- Adaptive method: $\hat{P} = P_{\mathrm{MPPT}}(\omega_{\mathrm{gen}}) \; \forall \, t \in T_{\mathrm{OL}}$





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Studied System

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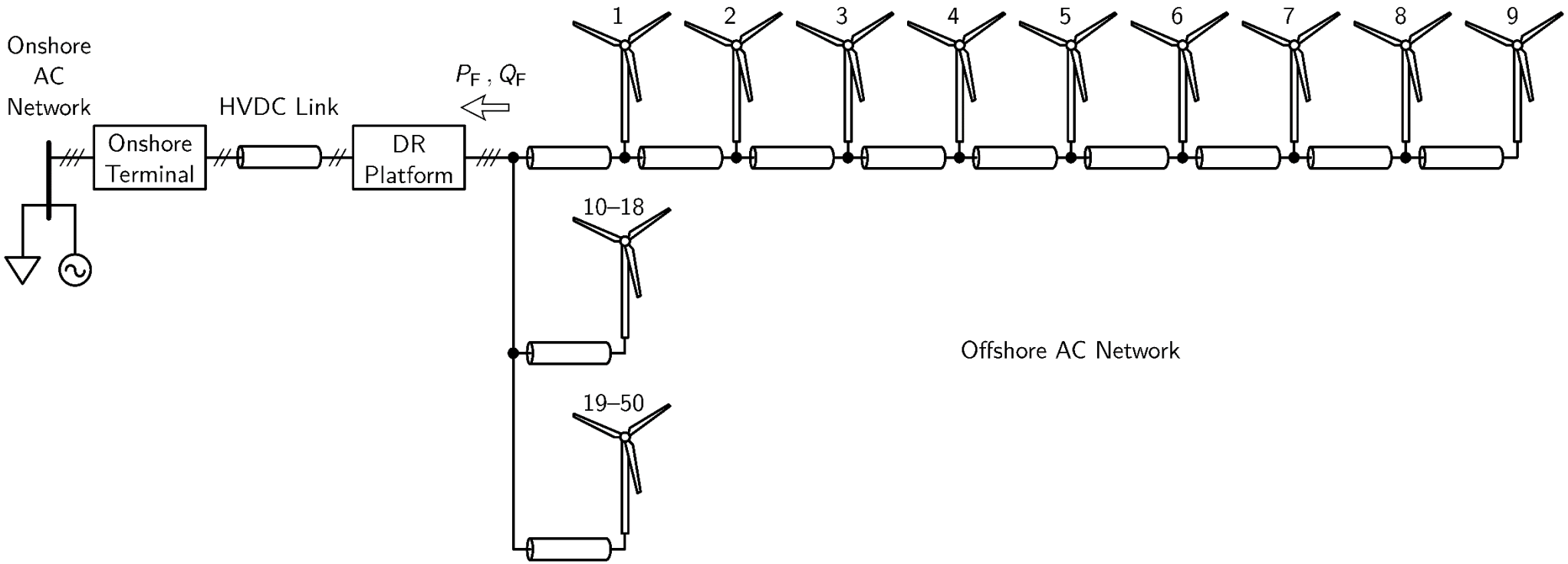

Figure: Overview of the studied system

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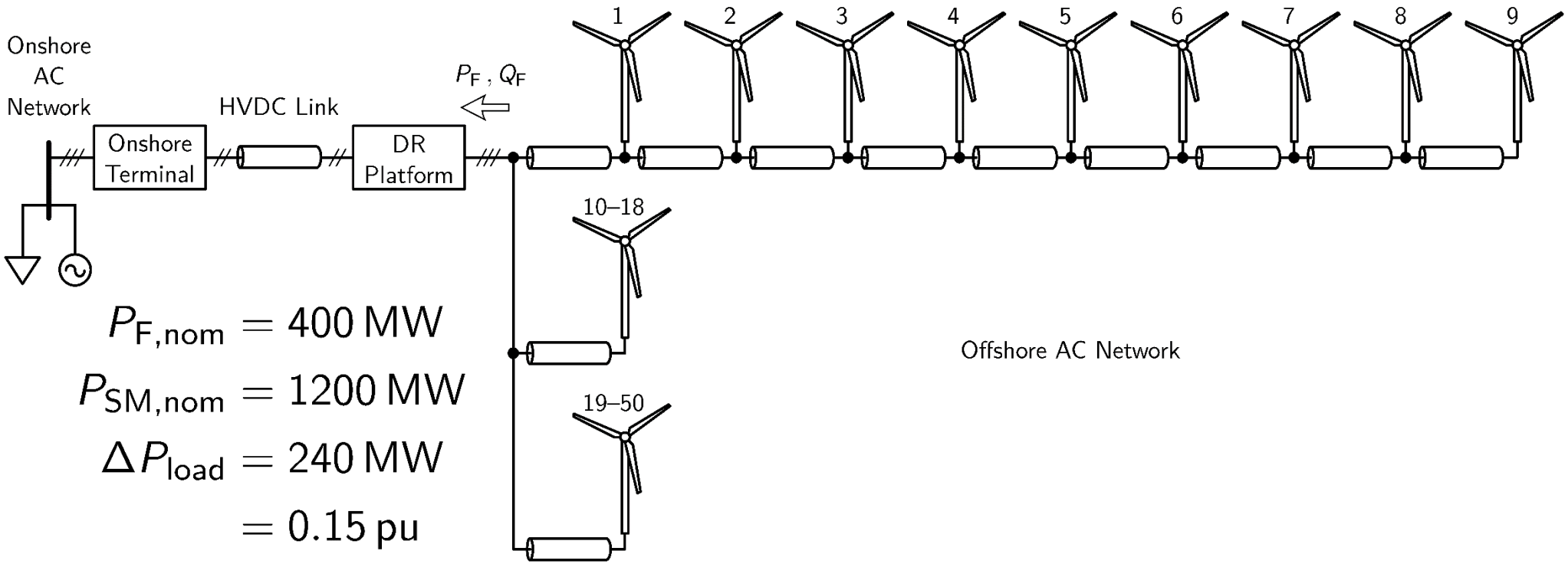

$$P_{F,nom} = 400\,MW$$
$$P_{SM,nom} = 1200\,MW$$
$$\Delta P_{load} = 240\,MW = 0.15\,pu$$

Wind Speed	Aerodynamic power available from the wind [pu]											
	P_{ava}	$P_{ava,1}$	$P_{ava,2}$	$P_{ava,3}$	$P_{ava,4}$	$P_{ava,5}$	$P_{ava,6}$	$P_{ava,7}$	$P_{ava,8}$	$P_{ava,9}$	$P_{ava,10-18}$	$P_{ava,19-50}$
Low	0.400	0.930	0.345	0.421	0.366	0.344	0.318	0.299	0.289	0.289	0.400	0.400
Medium	0.600	0.987	0.564	0.644	0.586	0.562	0.535	0.515	0.504	0.504	0.600	0.600
High	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

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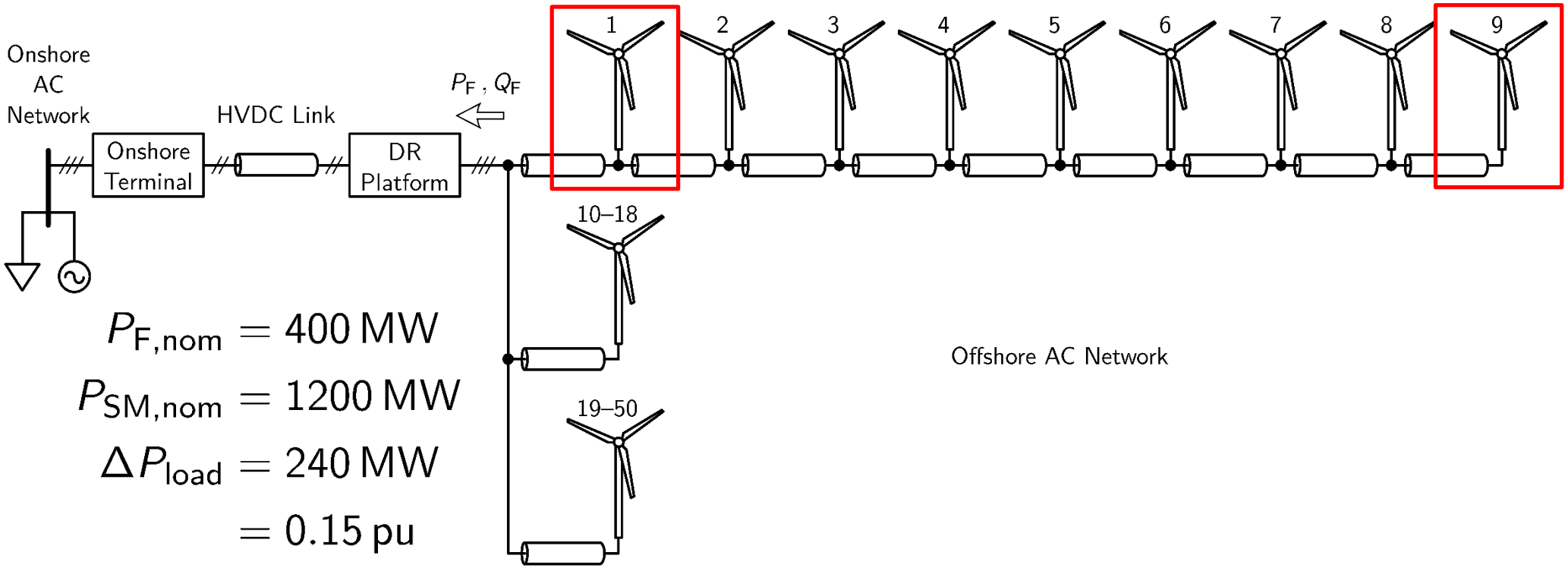

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Simulation Results

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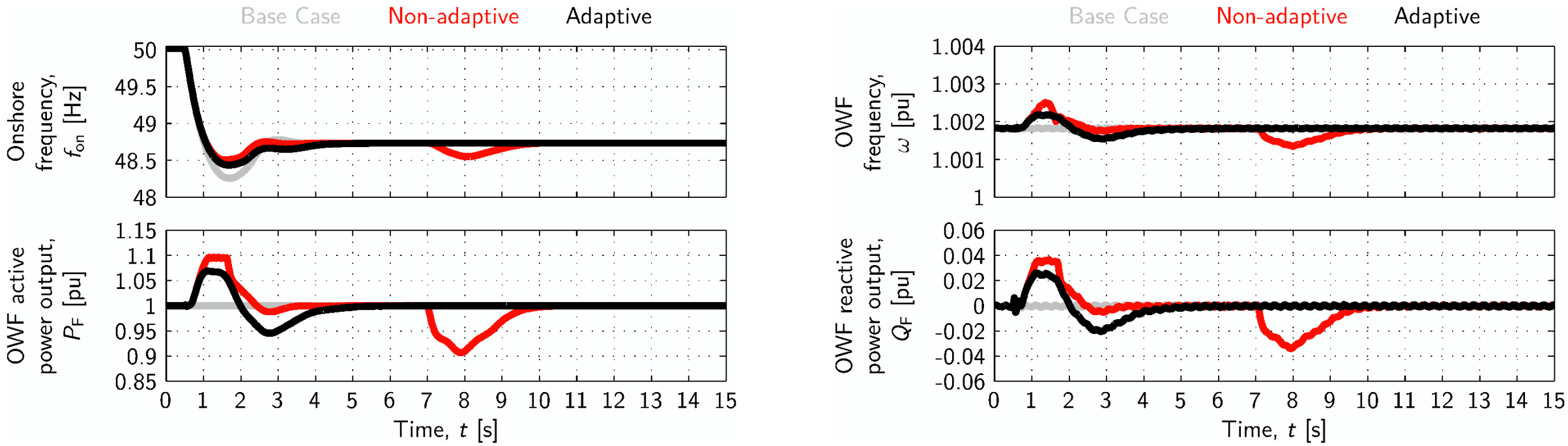
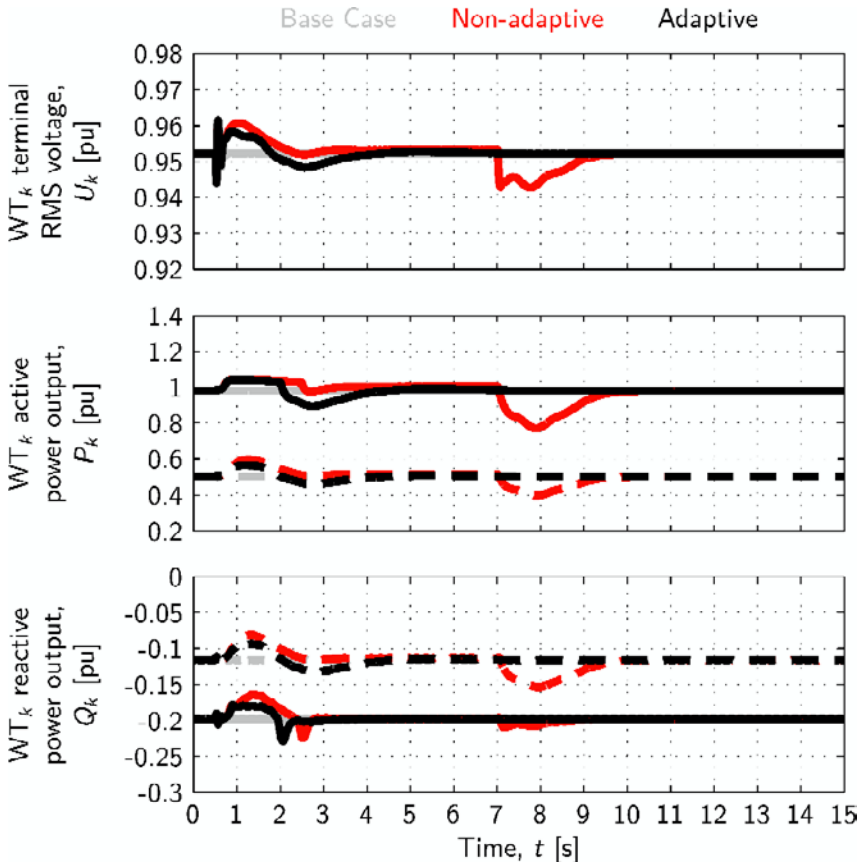
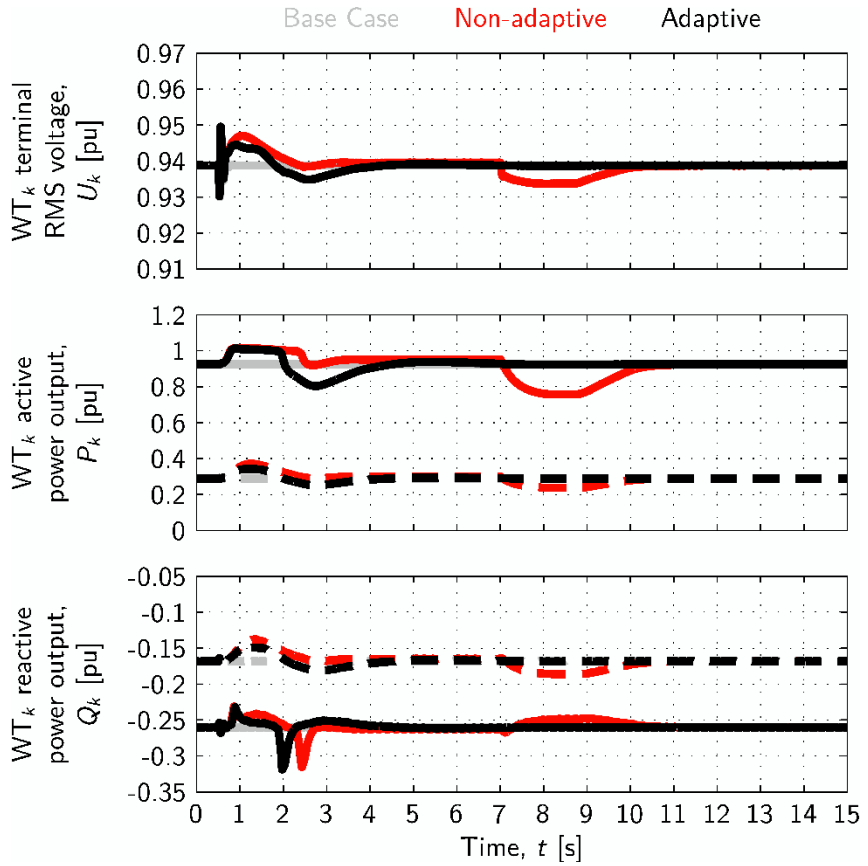


Figure: Wind farm response to an onshore underfrequency event at high wind speed

Simulation Results



(a) Medium wind speed



(b) Low wind speed

Figure: kth wind turbine's response to an onshore underfrequency event – solid: $k = 1$, dashed: $k = 9$

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- By overloading their WTs, such OWFs can provide more than the available power for several seconds, but this can result in a new onshore frequency dip
- Adaptive overloading method can help to reduce such adverse secondary effects