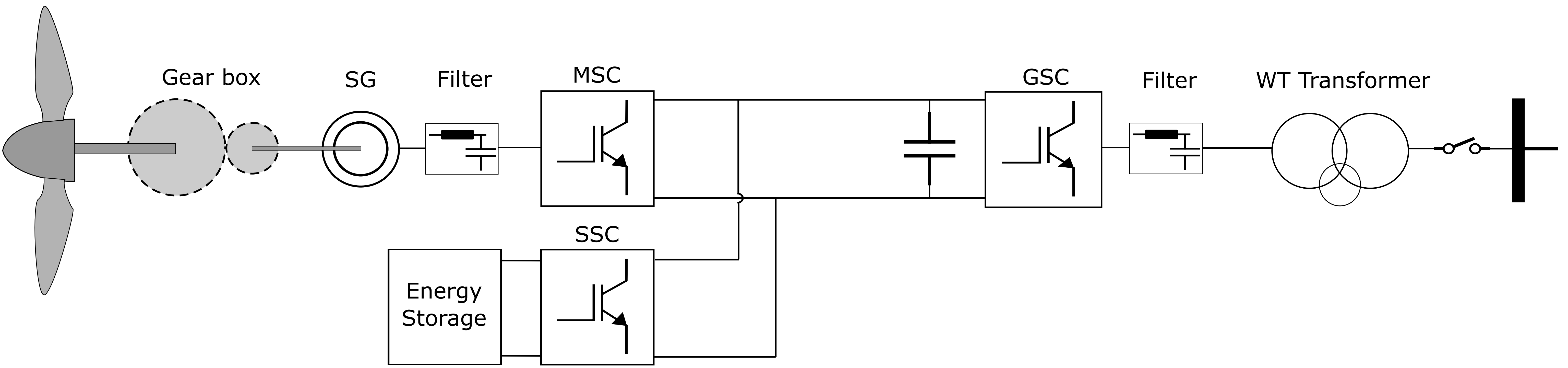


# Virtual Synchronous Machine Control for Wind Turbines: A Review

Liang Lu\* and Nicolaos A. Cutululis  
\*Email: lilu@dtu.dk



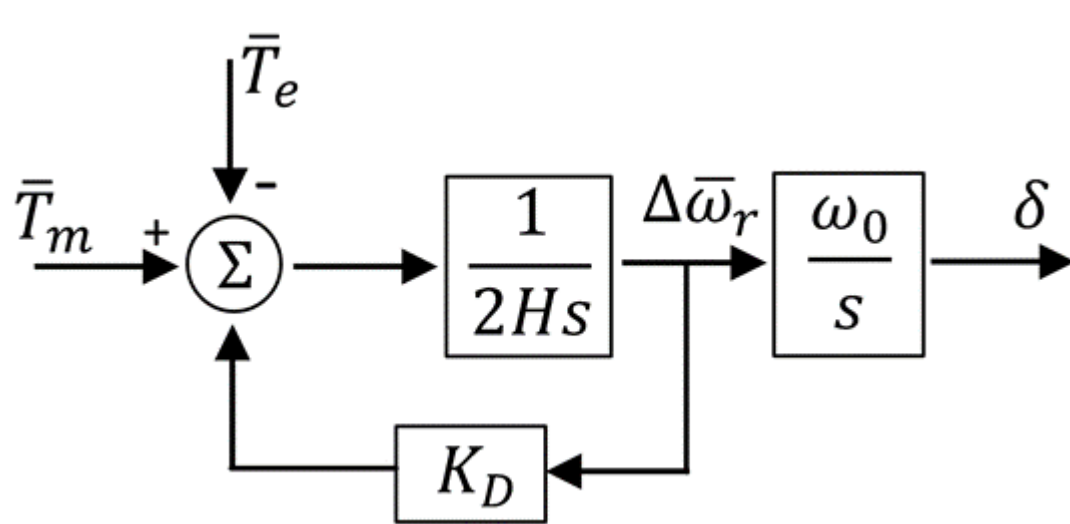
## 1 VSM Control Schemes for WTs



### Swing equations

$$\frac{d\Delta\bar{\omega}_r}{dt} = \frac{1}{2H}(\bar{T}_m - \bar{T}_e - K_D\Delta\bar{\omega}_r)$$

$$\frac{d\delta}{dt} = \omega_0\Delta\bar{\omega}_r$$

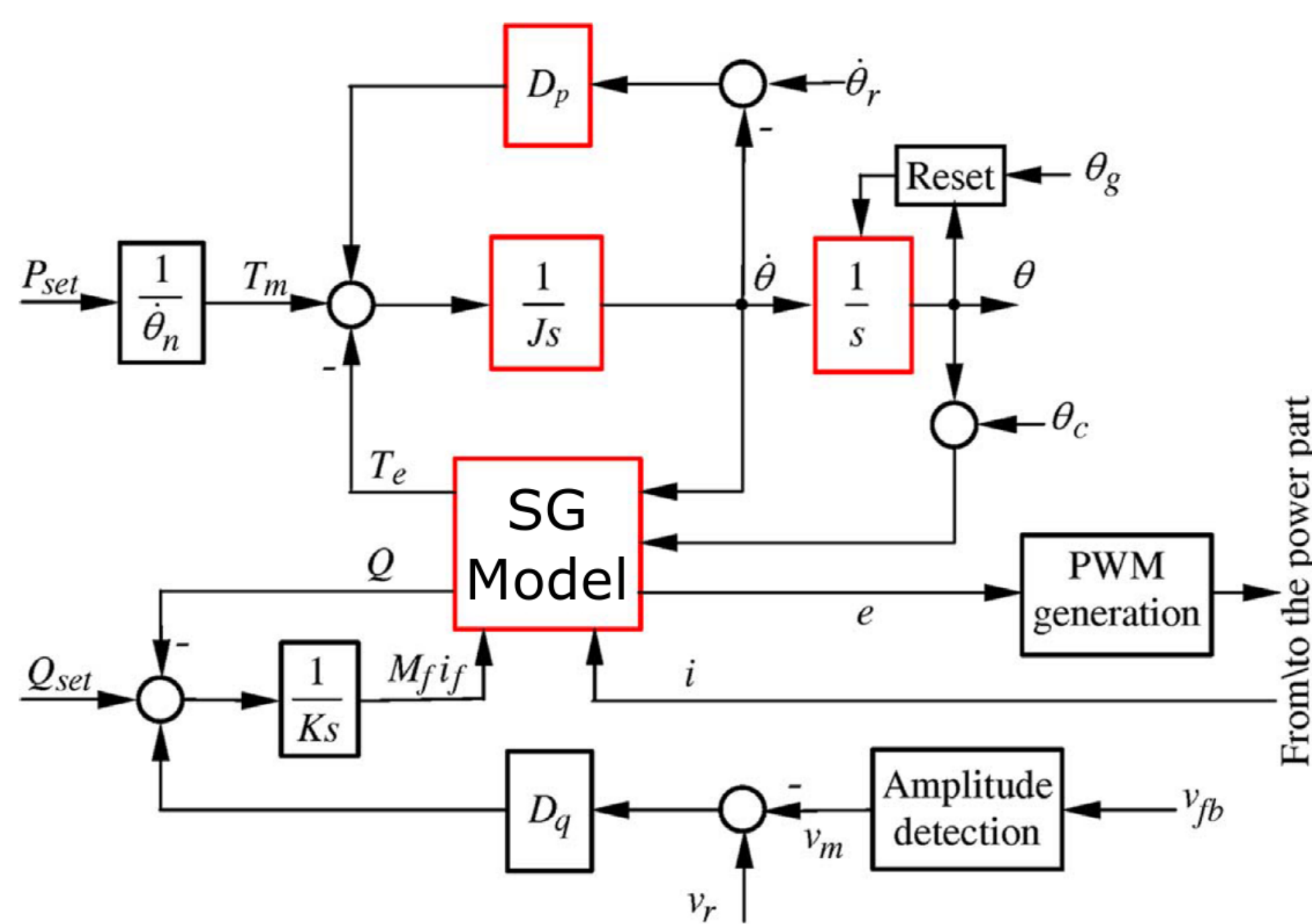


### Electrical equations

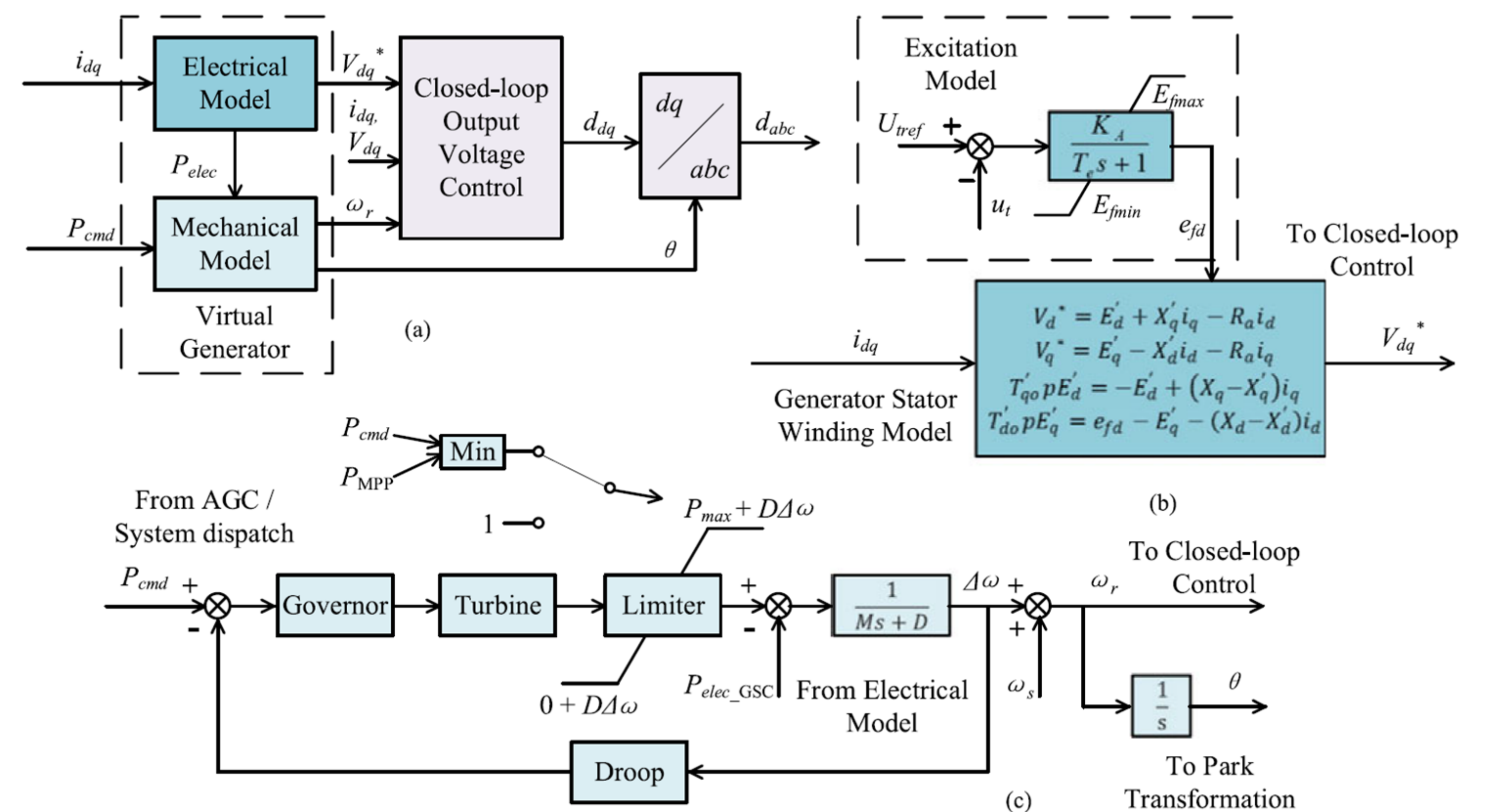
$$T_e = M_f i_f \langle i, \widehat{\sin\theta} \rangle$$

$$e = \dot{\theta} M_f i_f \widehat{\sin\theta}$$

$$Q = -\dot{\theta} M_f i_f \langle i, \widehat{\cos\theta} \rangle$$



Synchronverters: Inverters That Mimic Synchronous Generators



Virtual Synchronous Generator Control of Full Converter Wind Turbines with Short-Term Energy Storage

### Electrical equations

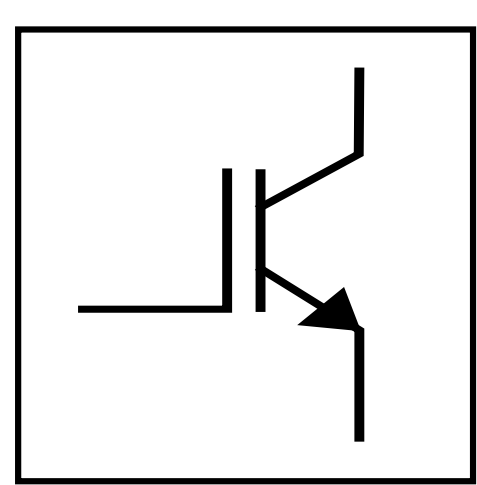
$$U_d = -x'_q I_q + E'_d$$

$$U_q = x'_d I_d + E'_q$$

$$T'_{q0} \dot{E}'_d = -E'_d - (x_q - x'_q) I_q$$

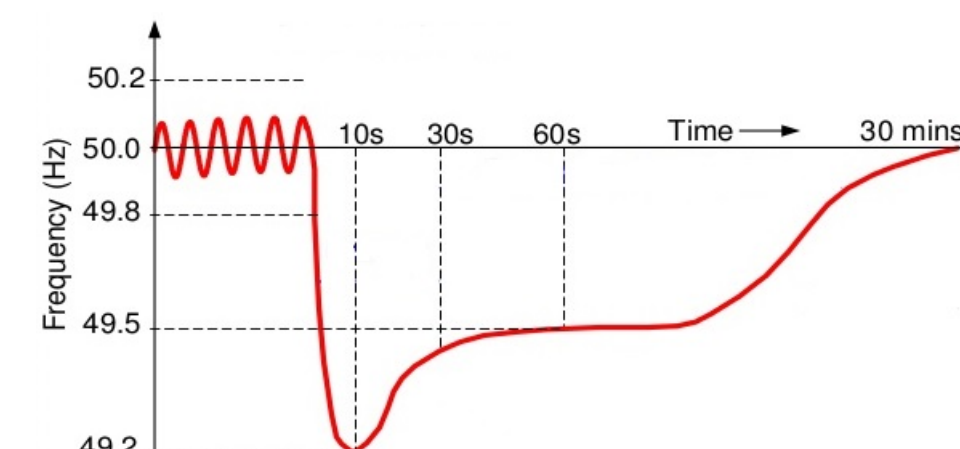
$$T'_{d0} \dot{E}'_q = E_f - E'_q + (x_d - x'_d) I_d$$

## 2 Further Research Work



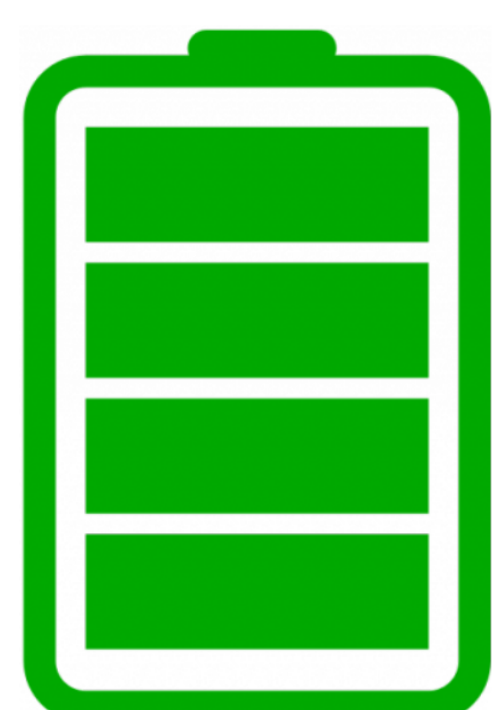
VSM

Field tests of availability  
Performance and stability comparison of different schemes  
Special requirements like parameter design and tuning  
Standardisation of control parameters, interface etc.  
Influence on WTs in mechanical load and stress



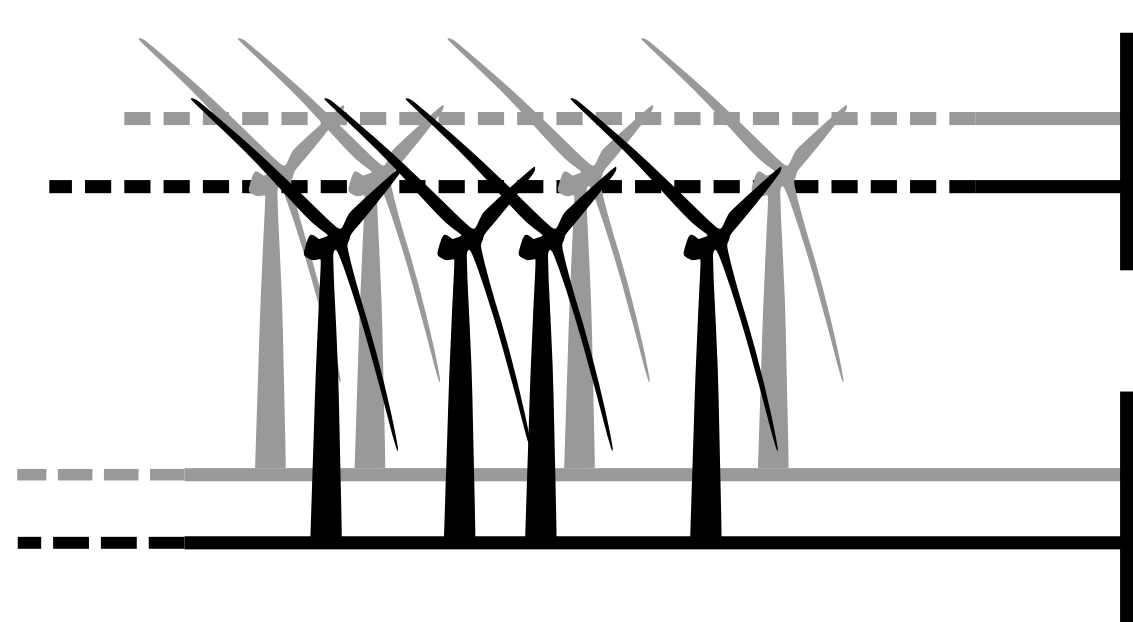
Frequency control

Frequency second drop  
Performance indexes to be defined quantitatively  
Assessment methods to be developed  
Optimized control from a WPP



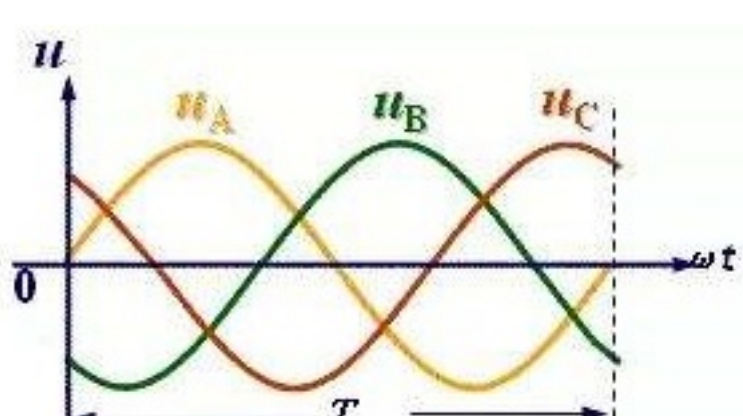
ES

Techno-economic analysis  
Advantage of MPPT+frequency control  
Suitability of different types  
Locations, especially in WPPs  
Control strategy of SoC  
Optimization of capacity



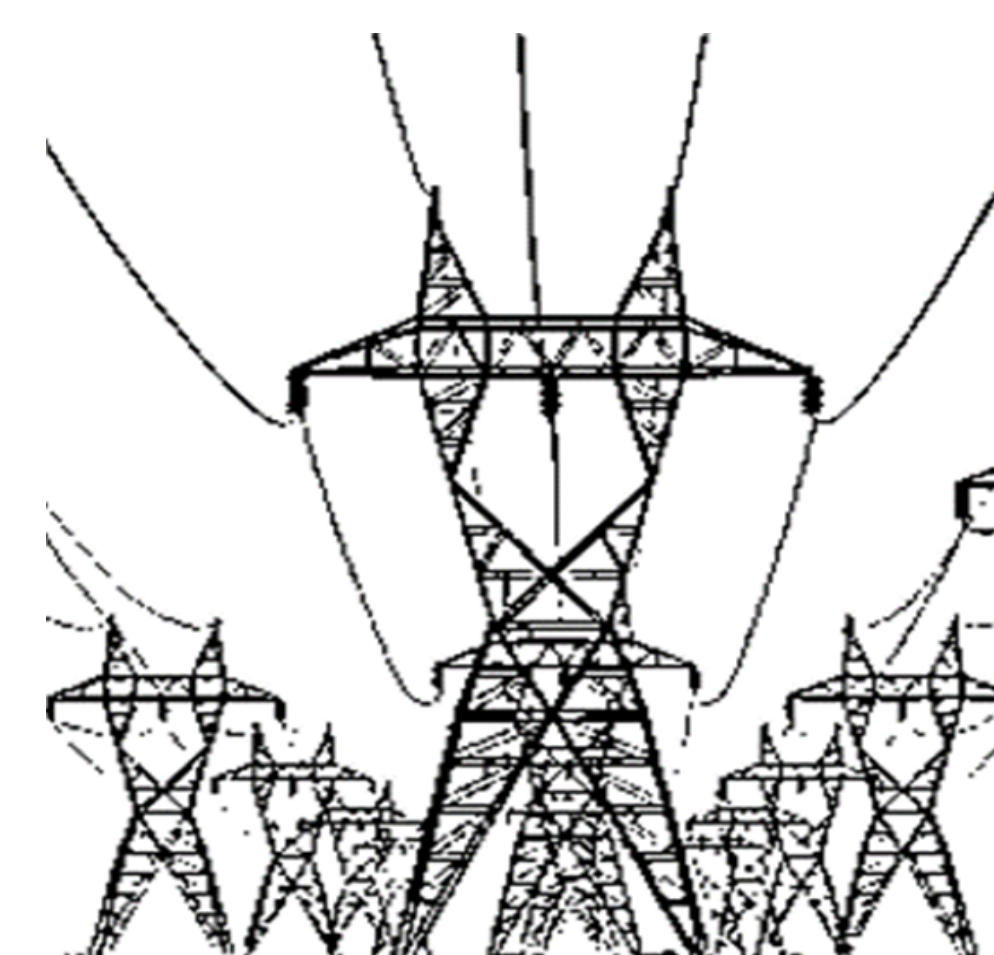
WPP application

Coordinated control & stable operation of multiple VSM-controlled WTs  
Optimization of ES configuration and layout



Voltage control

Well-founded verifications  
Availability in different grid conditions  
Fault ride-through capability



Grid conditions

Voltage sags  
Unbalanced voltages  
Grid faults  
Weak grids  
Islanded systems with black start

