DC Bus Collection of Type-4 Wind Turbine Farms with Phasing Control to Minimize Energy Storage

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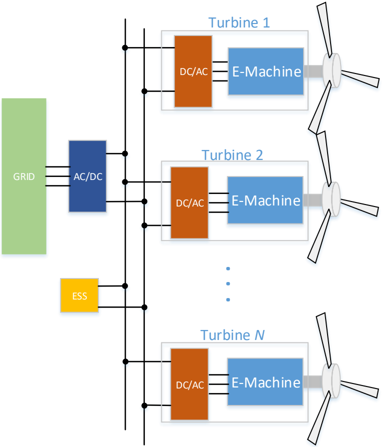
Introduction

- Typical Type-4 wind turbines use DC-link inverters to couple the electrical machine to the power grid.
- An N-turbine farm will have $2N$ power converters
- A DC bus collection system reduces the overall required number of converters.
- Only $N + 2$ converters are required.
- Trade-offs is the need for increased energy storage system (ESS).
- A power *phasing* control method between turbines that filter the variations and improves power quality while minimizing the need for added ESS.

Proposed DC collection system

- N turbines with electrical induction machine and DC/AC converter.
- Generic ESS
- Grid connected inverter



Aerodynamic Model

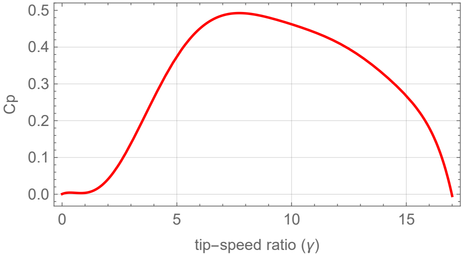
The aerodynamic power and toque is approximated as

$$P_a = \frac{1}{2}\rho\pi R^2 C_p(\gamma) v^3 \tag{1}$$

$$T_a = \frac{P_a}{\omega_r} = \frac{1}{2\omega_r}\rho\pi R^2 C_p(\gamma) v^3 = \frac{1}{2}\rho\pi R^3 C_p(\gamma) v^2 \tag{2}$$

The tip-speed ratio is

$$\gamma = \frac{R}{v}\omega_r. \tag{3}$$



Induction Machine Model and Control

The squirrel cage induction machine model

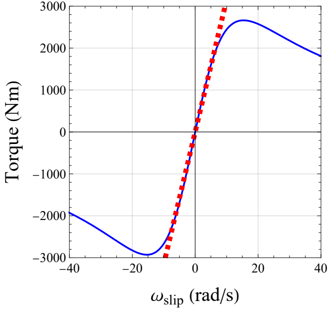
$$\dot{\lambda}_{ds} = v_{ds} - R_s i_{ds} + \omega_s \lambda_{qs} \quad (4)$$

$$\dot{\lambda}_{qs} = v_{qs} - R_s i_{qs} - \omega_s \lambda_{ds} \quad (5)$$

$$\dot{\lambda}_{dr} = 0 - R_r i_{dr} + (\omega_s - p\omega_m)\lambda_{qr} \quad (6)$$

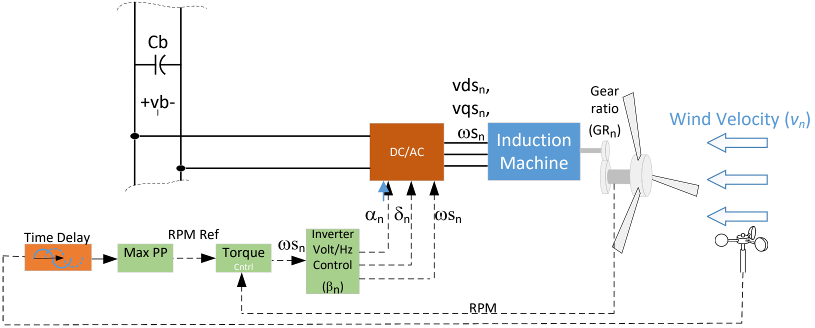
$$\dot{\lambda}_{qr} = 0 - R_r i_{ds} - (\omega_s - p\omega_m)\lambda_{dr} \quad (7)$$

$$T_e = pL_m(i_{qs}i_{qr} - i_{ds}i_{qr}). \quad (8)$$



- A *volts-per-hertz* control of the electrical machine is used.
- Torque Actuated through Control of the *Slip* frequency $(\omega_{slip} = \omega_s - p\omega_m)$
- This linear slip to torque relationship for this model is $k = T_e/\omega_{slip}$.

Phasing Turbine Control Structure



- Max power is at tip-speed ratio $\gamma_{opt} = 7.7$.
- A time delay in the wind velocity signal has been introduced into the max power point tracking control.
- Time shifts power injected into DC bus.
- Sub-optimal power tracking on the turbine.

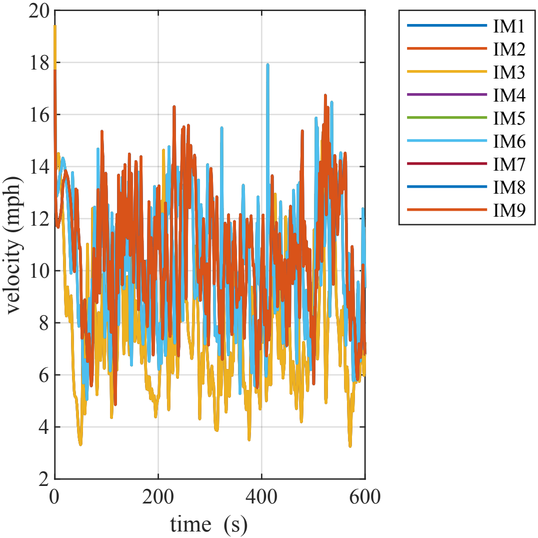
Example System

- Wind farm has 9 turbines.
- Sandia DOE SWiFT facility Vestas V27 wind turbines
  Inducton Machines: ABB IDDRPM364004R1
- $460\ V_{DC}$ Collection Bus

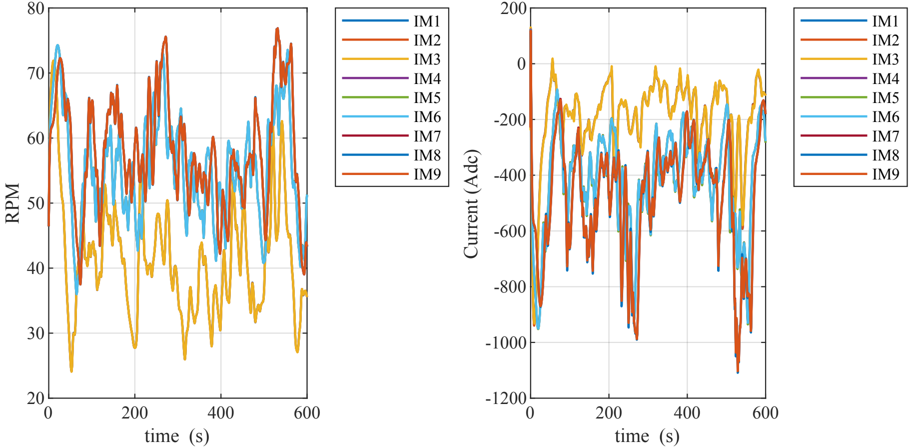
Model Parameters

Parameter	**Description**	**Value**
ρ	Density of air	$1.2 kg/m^3$
R	Rotor radius	$13.5\ m$
J	Rotor moment of inertia	$109,900\ kg\ m^2$
B	Friction damping coefficient	$565\ Nm/rad/s$
GR	Gear ratio	38.8
γ_{opt}	Optimal tip-speed ratio for max power	7.7
R_s	Stator winding resistance	$9.57\ m\Omega$
R_R	Rotor winding resistance	$7.65\ m\Omega$
L_{ls}	Stator leakage inductance	$253\ \mu H$
L_{lr}	Rotor leakage inductance	$253\ \mu H$
L_m	Mutual inductance	$7.07\ mH$
p	Pole-*pairs*	2

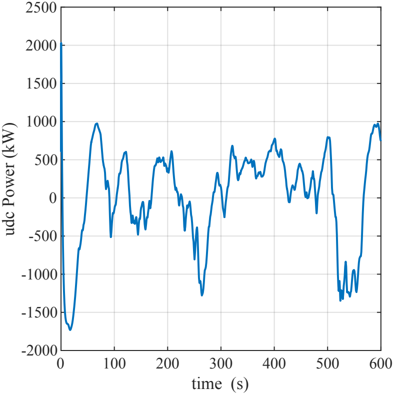
Applied Wind Velocity Profile

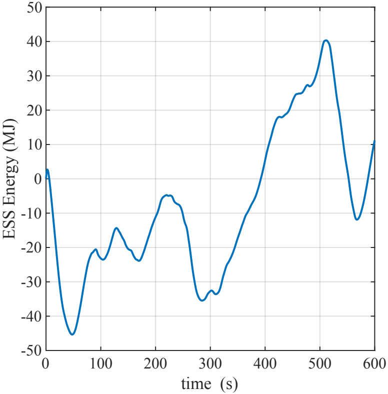


RPMs and Current for $0\ s$ Phase Delay.

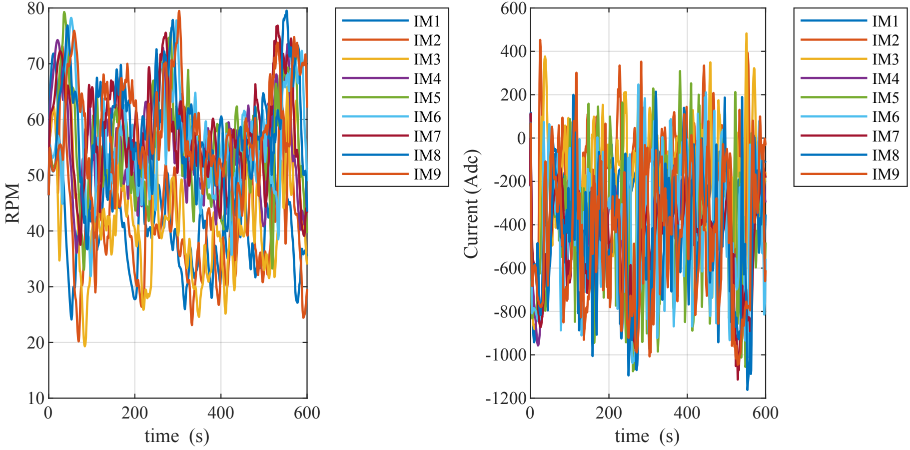


Energy for $0\ s$ Phase Delay.

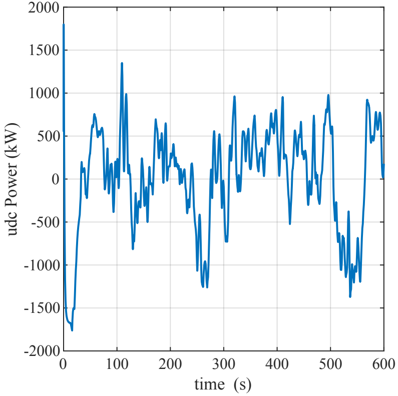


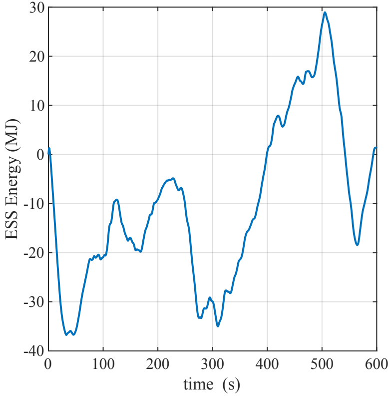


RPMs and Current for $32\ s$ Phase Delay.



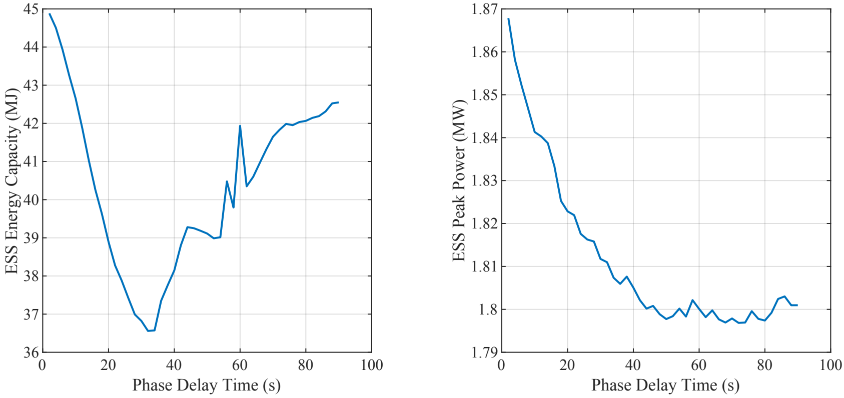
Energy for $32\ s$ Phase Delay.





Peak Power and Energy of ESS vs turbine phase delay time

The minimum required energy storage capacity of the ESS is $36.6\ MJ$ and occurs when the phase delay time is $32\ s$.



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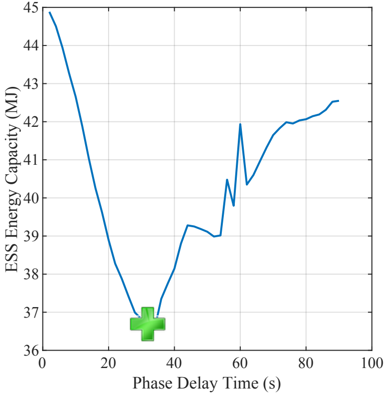
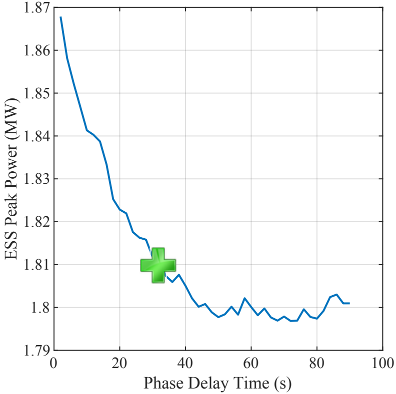
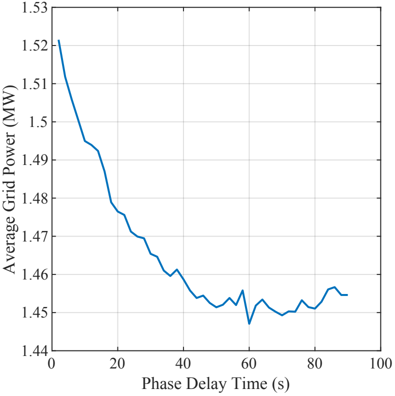




Average Power to the Grid vs Turbine Phase Delay Time.

Power to exported to grid is reduced when phasing.



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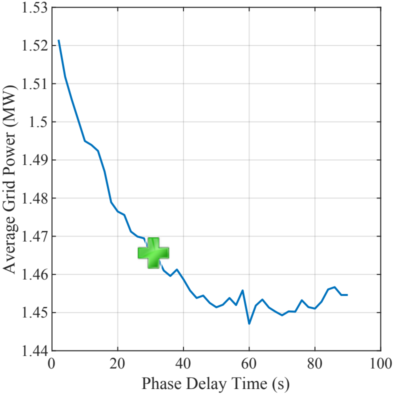
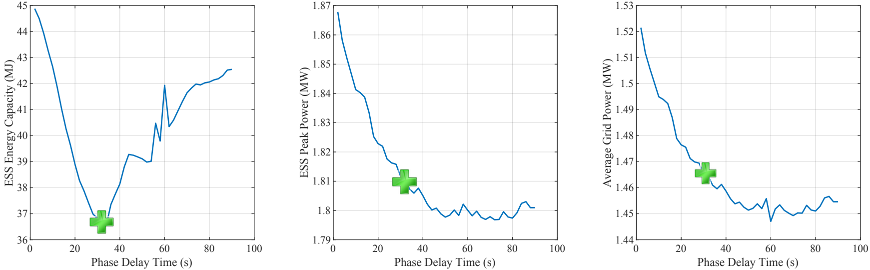


Minimum ESS Energy Capacity Operating Point



The cost of implementing the phasing control and reducing the ESS power and energy requirements.

- ESS Capacity reduced 18%.
- Peak power of ESS reduced 3%.
- Grid power reduced 3%.

Conclusions

- The DC collection approach will lead to $N + 2$ number of converters.
- Phasing control of turbine minimizes ESS
- Incorporation of blade-pitch control of the turbines could also lead to further improvements.

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Questions?