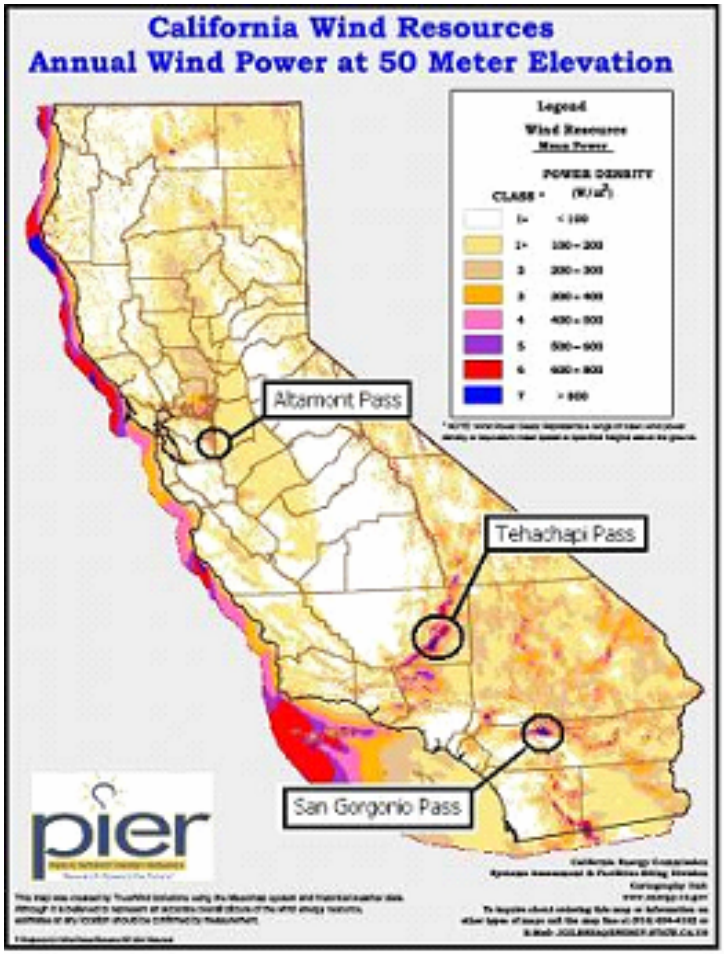
Reductions in the Cost Wind Generated Electricity: The Role of Power Conversion Systems

APEC 2006

William L. Erdman
BEW Engineering
San Ramo, Ca.

California's Wind Rush of 1980's

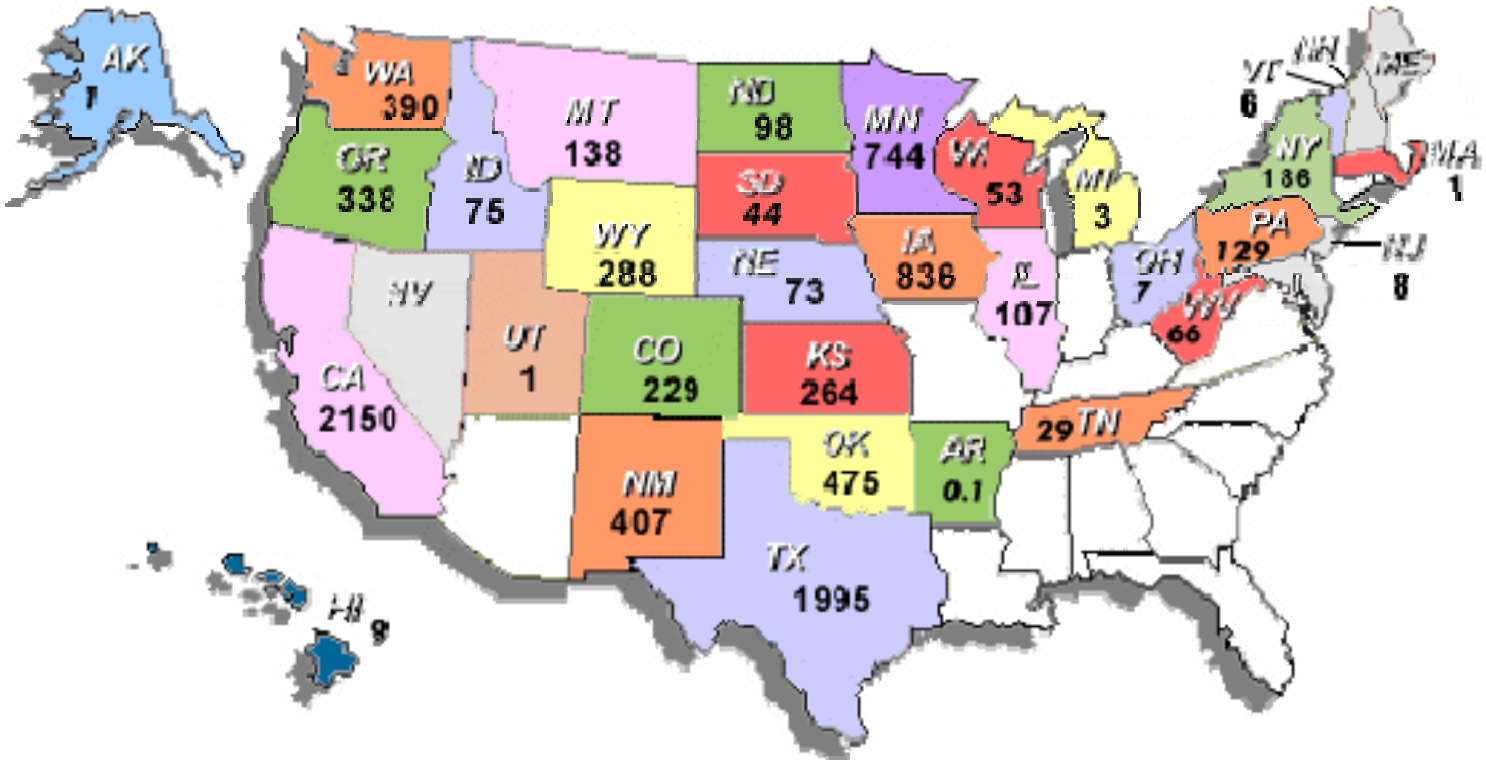
- 1970's OPEC Embargo
- 1978 Passage of PURPA
- State Mandated SO-4 Power Purchase Agreements
- Combined Federal and State Tax Incentives



First Laboratory for the Investigation of Large Scale Transmission Connected Wind

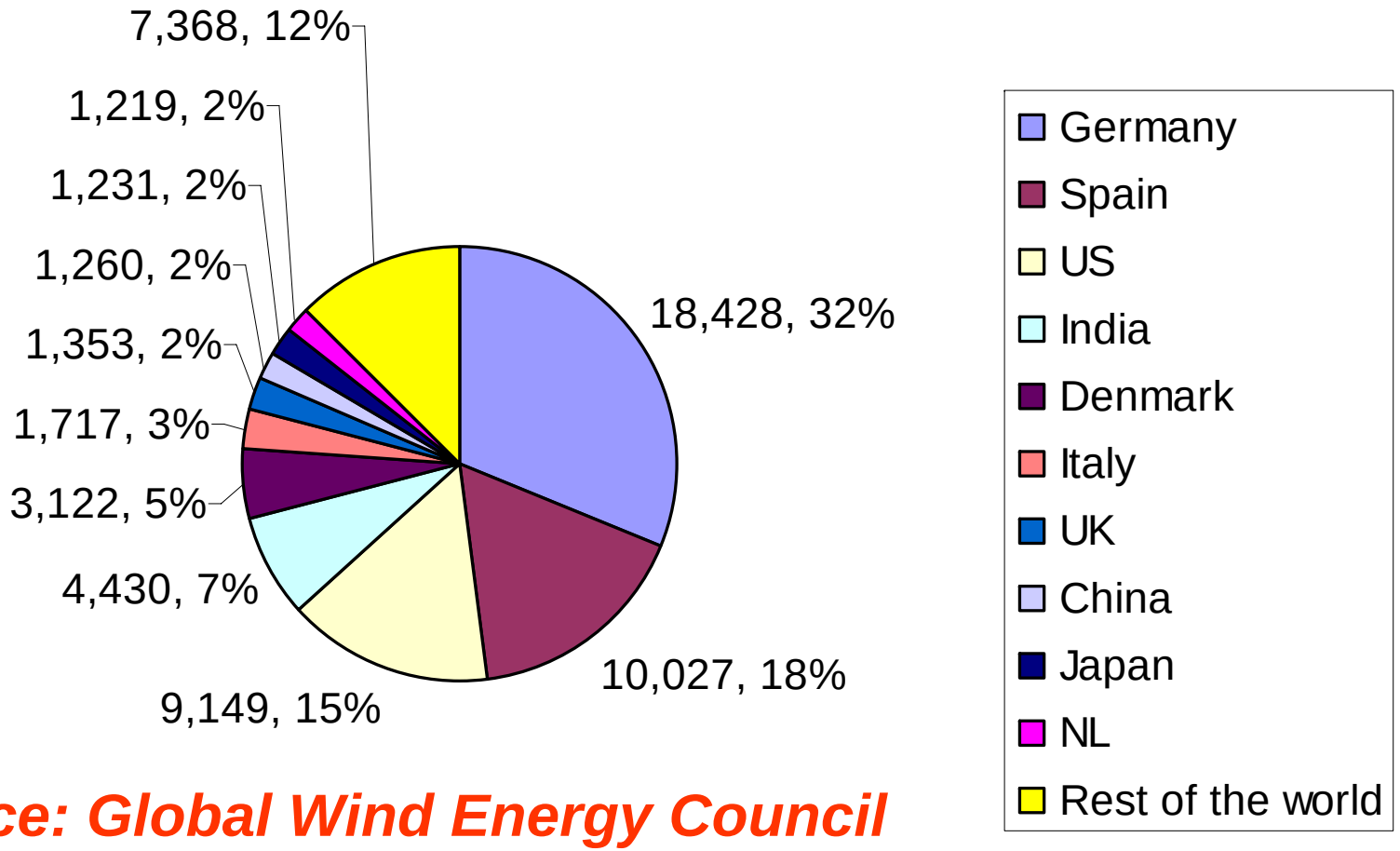
17,000 Turbines Installed with a capacity of 1600 MW

Current Capacity in the US
(AWEA - January 2006)



Numbers Shown in MW

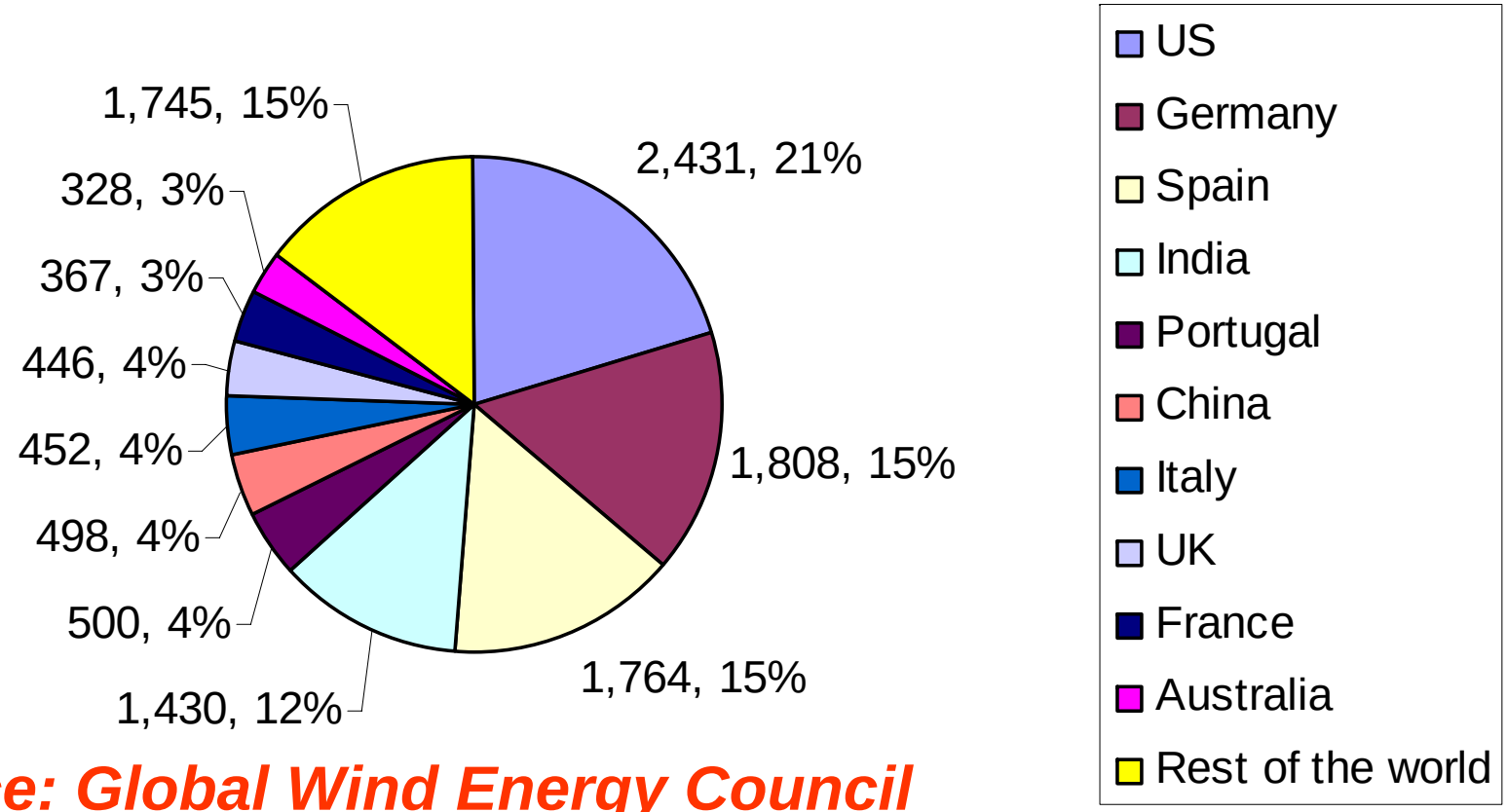
World Wide Installed Capacity as of December, 2005 (MW)



Source: Global Wind Energy Council

60,000 MW Installed, 75,000 MW Projected by Dec. 2006

Newly Installed Capacity Jan – Dec , 2005 (MW)

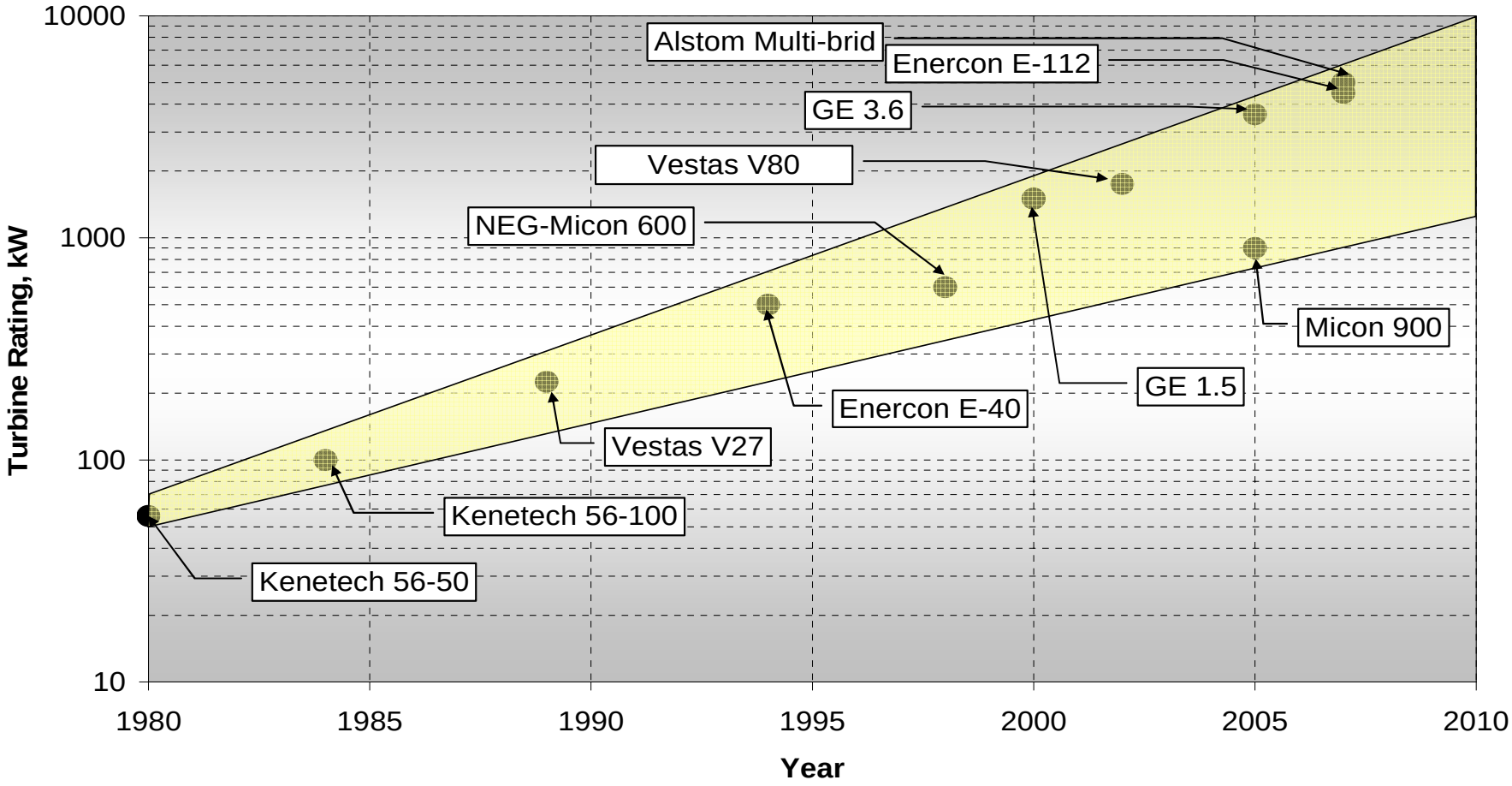


Source: Global Wind Energy Council

3,000 MW Projected for US in 2006

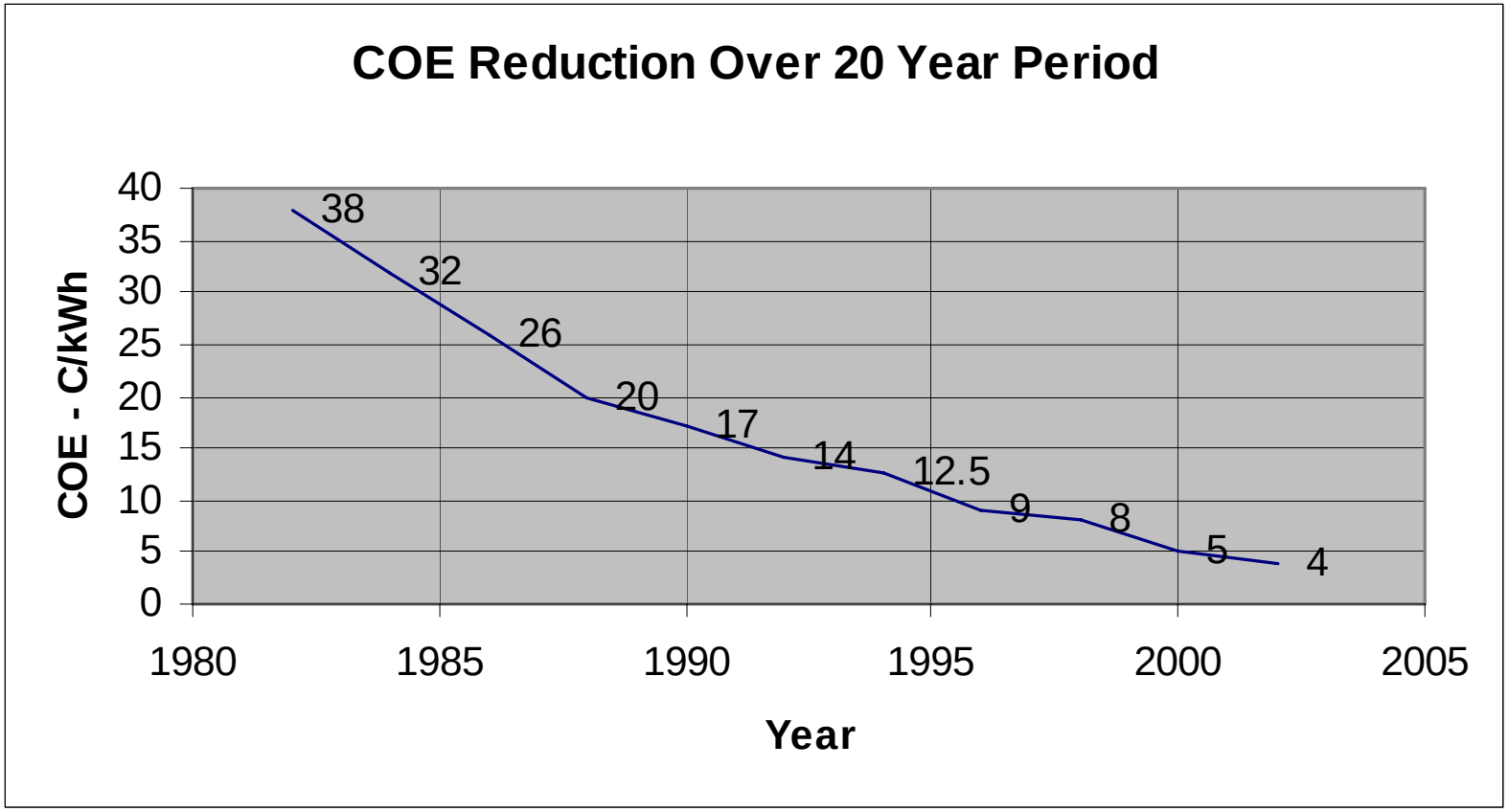
950,000 MW Total US Generation)

Turbine Ratings Over a Thirty Year Period



7.5 MW Offshore Turbines by 2010!

Wind Generated Cost of Energy

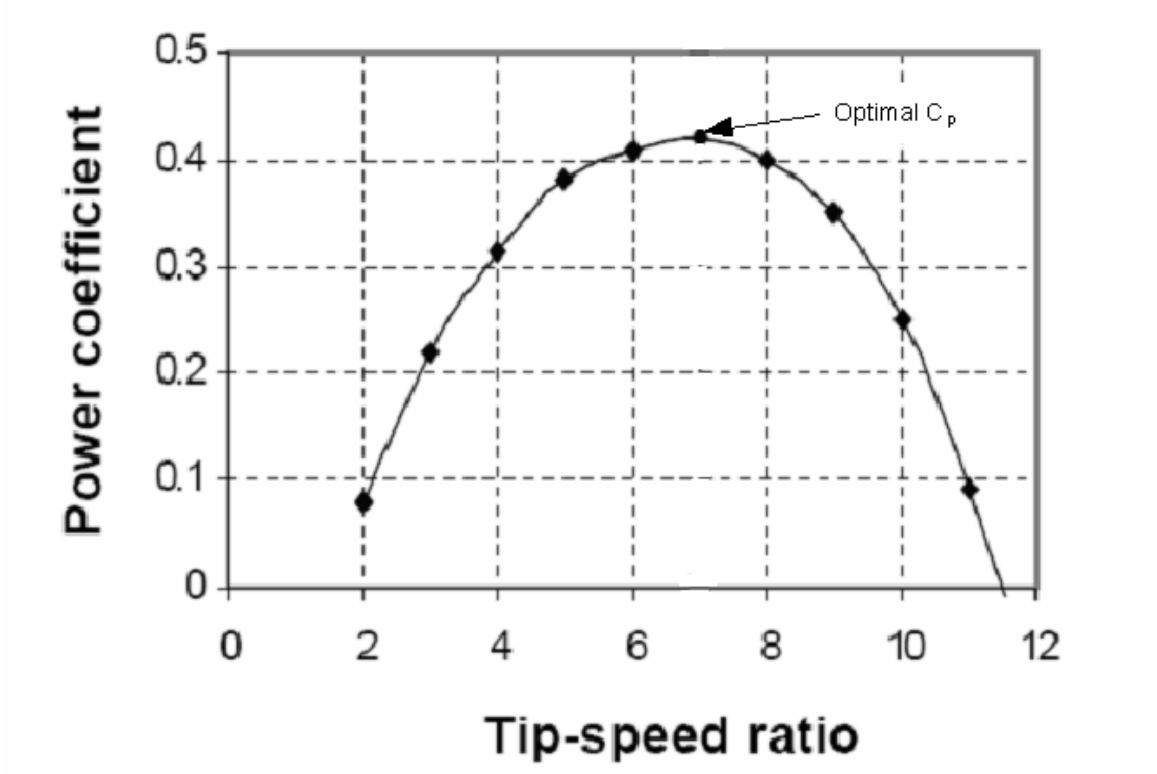


Reduction in COE are result of Policy and Technology!

Consortium Study of 1986
EPRI/US Windpower/PG&E

- Study Objective – How to make Wind Energy Competitive with Fossil Fuels
- One Important Conclusion – Variable Speed Operation
  - Increased Aero Efficiency – Increased Energy Capture
  - Structural Load Mitigation – Reduced Capital Cost

Constant Speed Vs. Variable Speed Turbines – Increased Energy Capture

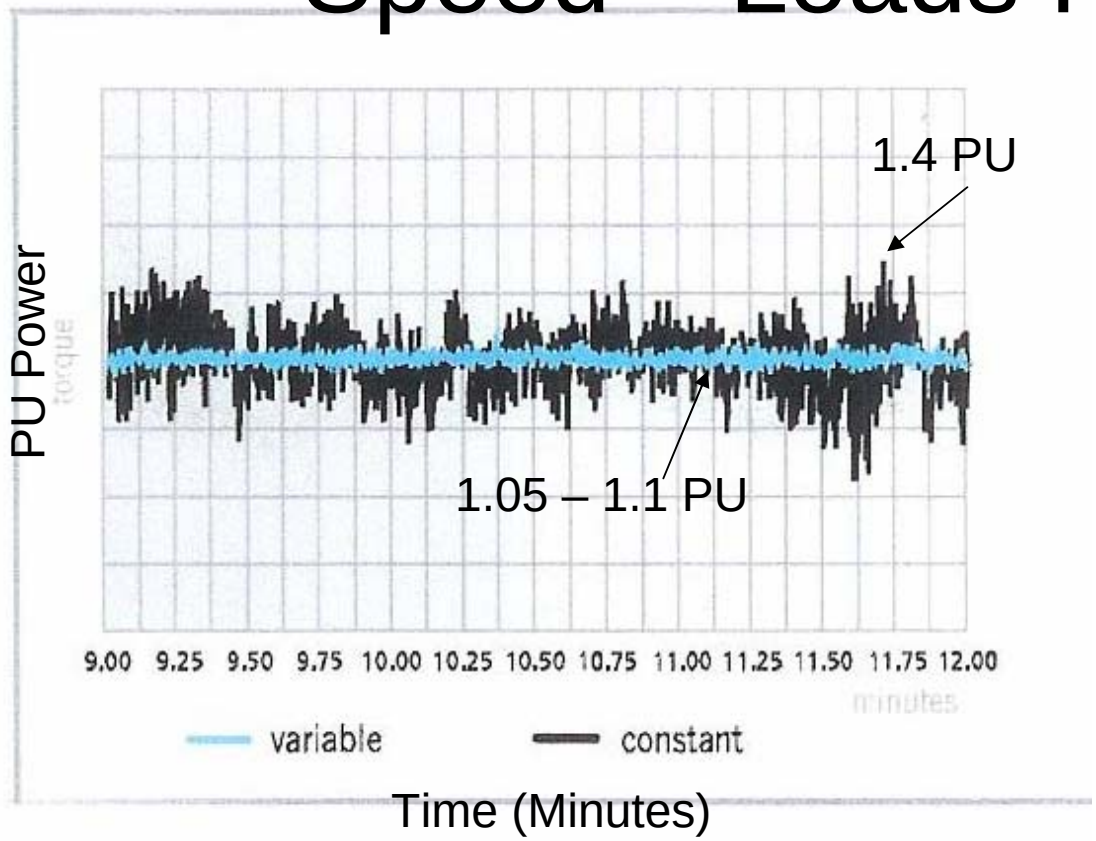


TSR = K * RPM/ Wind Speed

Optimal TSR Requires Varying RPM Directly Proportional to Wind Speed

8 – 15% Increase in Energy Capture!!!!!

Constant Speed Vs. Variable Speed – Loads Reduction



Constant Speed (Induction Generator)

$$\frac{\partial T}{\partial S} = \text{Large}$$

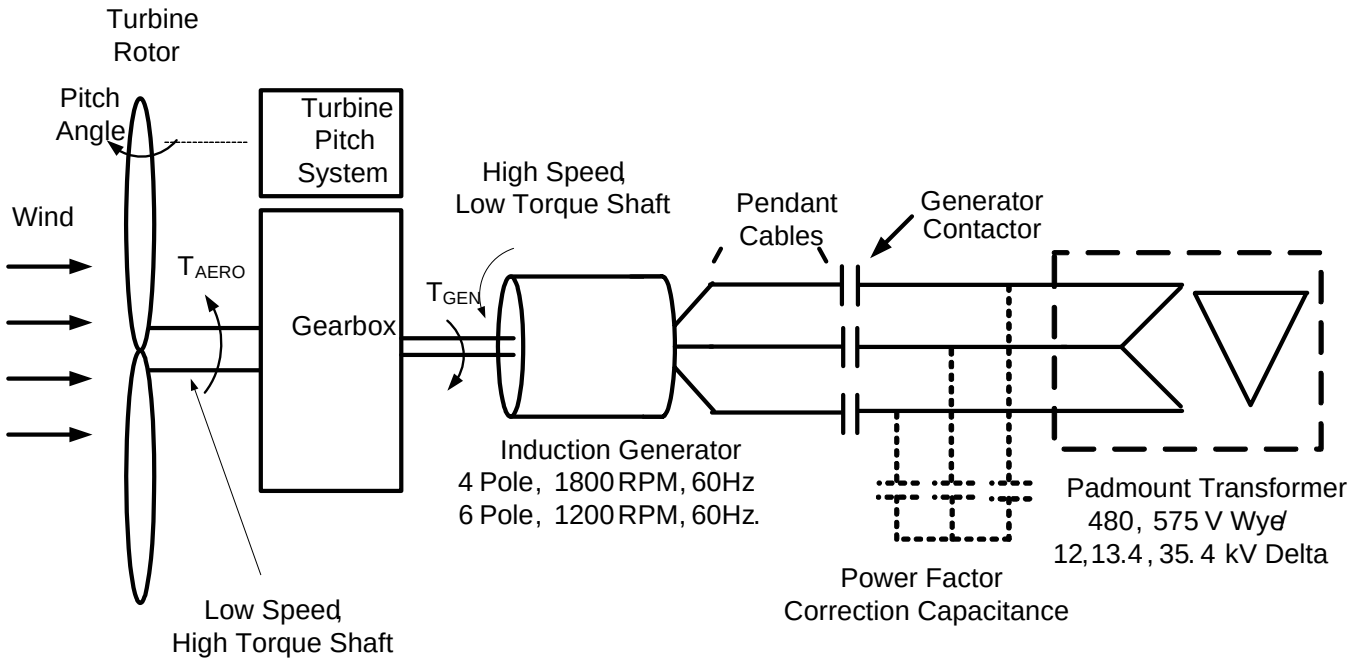
Variable Speed (Arbitrary)

$$\frac{\partial T}{\partial S} = 0$$

Where
T: Generator Torque

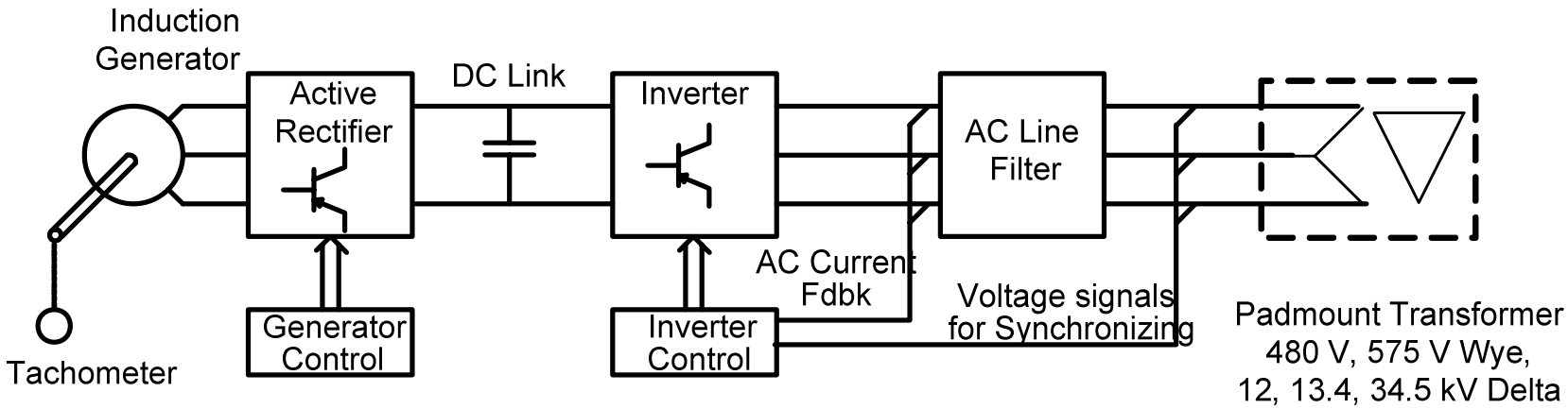
S: Generator Speed

Conventional Constant Speed Turbine Architecture



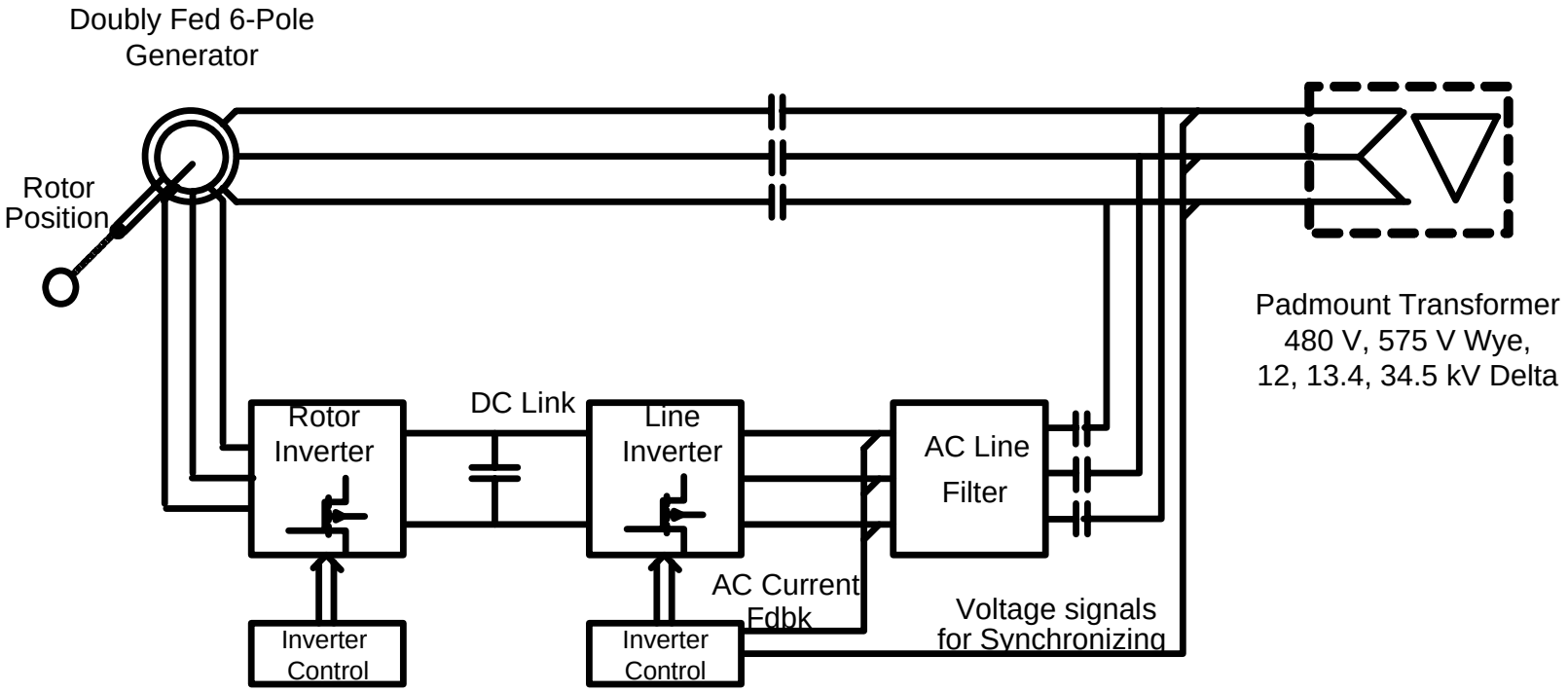
- Examples:
  - US Windpower 56-100
  - Many 1980's vintage Danish wind turbines

Full Conversion Early Architecture



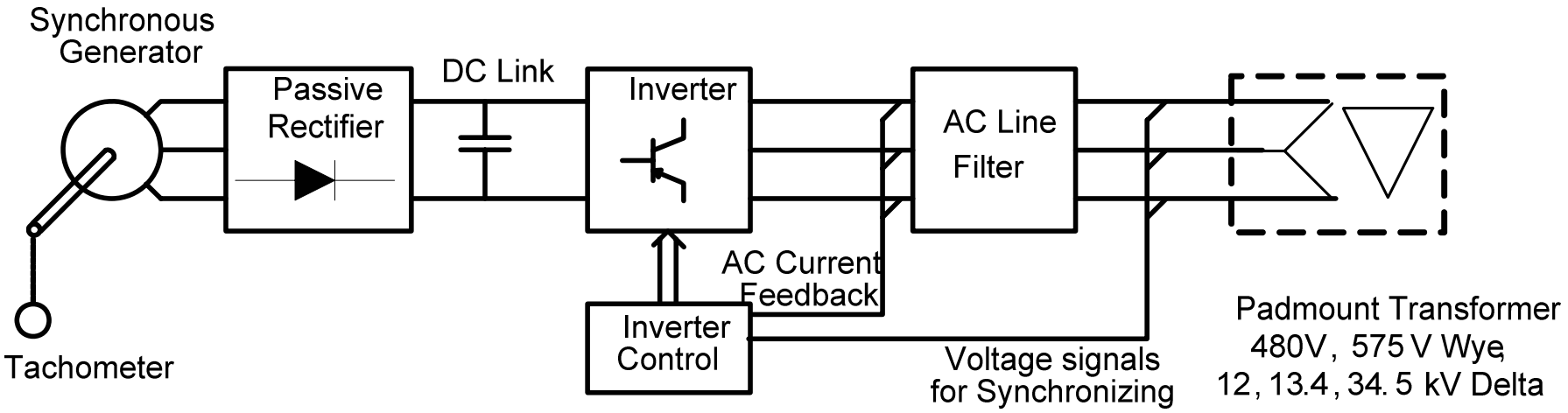
- Examples:
  - Kenetech KVS-33
  - Siemens (Bonus) 2.3 MW VS

Doubly Fed Partial Conversion System



- Examples:
  - GE 1.5 MW
  - Gamesa G90
  - ENRON 750

Full Conversion, Passive Generator Rectifier



- Examples:
  - Clipper C93
  - Enercon
  - Bergey Excel

Power Quality on a 2.5 MW Split Drive Train Full Converter System

650 kW

Unity Power Factor

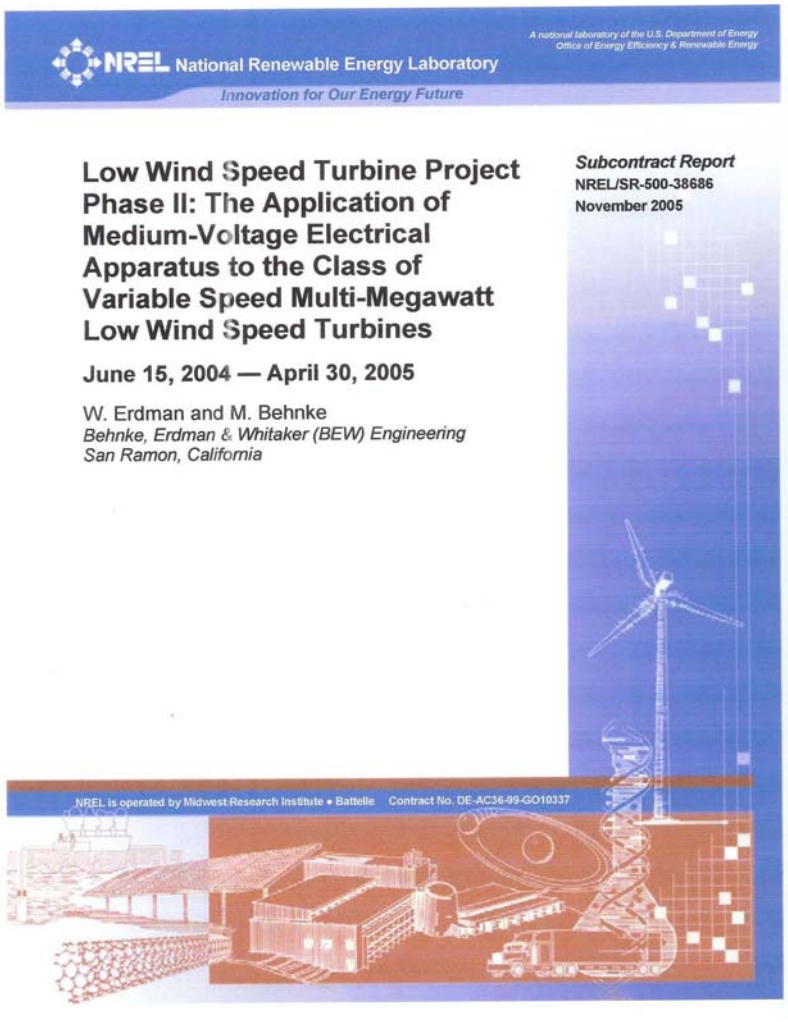
DMM [No.7 01/27 09:33:14.919 I peak+ CH3 OUT]

POWER		VOLTAGE		CURRENT	
Freq	59.995 Hz				
P1	0.2136MW	U1	414.20 V	I1	0.5188kA
P2	0.2169MW	U2	415.49 V	I2	0.5254kA
P3	0.2169MW	U3	415.72 V	I3	0.5250kA
Psum	0.647MW	U4	0.00 V	I4	0.00 A
S1	0.2149MVA	THD-U1	2.36 %	THD-I1	2.82 %
S2	0.2183MVA	THD-U2	2.25 %	THD-I2	2.65 %
S3	0.2183MVA	THD-U3	2.42 %	THD-I3	2.99 %
Ssum	0.651MVA	THD-U4	---- %	THD-I4	255.12 %
Q1	0.0232Mvar	Upk+1	0.6089kV	Ipk+1	0.785kA
Q2	0.0247Mvar	Upk+2	0.6029kV	Ipk+2	0.786kA
Q3	0.0241Mvar	Upk+3	0.6053kV	Ipk+3	0.799kA
Qsum	0.072Mvar	Upk+4	0.35 V	Ipk+4	0.0017kA
PF1	0.9942	Upk-1	-0.6066kV	Ipk-1	-0.777kA
PF2	0.9936	Upk-2	-0.5995kV	Ipk-2	-0.779kA
PF3	0.9939	Upk-3	-0.6025kV	Ipk-3	-0.803kA
PFsum	0.9939	Upk-4	- 0.18 V	Ipk-4	-0.0010kA
		Uave	415.14 V	KF1	1.09
		Uunb	0.25 %	KF2	1.07
				KF3	1.10
				KF4	446.39
				Iave	0.5231kA
				Iunb	0.40 %

Current THD – 2.7%

Measurements Made on NREL Dynomometer

Future Work – Medium Voltage Converter Development



Reluctance to Move Towards Medium Voltage Converters

Operational and Procurement History

Study Reveals Obvious Capital Advantages

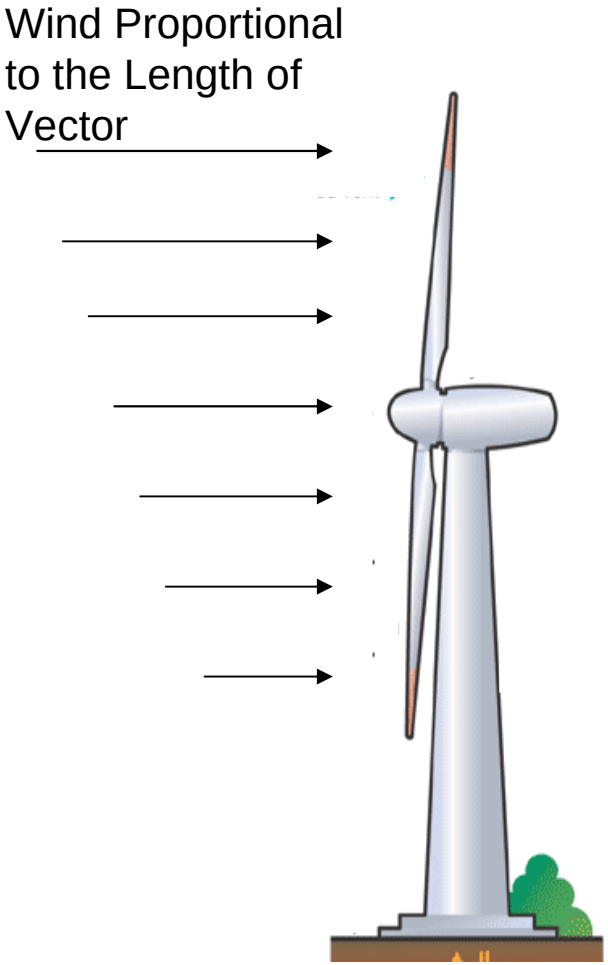
Retraining of Windsmiths and Operational Procedures

Need for 10kV Power Semiconductors

Multi-Level Neutral Point Clamp Inverter

Current Source Technologies

Blade Pitch Servos



60 kW of Position Servos on a 2.5 MW Machine

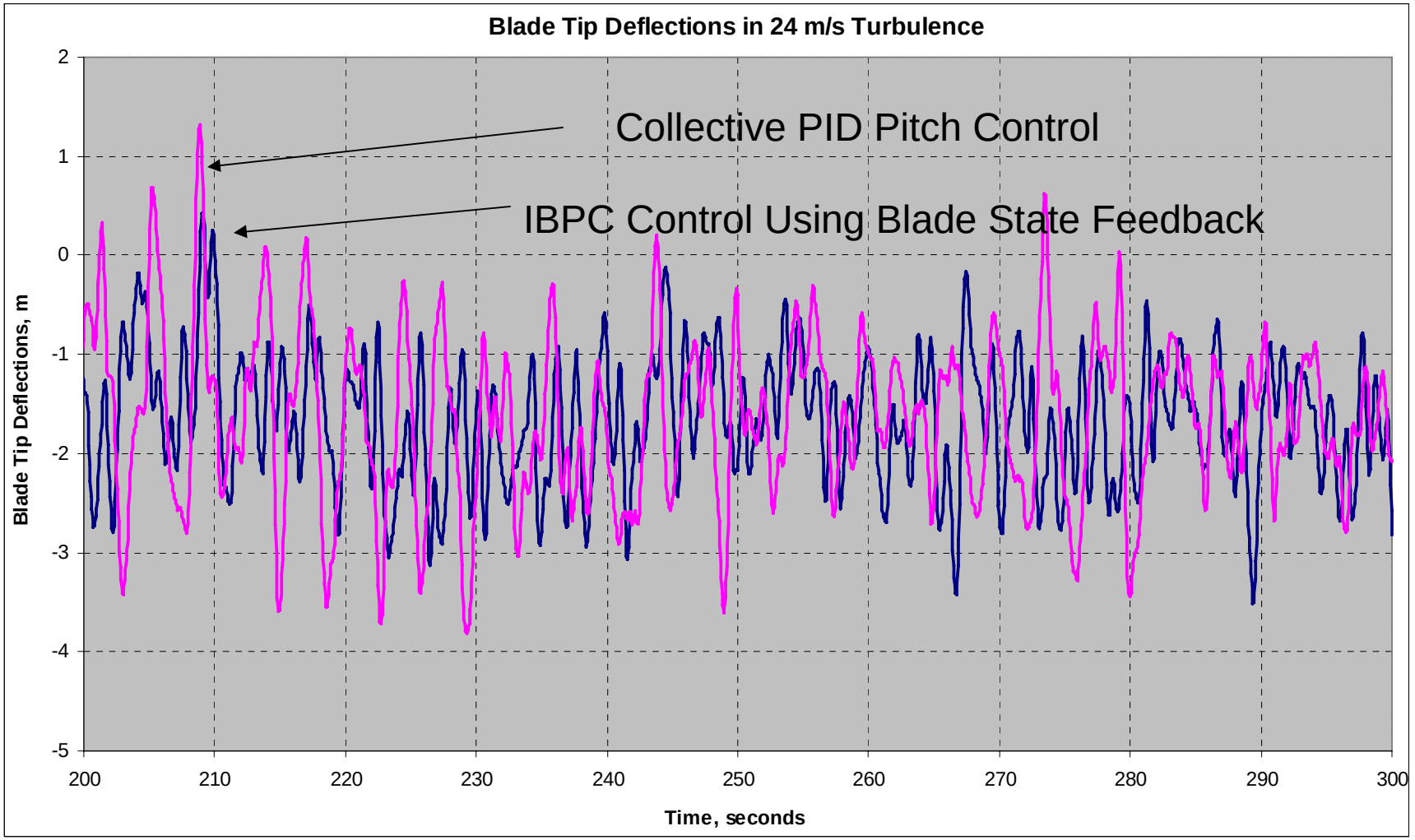
Collective Pitch

Independent Blade Pitch Control (IBPC) Cyclic Control Policy Based on Blade Azimuth

Blade Based Sensor IBPC to Minimize Fatigue Loads on Blades

Use of IBPC, Torque and Yaw in Full State Feedback Control – Objective Function Minimizes Linear Combination of Loads

Independent Blade Pitch Control Benefits



Questions?