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Power and Frequency Control in Rhodes Autonomous Power System with Increasing Wind Power Penetration

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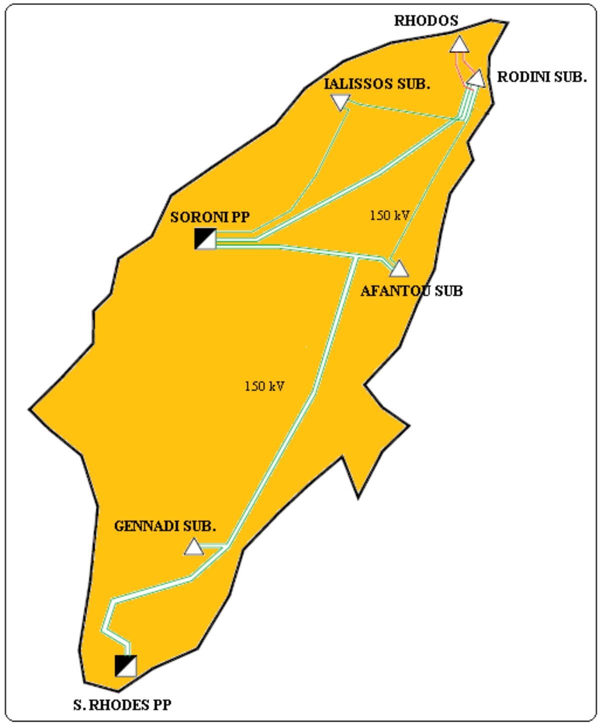
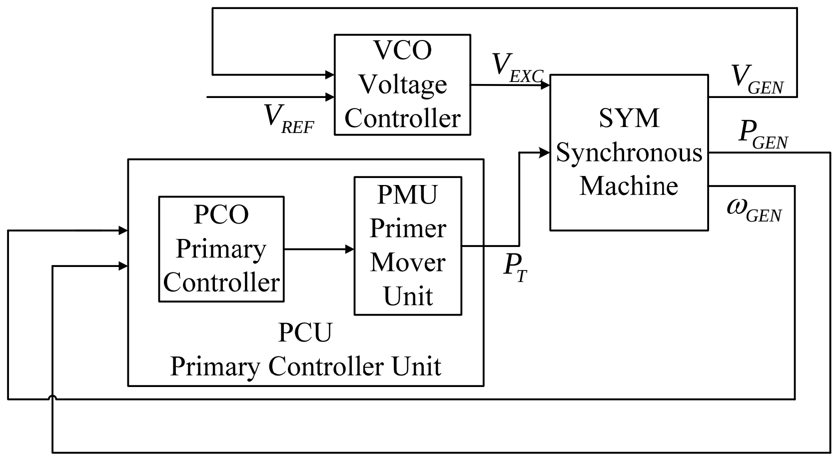
Rhodes power system (1) - reference year 2012

Rhodes power system	
Max Power Demand (MW)	233.1
Rated Thermal Power (MW)	322.9
Rated Wind Power Capacity (MW)	48.8



Rhodes power system (2)- conventional units and dynamic loads models

Two conventional power stations:
- Gas, diesel and steam units
- Automatic voltage regulators,
- Primary controller units

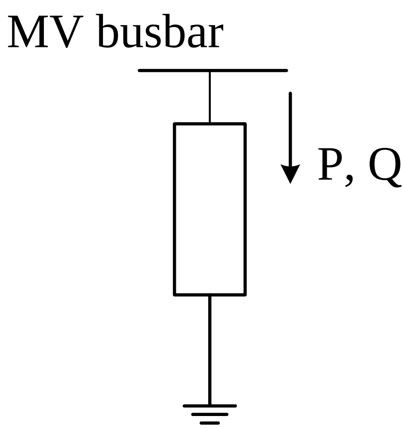


Standard conventional unit model

Dynamic loads model

$$P = P_0 (V / V_0)^2$$

$$Q = Q_0 (V / V_0)^2$$



Rhodes power system (3) – protection system

Under/over frequency protection systems available in power systems like Rhodes:

- ROCOF: measuring the rate of change of frequency

- Frequency level: measuring the actual frequency (implemented in Rhodes model)

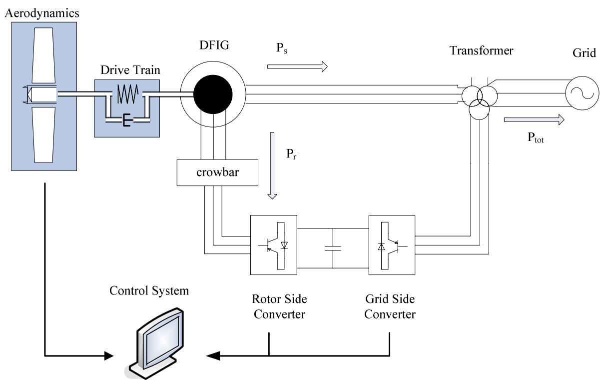
Under/over voltage protection system:

- Bus voltages should be in the range of $\pm 5\%$ around the nominal voltage for normal operation (N)

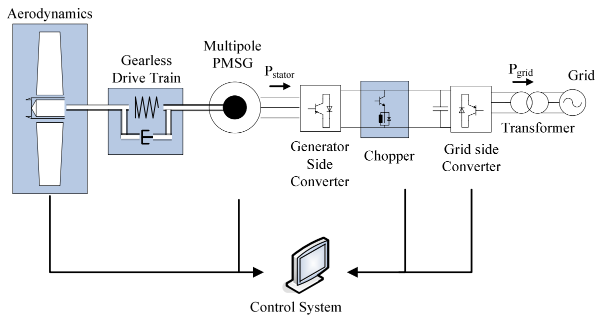
- Bus voltages should be in the range of $\pm 10\%$ around the nominal voltage for emergency operation (N-1).

Rhodes power system (4) – wind turbine configurations

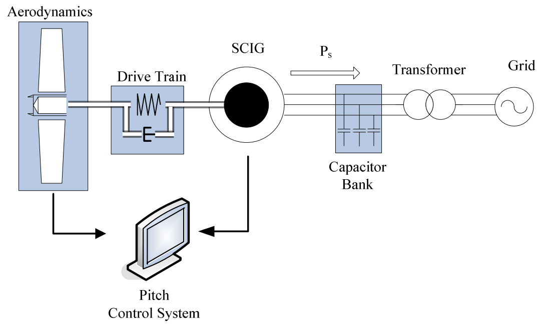
(a)



(b)



(c)



System configuration for: (a) DFIG, (b) PMSG, (c) ASIG wind turbines

Rhodes power system (4) – wind farms

	Wind Turbine Technology	Installed Capacity (MW)
Wind Farm A1	DFIG	11.05
Wind Farm A2	DFIG	5.95
Wind Farm B1	PMSG	18
Wind Farm B2	PMSG	3
Wind Farm C	ASIG	11.7
Total		48.8

Rhodes power system (5) – Case study

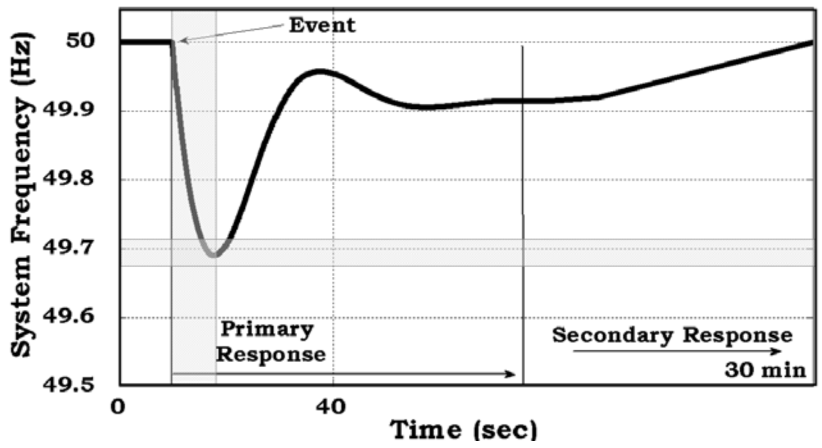
Two different scenarios studied:

- The Maximum Wind Power Production scenario (in absolute values of power) – (SCENA)
- The Maximum Wind Power Penetration scenario (in percentage of the load demand) – (SCENB)

	SCENA	SCENB
Total demand (MW)	167	83
Wind power production (MW)	45.21 (27%)	28.2 (34%)

Frequency definitions

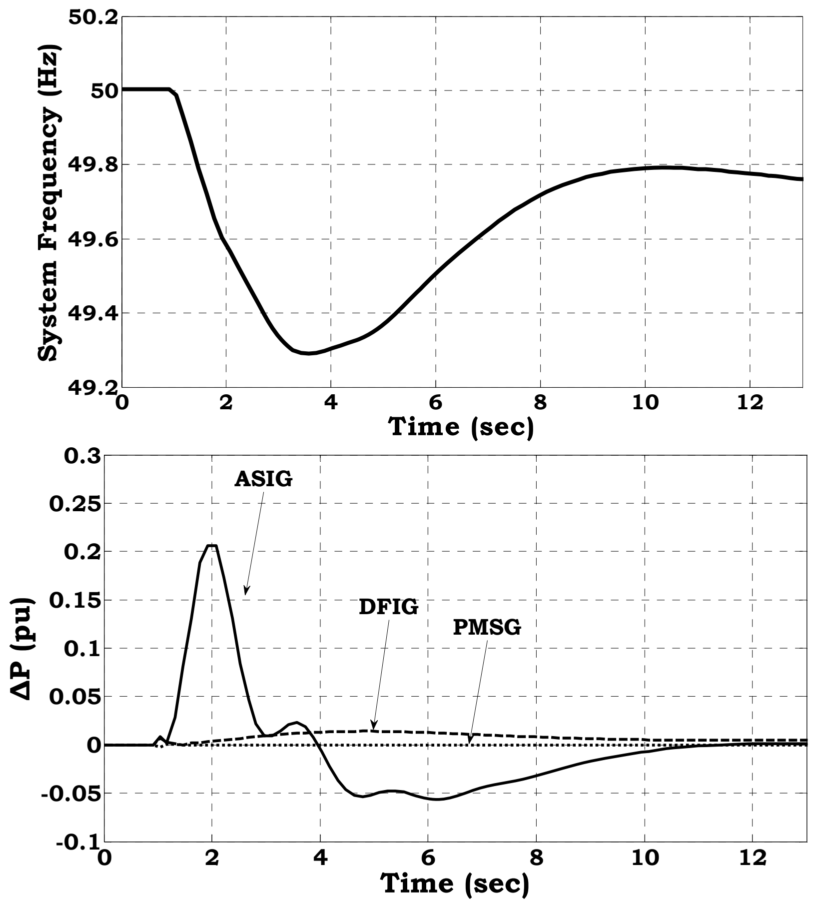
- *Primary Control* – first 30-40 sec after the event, new steady state of frequency
- *Secondary control* – up to 30 min after the event, establishment of nominal frequency



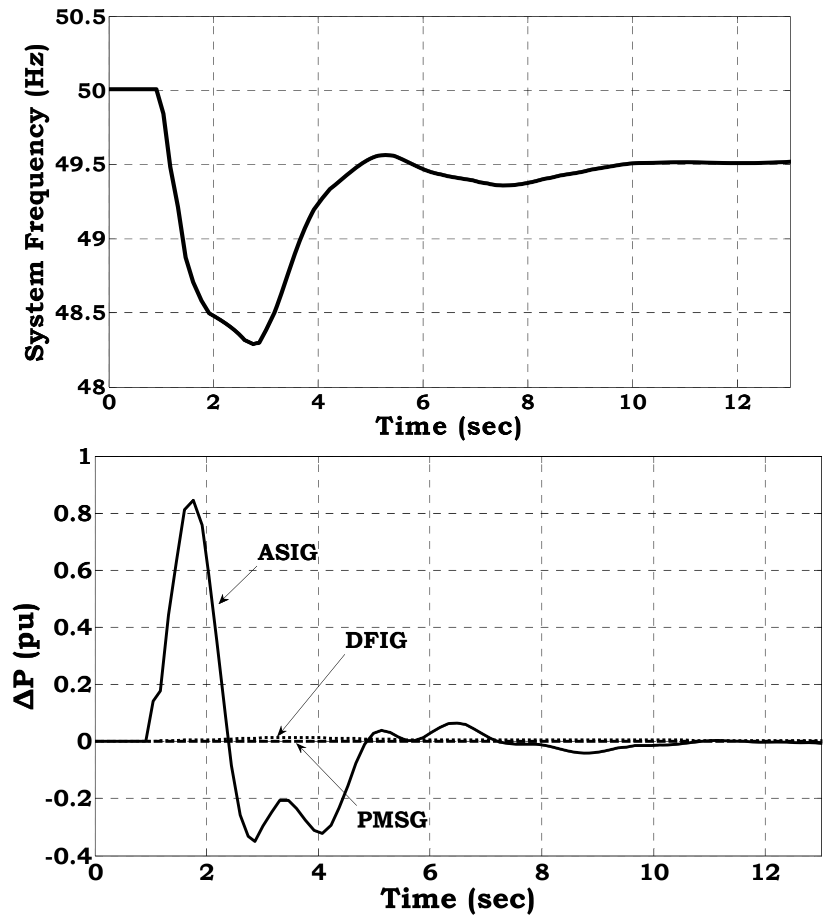
Definitions of frequency control

- Dead zone of normal operation: 50 ± 0.1 Hz

Frequency response of WTs (1) – loss of largest unit in the system



Response for SCENA



Response for SCENB

Frequency response of WTs (1) – loss of largest unit in the system

- **Fixed Speed WTG (ASIG):**

  Rotor speed attached to the system frequency
  Provides inertial response

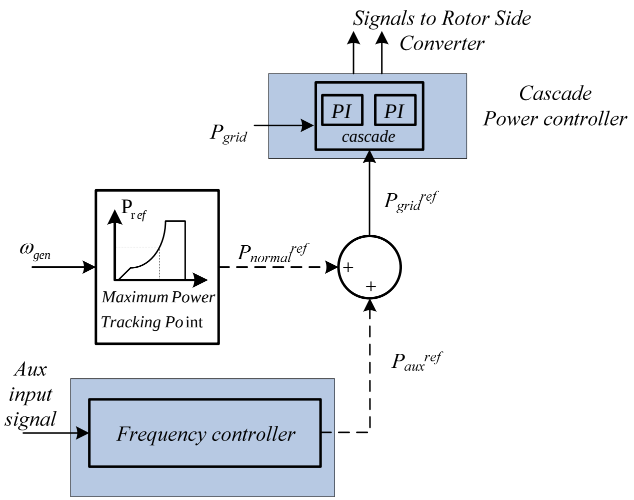
- **Variable Speed WTG (PMSG, DFIG):**

  Power electronic converters detach rotor speed from the system frequency
  PMSG: No inertial response
  DFIG: Small inertial response

Frequency control methods for DFIG wind turbines (1) – general scheme

Frequency control initiative:

Active contribution of DFIG wind turbines during frequency deviations in the system

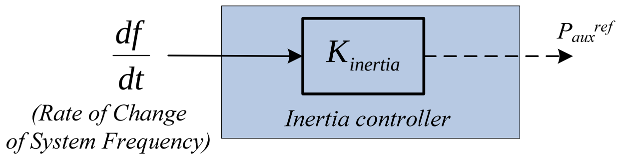


General frequency control scheme

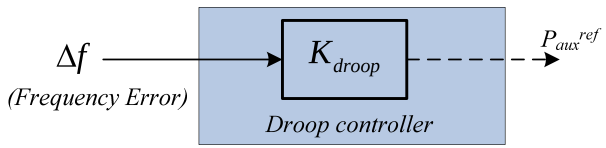
Frequency control methods for DFIG wind turbines (2)

Three different control methods applied:

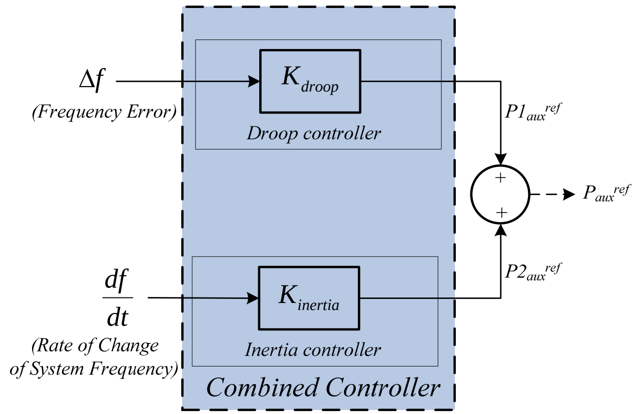
(i) Inertia Control (“virtual inertia”)



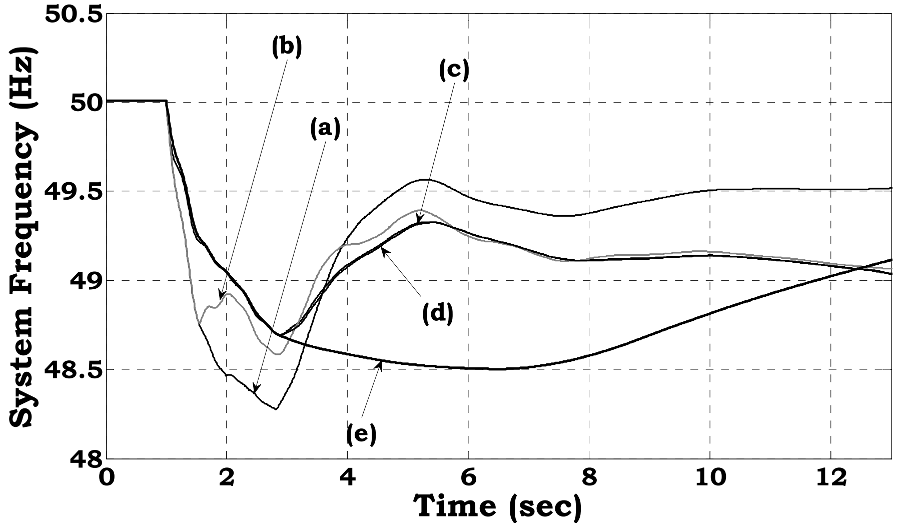
(ii) Droop Control



(iii) Combined Control

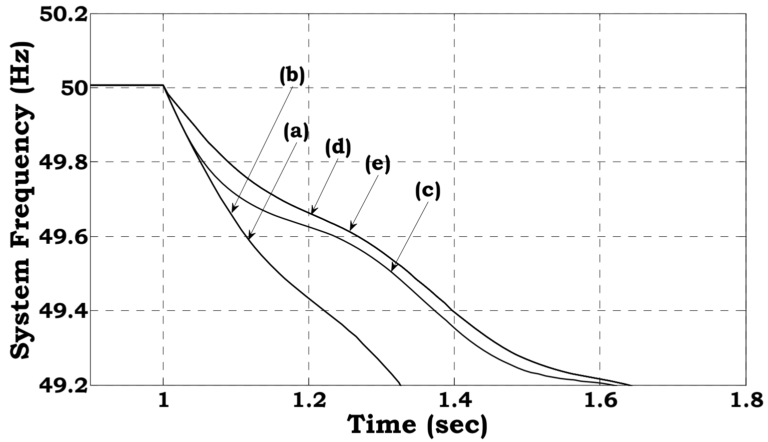


Results (1) - SCENB



(a) No auxiliary control
(b) Droop control on WF level
(c) Droop control on WT level
(d) Combined control
(e) Inertia control

System frequency for loss of largest unit

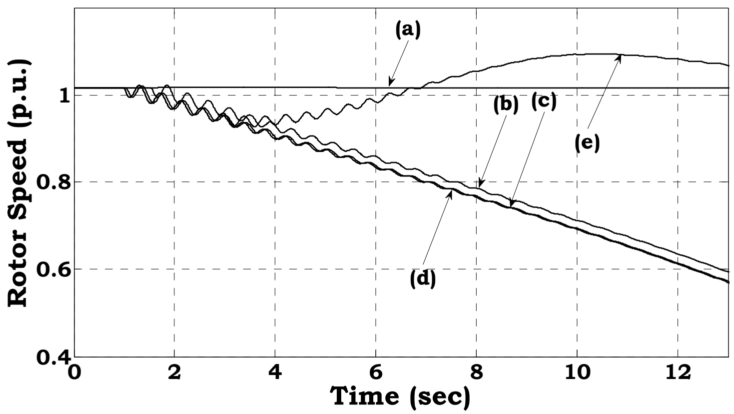


Results (2) – SCENB

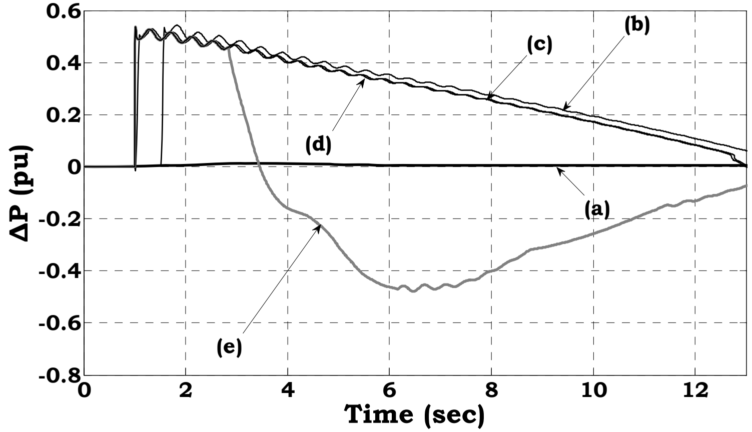
Frequency Control Scheme		Minimum Frequency (Hz)	Maximum Rate of change of frequency (Hz/sec)	Load Shedding (MW)
(a)	No auxiliary Control	**48.28**	**-5**	15.1 (18%)
(b)	Droop control on WF level	48.58	-5	0
(c)	Droop control on WT level	**48.69**	-5	0
(d)	Combined Control	**48.69**	**-3.8**	0
(e)	Inertia control	48.5	**-3.8**	0

Results (3) - SCENB

DFIG wind turbine rotor speed



(a) No auxiliary control
(b) Droop control on WF level
(c) Droop control on WT level
(d) Combined control
(e) Inertia control



DFIG wind turbine change in active power output

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Conclusions (1)

- Non interconnected systems face the problem of reduced inertia especially when wind turbines tend to substitute conventional units

- The fixed speed wind turbines have inherent inertial response during frequency deviations in the system

- DFIG wind turbines have negligible inertial response and PMSG have no inertial response

- Auxiliary frequency control needed in variable speed wind turbines to allow expanded wind power penetration beyond the rule of thumb of 30 %

- Inertia control used in DFIG: reduced initial rate of change of frequency

Conclusions (2)

• Droop control used in DFIG: Reduced minimum frequency after the event

• Combined control: Best compromise for initial rate of change of frequency and minimum frequency

• Wind turbine side: Cases where the WT is forced to operate away from the maximum power tracking curve. Economic cost should be evaluated and motivation should be given to the wind farm operators

• Review of the protection system, which should follow the progress made in the support capabilities of the wind farms

• Technology such as flywheel although available but only advanced frequency control capability of modern wind turbines can expand the penetration levels

Thank you for your attention!