

Distributed Generation: Stability and Protection Issues

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Distributed Generation Technologies

- Next two decades will see an increasing penetration of distributed generation (DG) at the distribution level of the grid. **DG as a Micro-grid?**
- Technologies
 - ✓ Reciprocating engine (Diesel)
 - ✓ Reciprocating engine (Natural gas (NG))
 - ✓ Micro-turbine (Air craft engine design)
 - ✓ Combustion turbine (CT)
 - ✓ Fuel cells (FC)
 - ✓ Wind power

DG Technologies

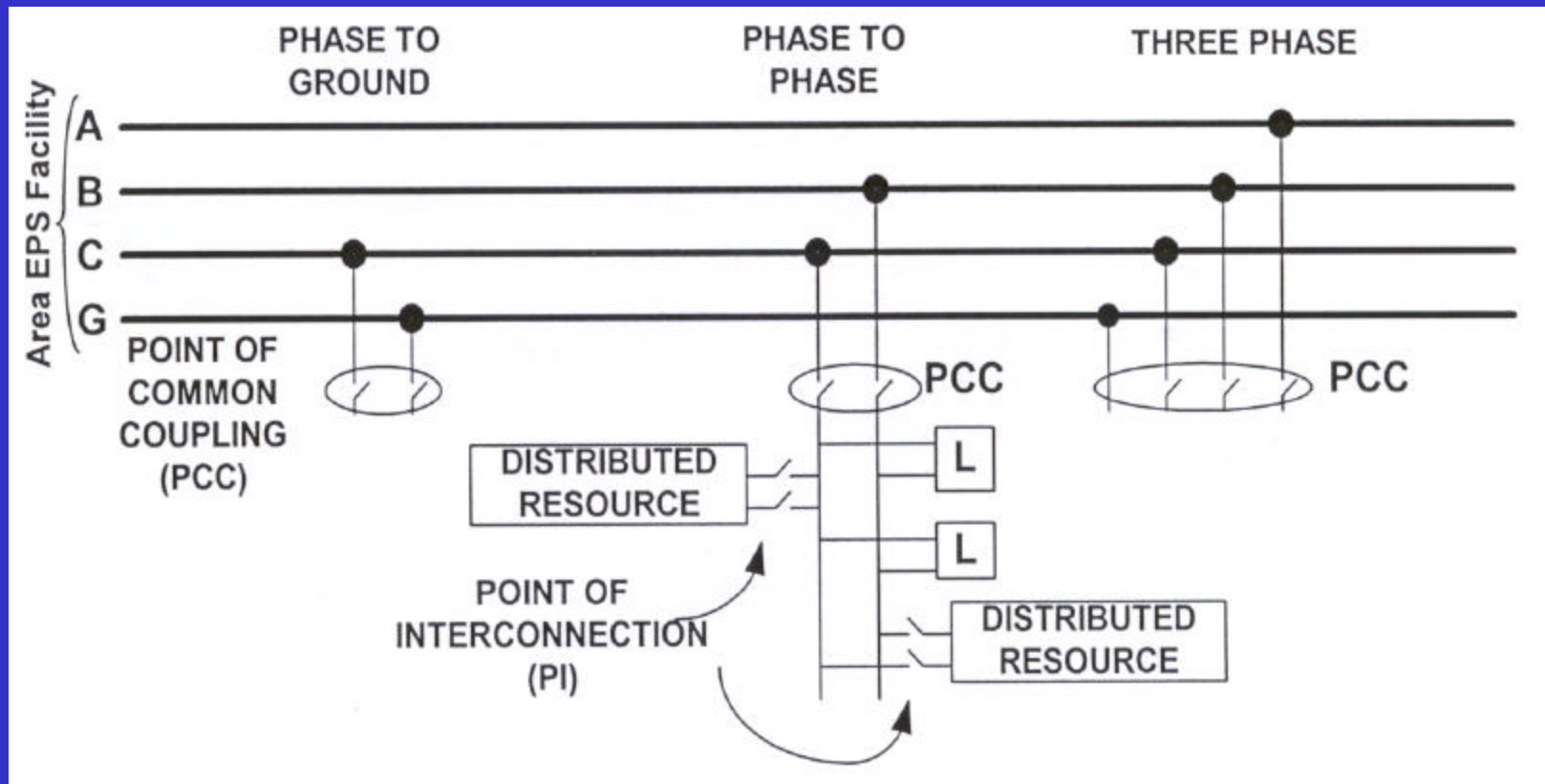
- Look at two technologies: CT and FC
 - ✓ CT adds inertia, dynamics comparable to synchronous generators if CT is big enough.
 - Stability will be a problem.
 - Protection system needs to be looked at.
 - ✓ FC will add power electronics.
 - Harmonics at the distribution end is a matter of concern.

Cost of different technologies

Technology	Recip Engine: Diesel	Recip Engine: NG	Microturbine	Combustion Gas Turbine	Fuel Cell
Size	30kW-6MW	30kW-6MW	300-400kW	0.5-30+MW	100-3000kW
Installed cost (\$/kW)	600-1000	700-1200	1200-1700	400-900	4000-5000
Elec. efficiency (LHV)	30-43%	30-42%	14-30%	21-40%	36-50%
Overall efficiency	~80-85%	~80-85%	~80-85%	~80-90%	~80-85%
Total maintenance costs (\$/kWh)	0.005-0.015	0.007-0.020	0.008-0.015	0.004-0.010	0.0019-0.0153
Footprint (sqft/kW)	0.22-0.31	0.28-0.37	0.15-0.35	0.02-0.61	0.9
Emissions (gm/bhp-hr unless otherwise noted)	NO _x : 7-9 CO: 0.3-0.7	NO _x : 0.7-13 CO: 1-2	NO _x : 9-50ppm CO: 9-50ppm	NO _x : <9-50ppm CO: <15-50ppm	NO _x : <0.02 CO: <0.01

Source: wysiwyg://15/http://www.distributed-generation.com/technologies.htn

Interconnecting DG with power grid (source: ABB)



Interconnecting ...

➤ Significant problem areas

- ✓ Does adding CT with its inertia contribute to stability?
- ✓ Does adding FC with its electronics add to PQ problem?

➤ Islanding

- ✓ Utility is still responsible for voltage and frequency of all its customer connections. Creating an islanding where some utility customers are supplied with uncontrolled voltage and frequency is unacceptable.

➤ Protection system design

- ✓ Radial distribution line protection is designed and coordinated for 'one way' power flow. Bi-directional flow in some part or all of a feeder is a whole new world problems

Interconnecting ...

➤ Basic problem:

- ✓ Most utility electric power systems were/are not designed to accommodate active generation and energy storage at the distribution level.

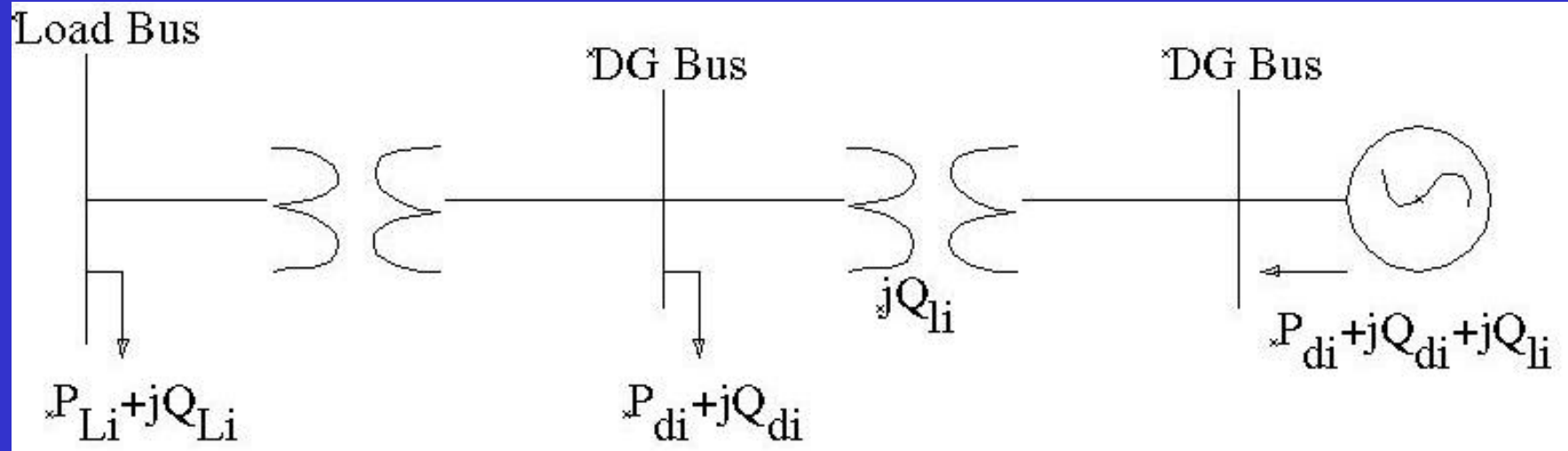
➤ Basic need:

- ✓ Develop technology and operational concepts that will enable realization of DG benefits while avoiding negative impacts on system reliability and safety.

Adding CT

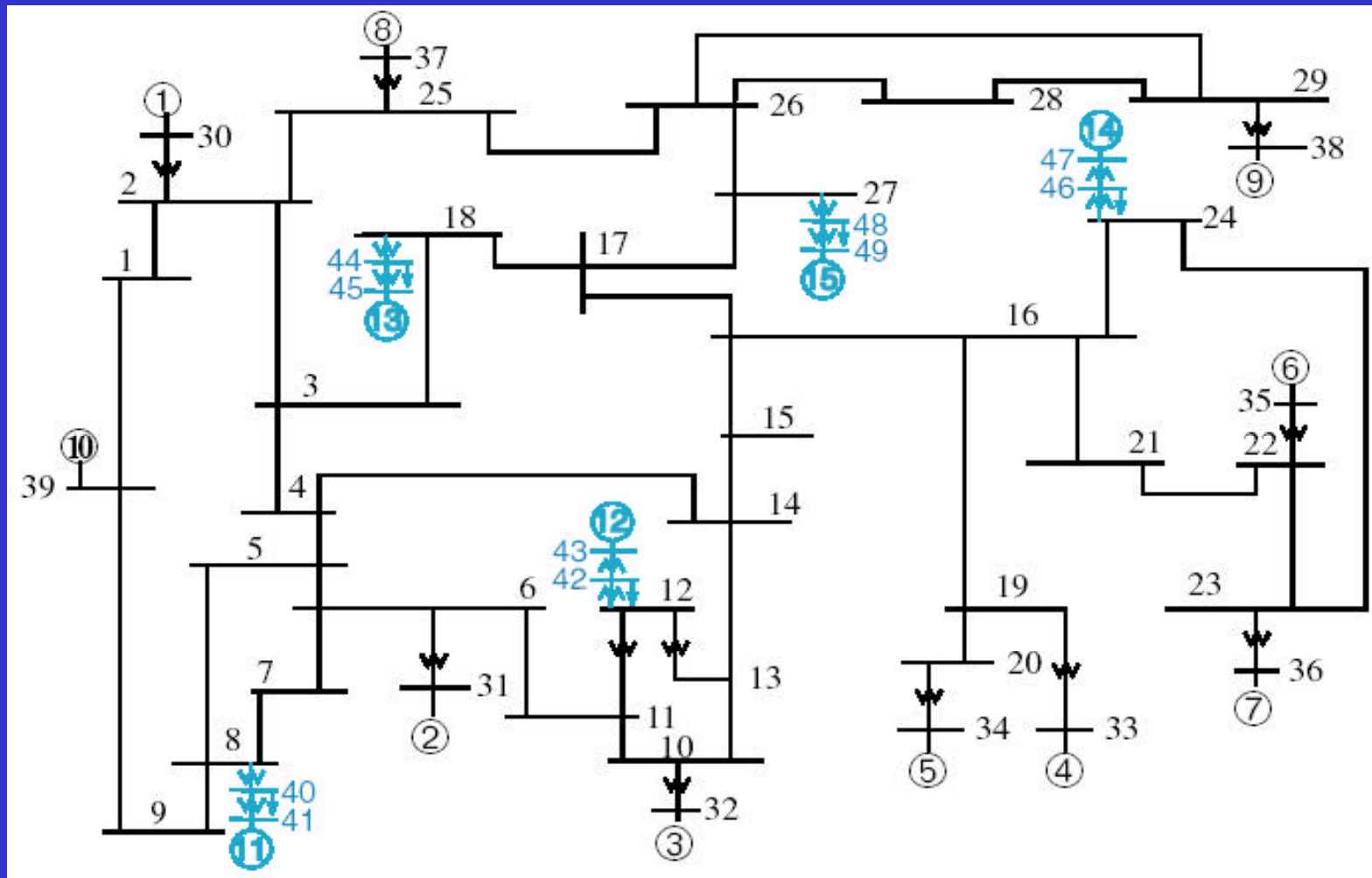
- Assume at 5 buses we add 2/3 of the existing load which will be met by the CT. Added load is 851 MW

$$\% \text{Penetration} = \frac{P_{di}}{P_{Li} + P_{di}} = 40\%, i=1, \dots, 5$$



DG system

➤ DG system: 15-machine, 49-bus system

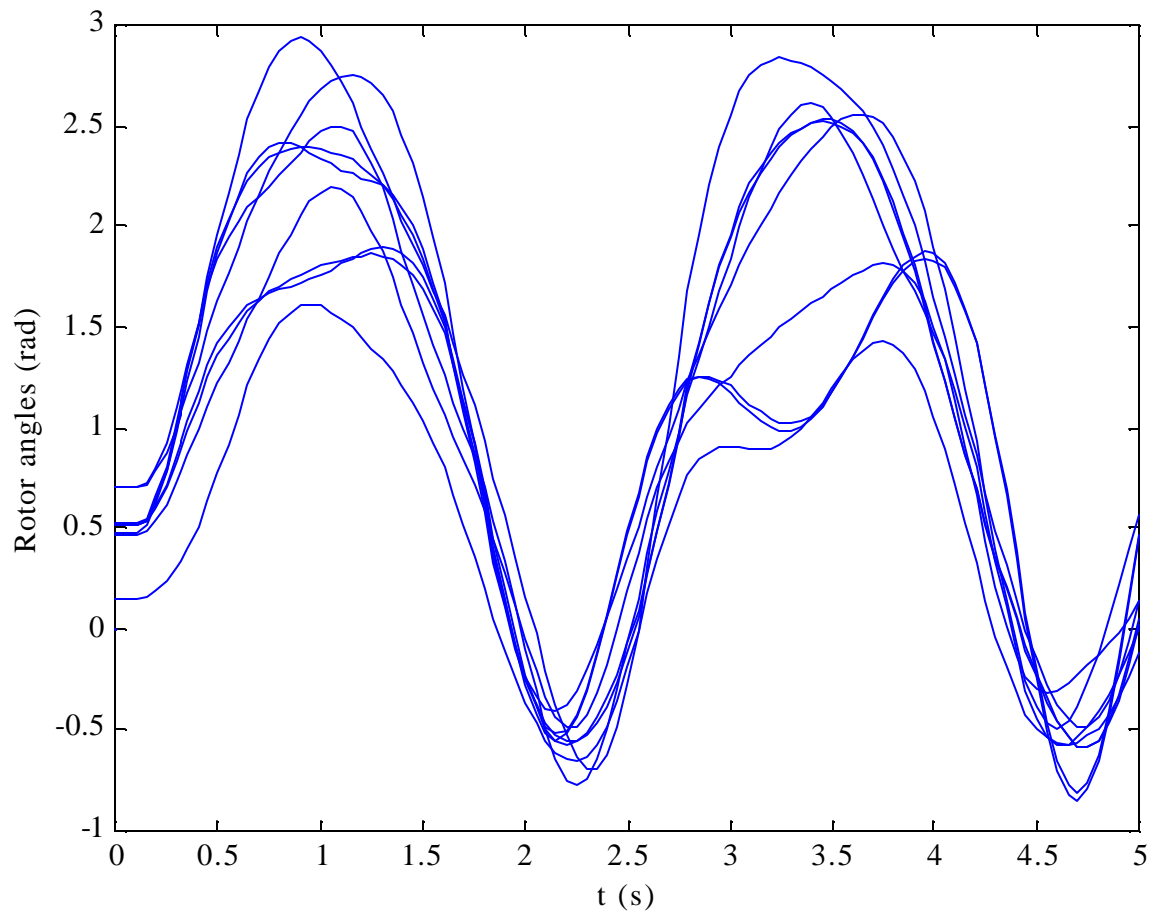


Numerical results

- A fault occurs at bus 15, cleared by tripping line 15-16. The green curves are relative rotor angles of the original system, and the red curves are those of the DG.
 - ✓ Classical model: $t_{cl}=0.22$ s
 - ✓ Two-axis model with exciter: $t_{cl}=0.15$ s

Numerical results

➤ Classical model: the original system is stable.

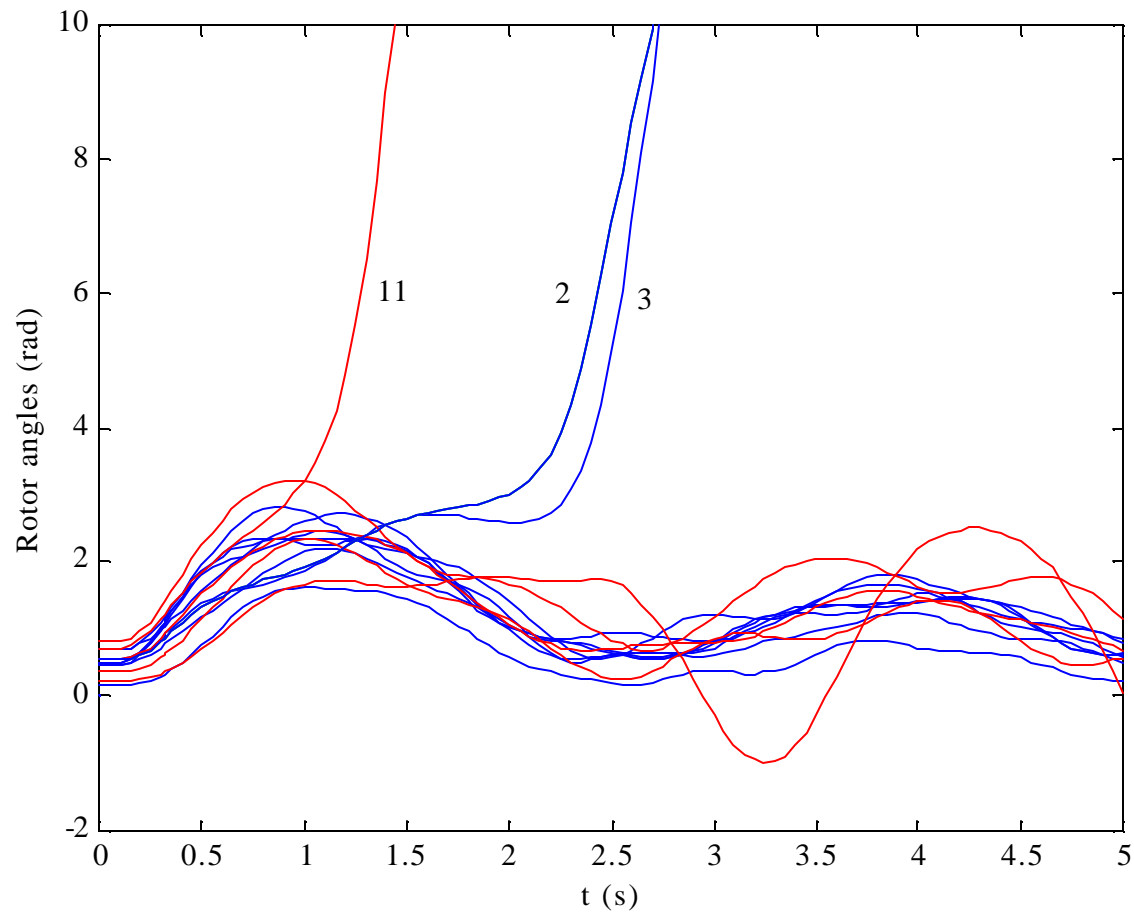


Numerical results

➤ Classical model:

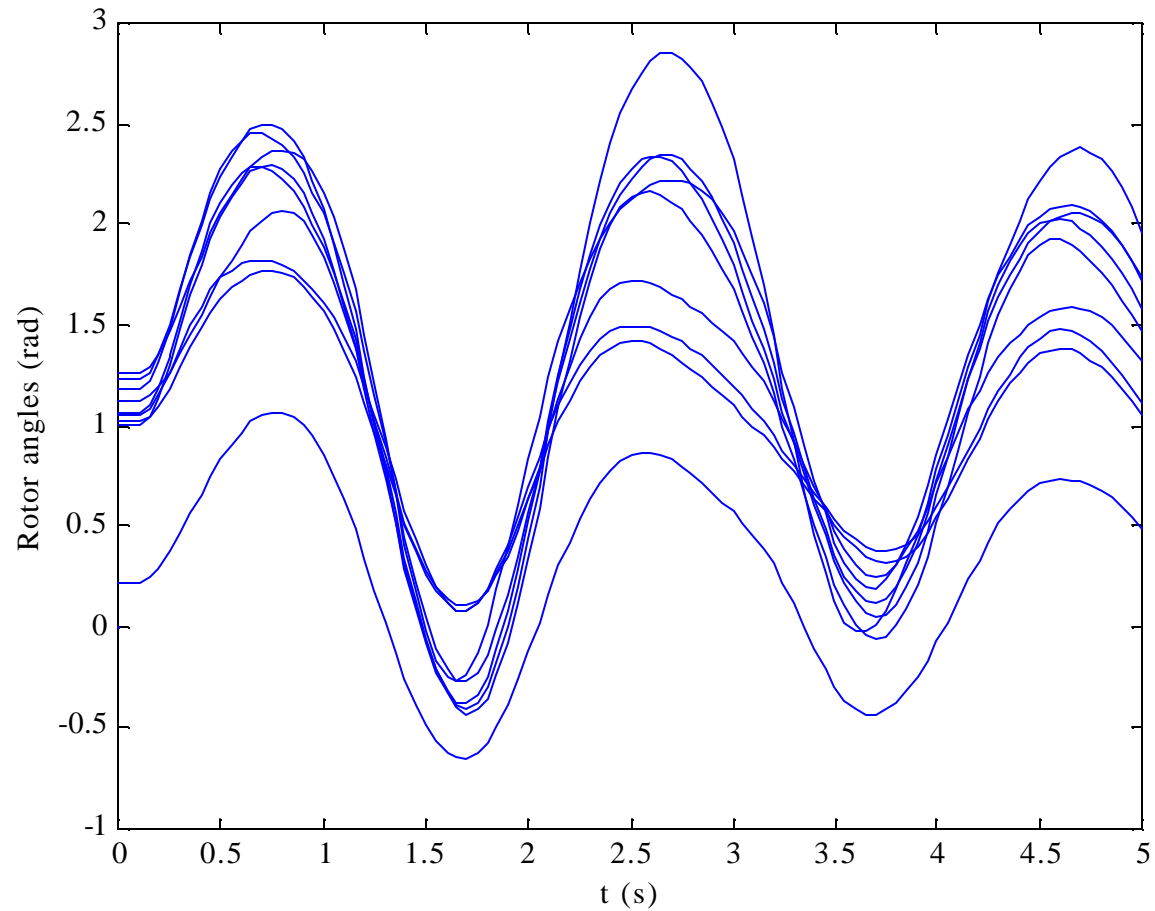
- ✓ Original system and DG: new system is unstable (Gen 2, 3, 11)

↓
DG



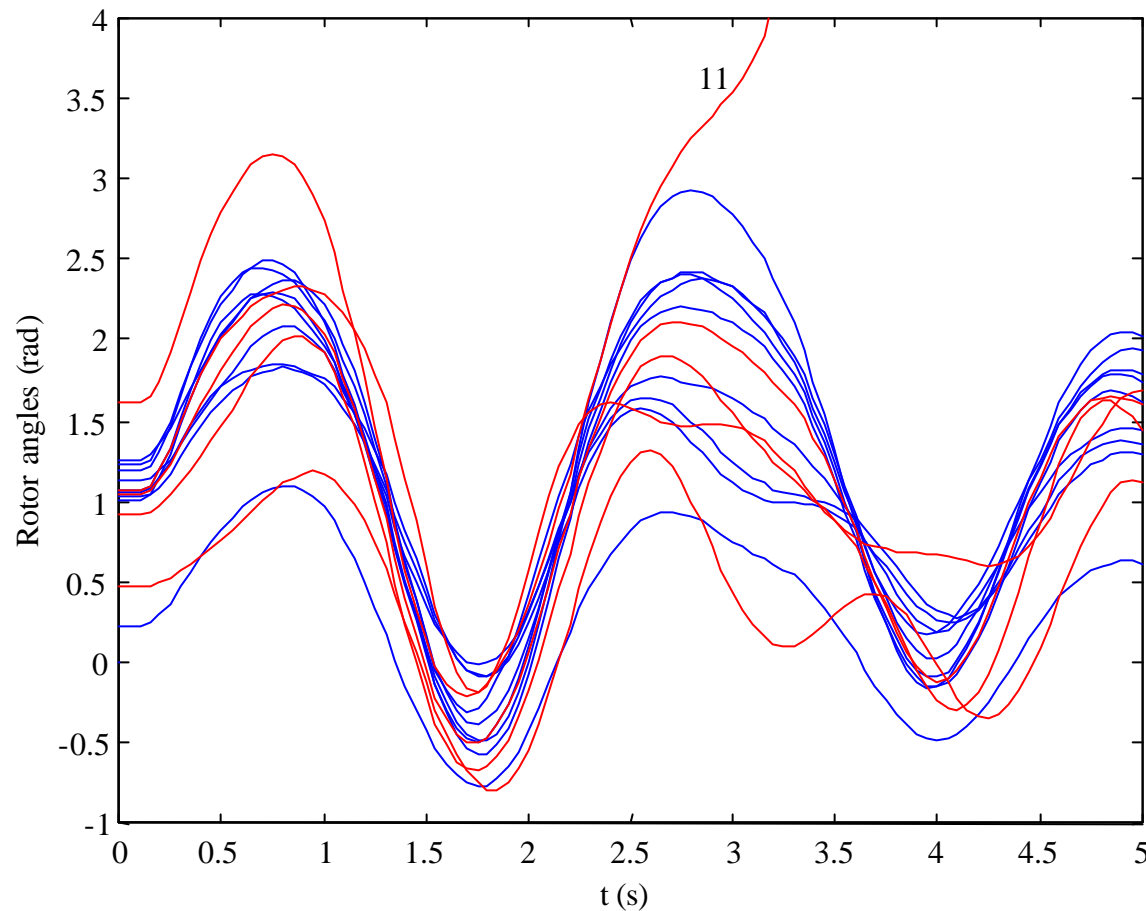
Numerical results

- Two-axis model: the original system is stable.



Numerical results

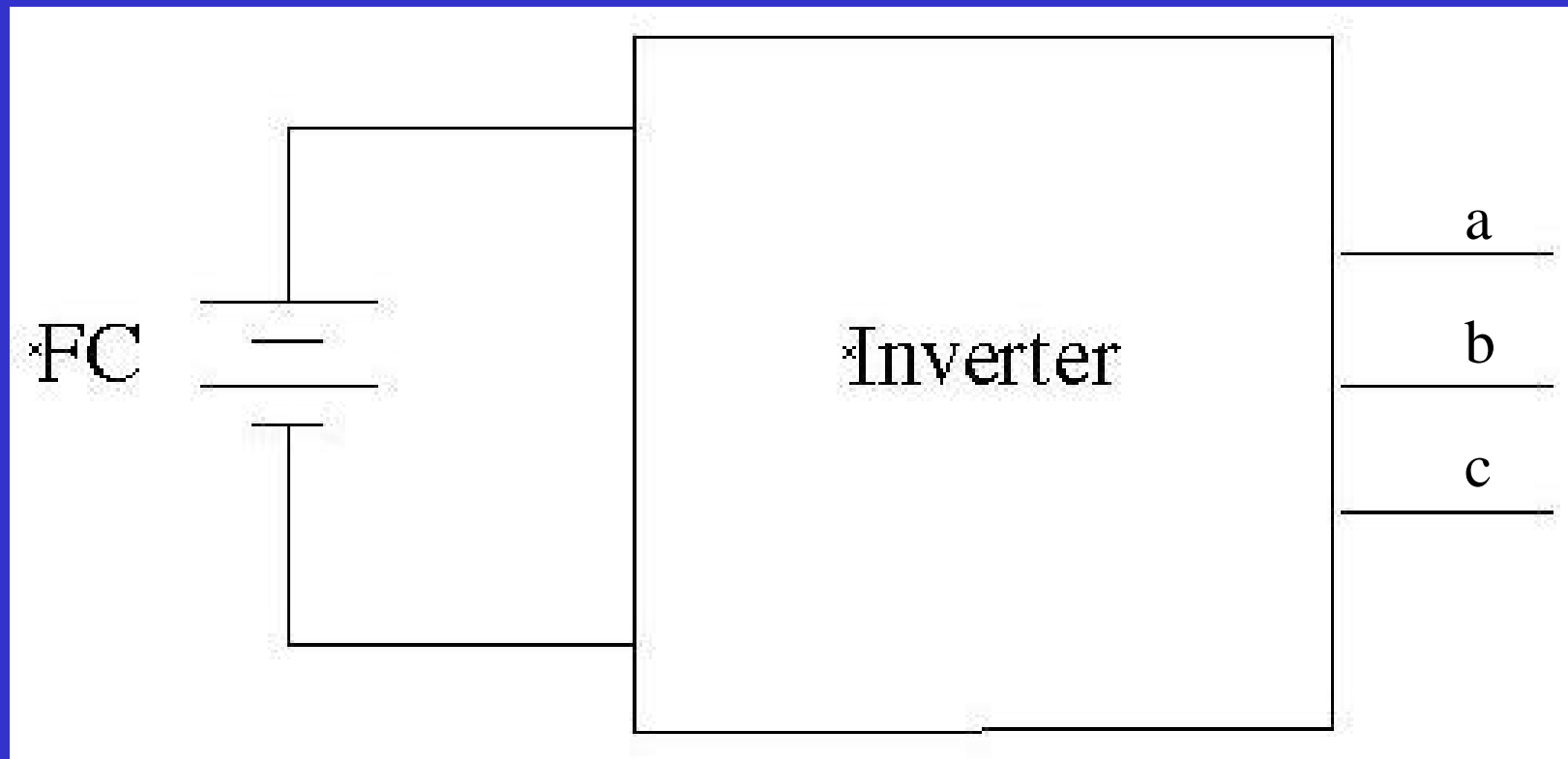
- Two-axis model with exciter
 - ✓ Original system and DG: new system is unstable (Gen 11)



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DG

Future work

- Fuel cell with inverter



Future work

- Dynamics of inverter and filters
- Fuel cell is a DC source
- Detailed investigation planned
- In a micro grid we can have a combination of CT and FC with different levels of penetration.

Interaction?

- Protection is generally radial. A fault may occur on a phase not connected to the single phase DG. The “upstream” circuit may open leaving DG as an island. Protection of the system and DG needs co-ordination