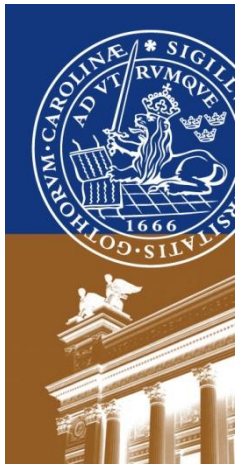


Island operation with induction generators

Olof Samuelsson

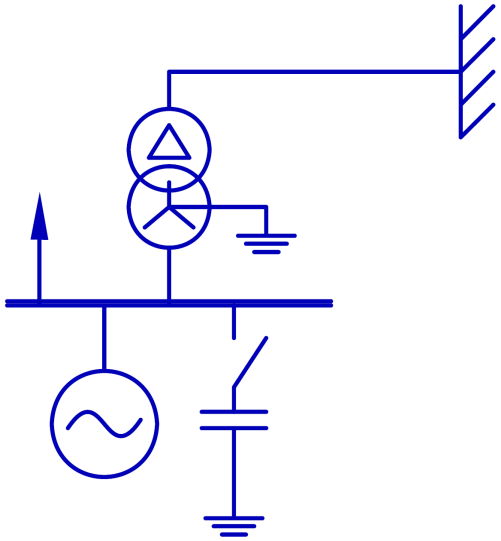
Industrial Electrical Engineering and Automation

Why induction generators?

- Hydropower
  - New small-scale plants often use IG
  - At renovation IG often replaces synchronous generator
- Windpower
  - Many Fixed-Speed Induction Generators installed

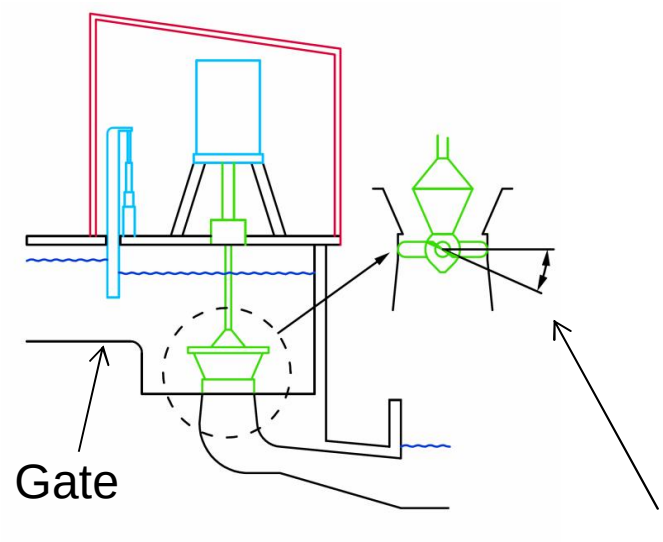
- Original question: Can IG contribute to island operation?
- Modified question: Can island operation be based on IG alone?

Forsa power station



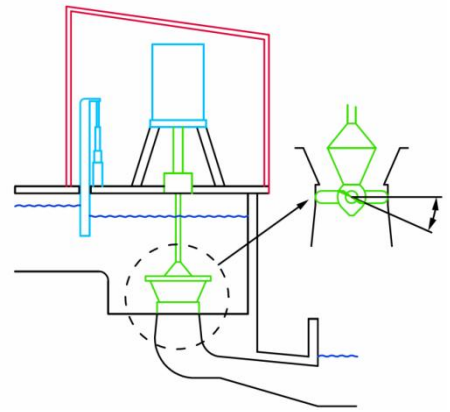
- Semi-Kaplan turbine 275 kW
- Induction generator 315 kW, 400 V
- Capacitors 3x50 kvar
- Transformer 0.4/10 kV, 500 kVA
- Customers connected to the transformer low voltage side

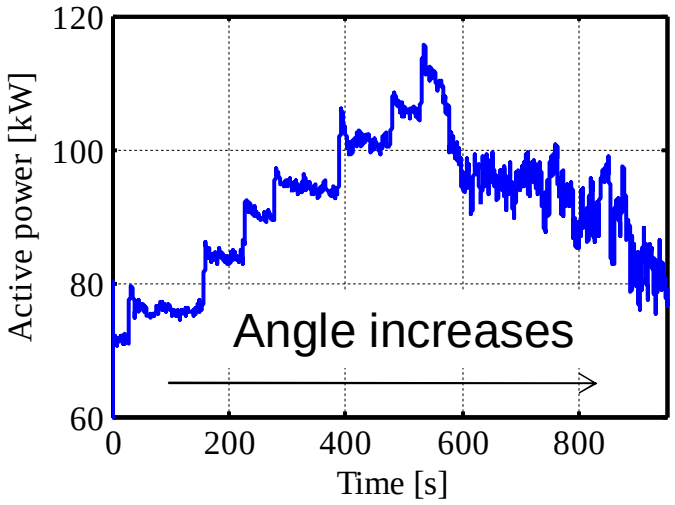
Grid connected operation

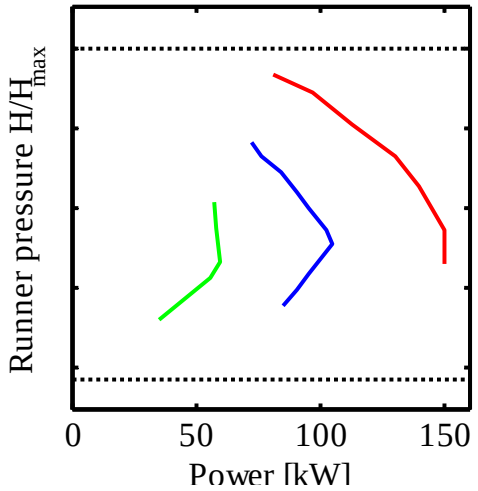


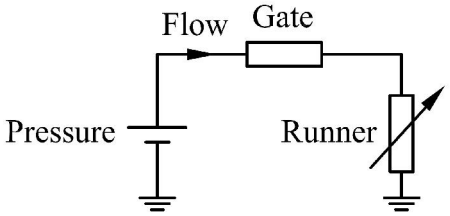
- Starting sequence
  - Gate starts to open
  - During opening
    - Generator accelerates
    - Close breaker near synchronous speed
    - Generator energized
  - Gate stops at fully open
- Power control by runner blade angle
- Minimum output power is 80 kW

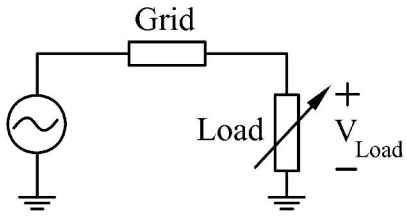
Reducing gate opening for low-load operation

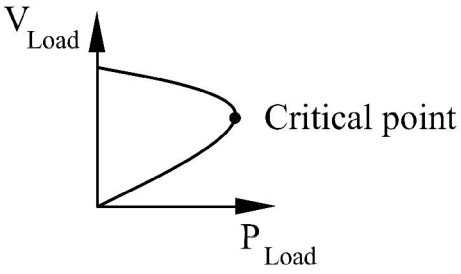






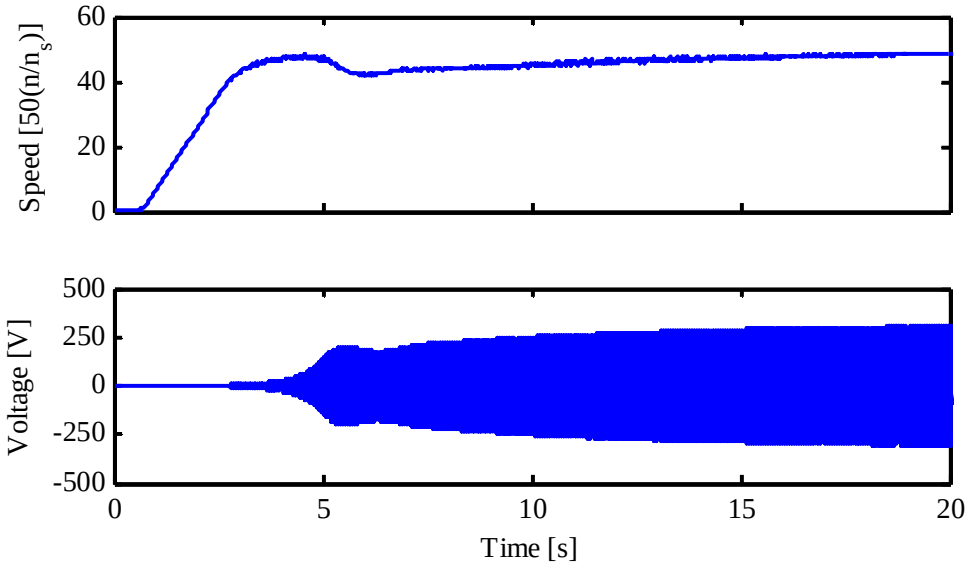


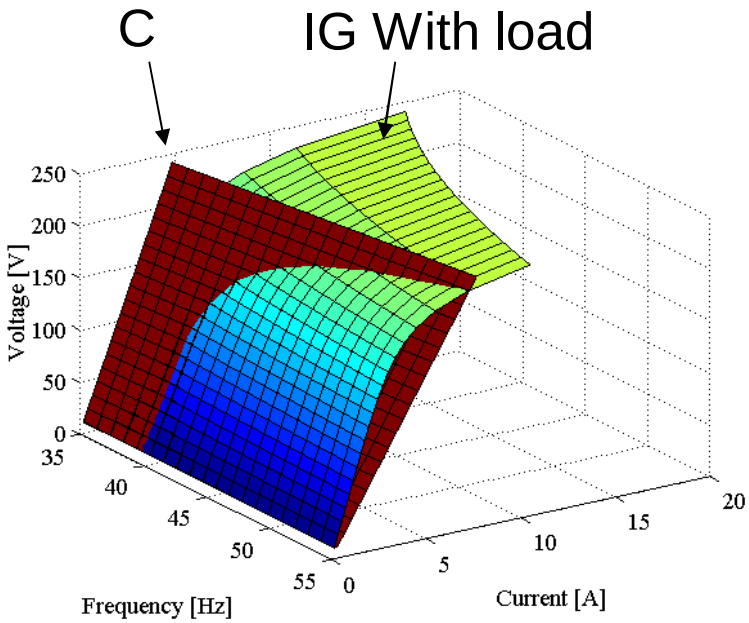




Gate control not possible ► use dump load for low load operation

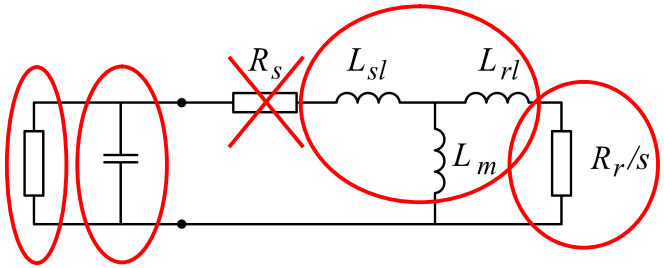
Black start of self-excited IG





- ω increases
  - generator is magnetized
  - voltage rises
- New method gives U and I without fixing ω

Mechanical analogy

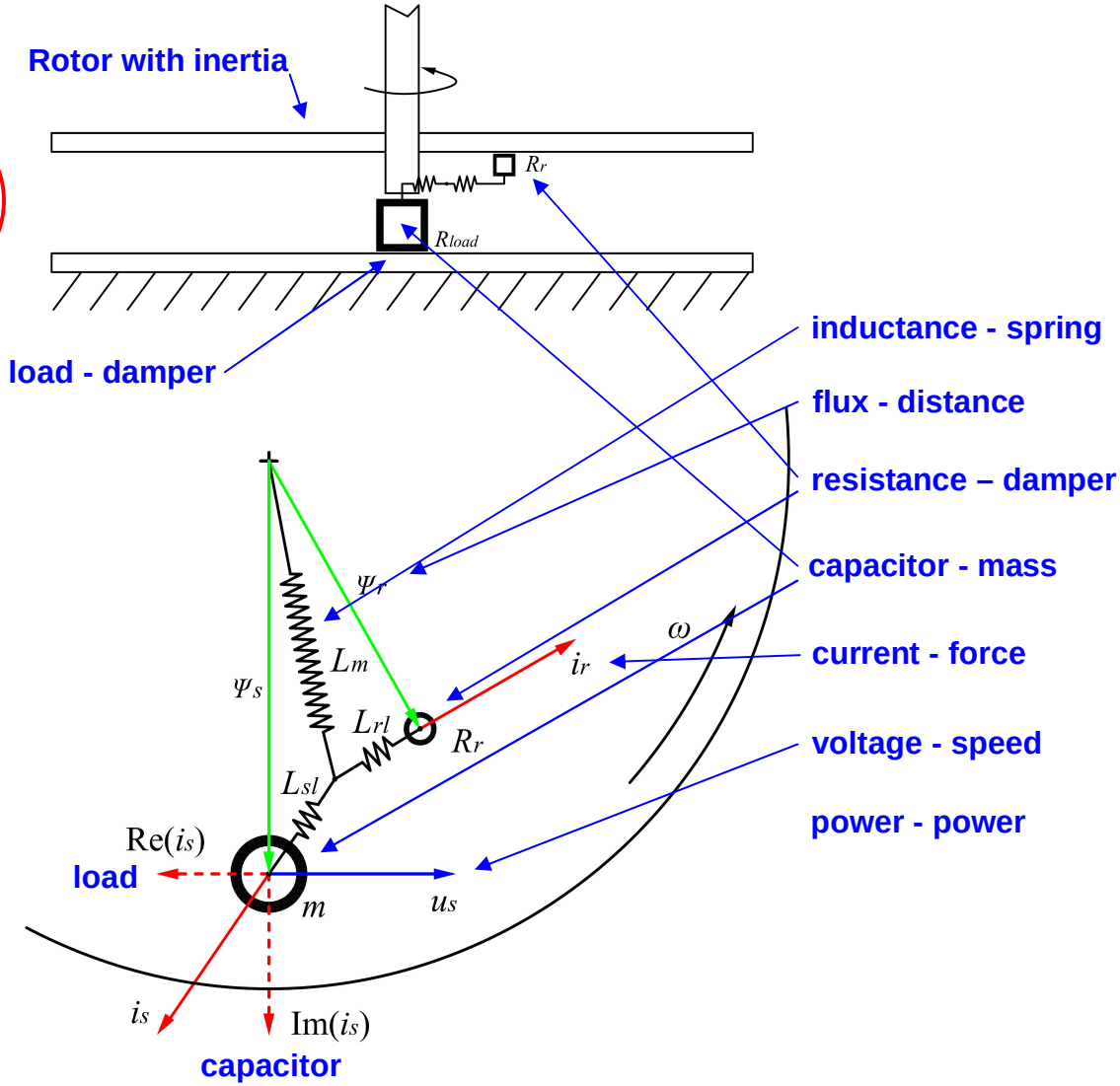


$$i = \frac{1}{L} \cdot \psi \Rightarrow F = k \cdot x$$

$$i = u \cdot \frac{1}{R} \Rightarrow F = v \cdot d$$

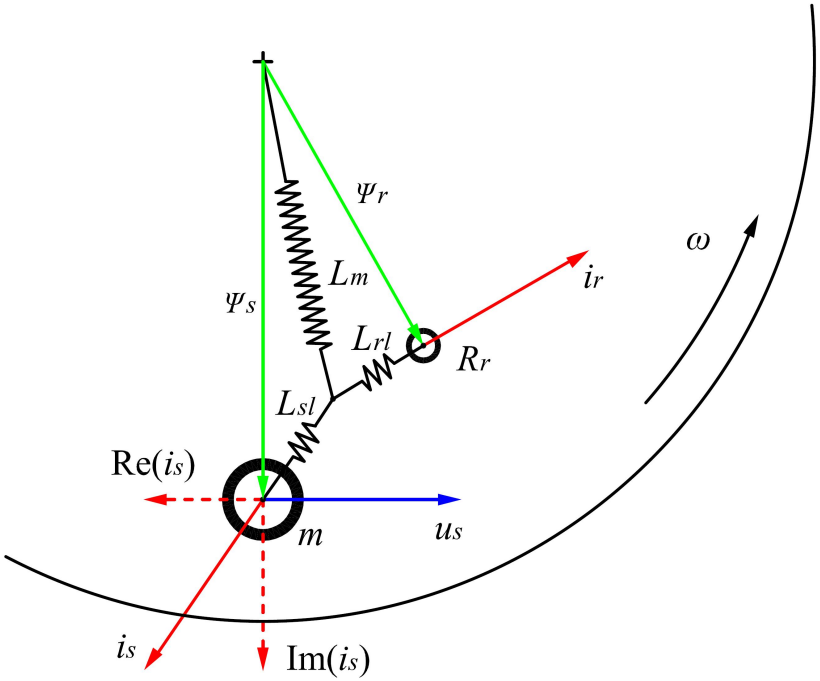
$$i = C\frac{du}{dt} \Rightarrow F = m\frac{dv}{dt}$$

Stator resistance neglected



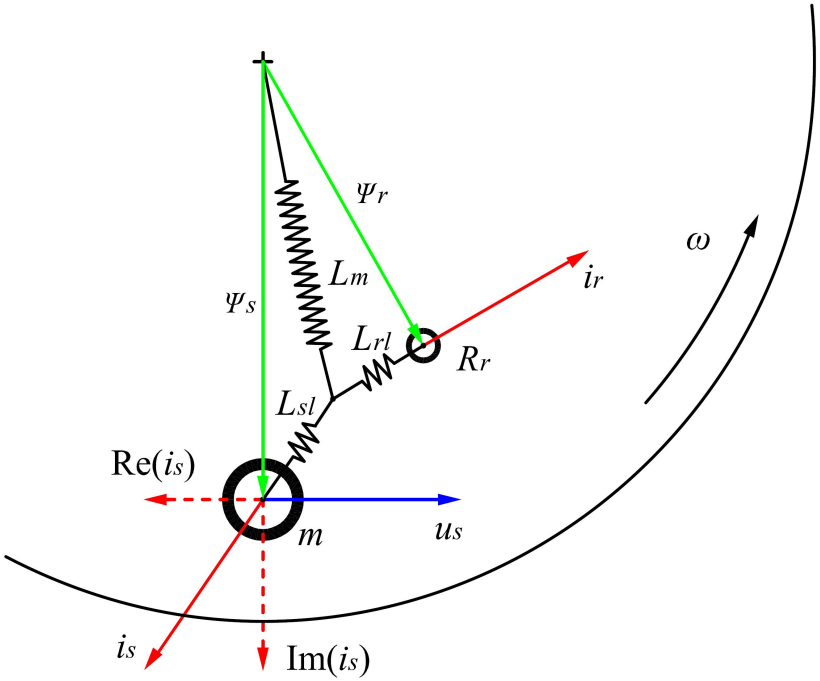
Black start

- Remanence
  - Offset R_r and m
- ω increases
  - Im(i_s) increases
- $m\omega^2 x > kx$
  - mass moves outwards
  - R_r moves outwards
  - u_s increases
- k increases with x
  - Stable operating point

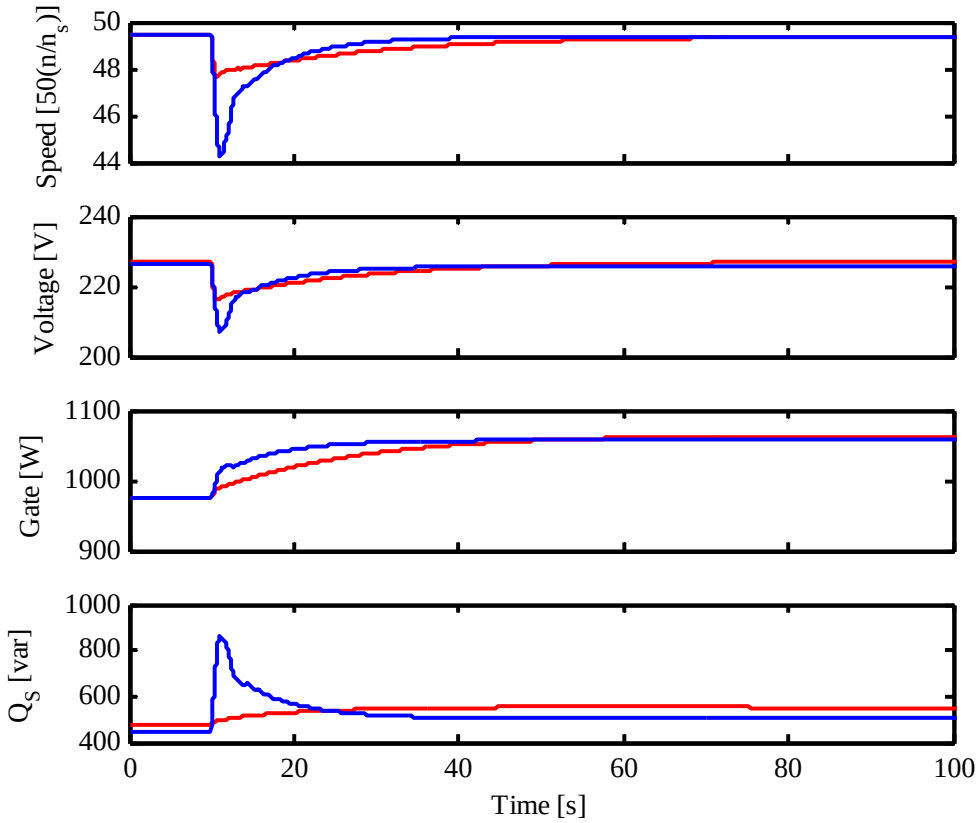


Loading and voltage control

- No-load
  - Re(i_s) = 0
- Connecting load with constant ω
  - slip increases
  - Re(i_s) increases
  - Im(i_s) decreases
  - mass moves inwards
  - u_s decreases
- m increases (STATCOM)
  - u_s increases

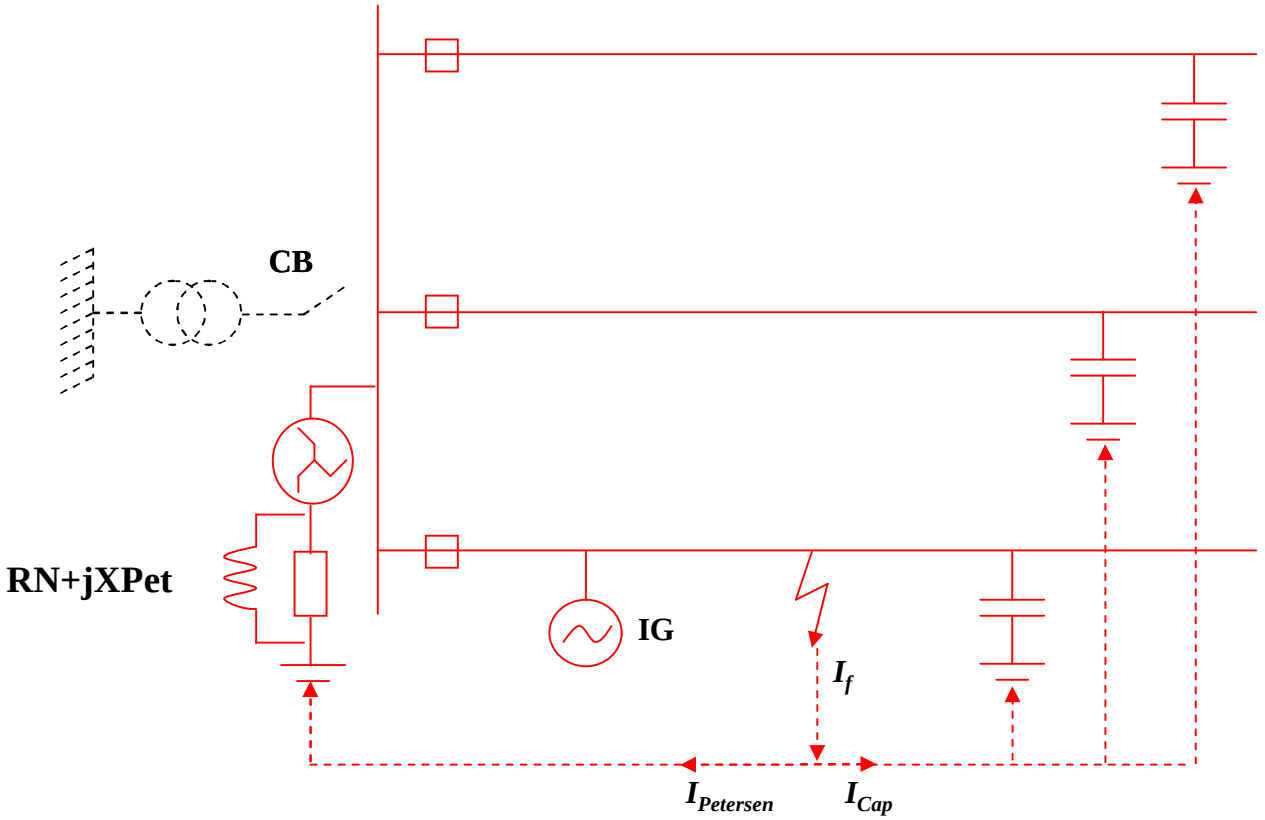


IG voltage and frequency coupled



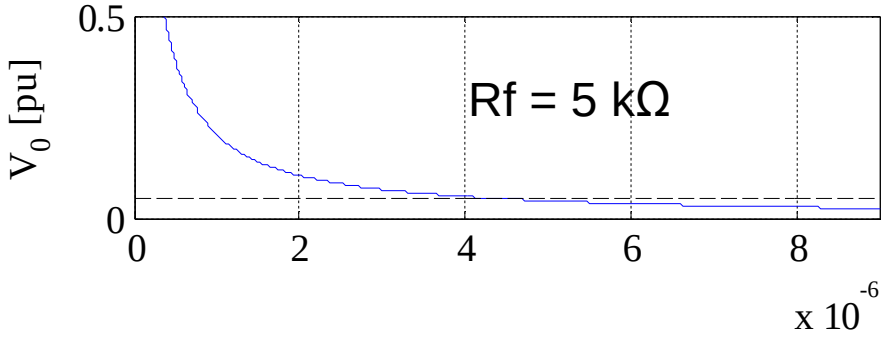
- **Slow** voltage control better than **fast**
- STATCOM affects both speed and voltage
- Voltage and frequency control need to be coordinated

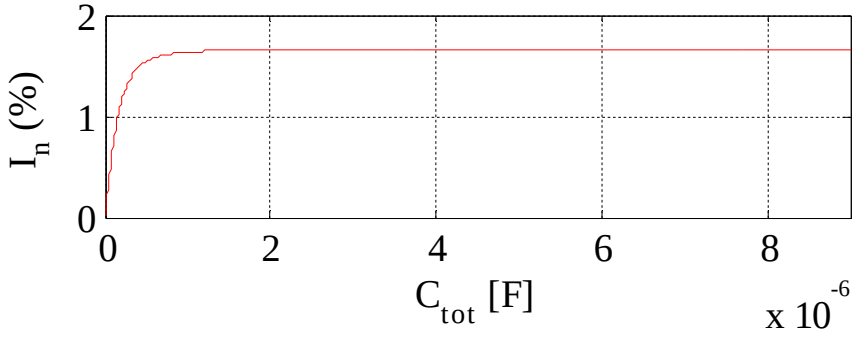
Earthing of MV network



- Petersen coil earthing of MV busbar
- Earthing at MV/LV transformer lost at islanding → unearthed

Self-excited IG behavior at earth faults

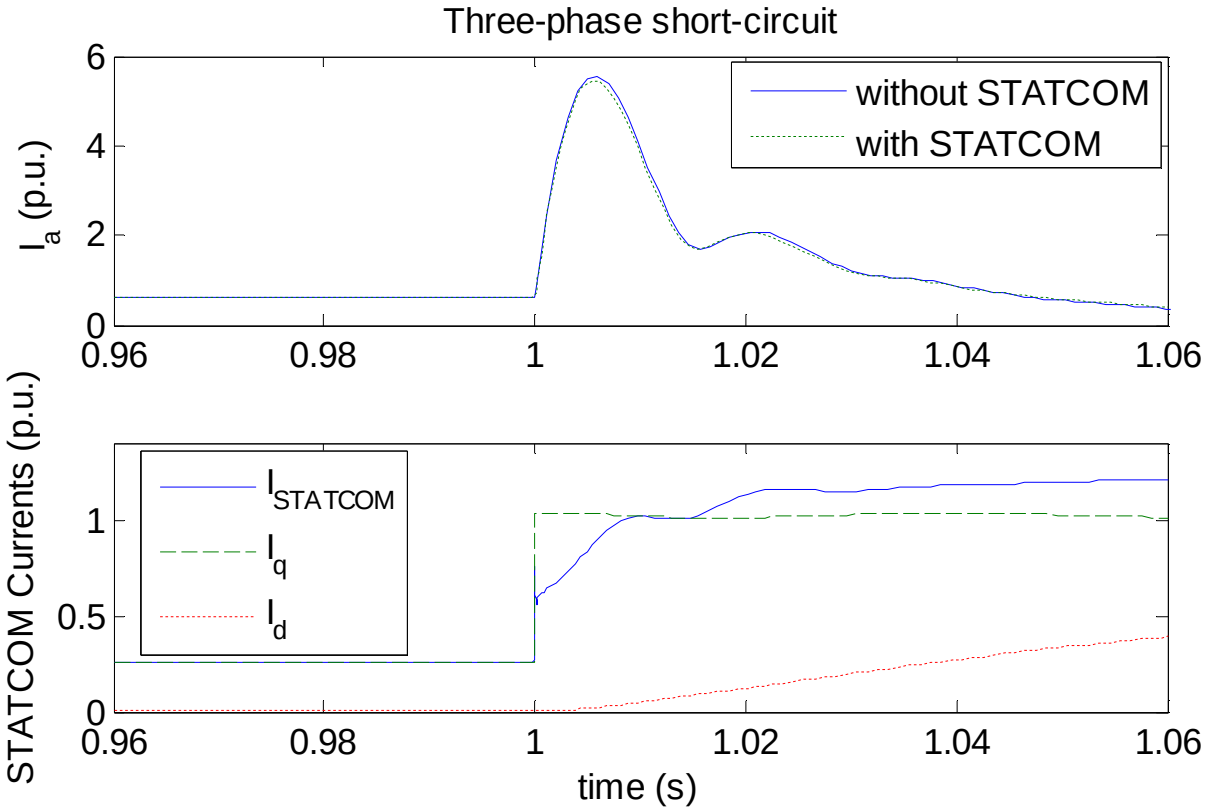




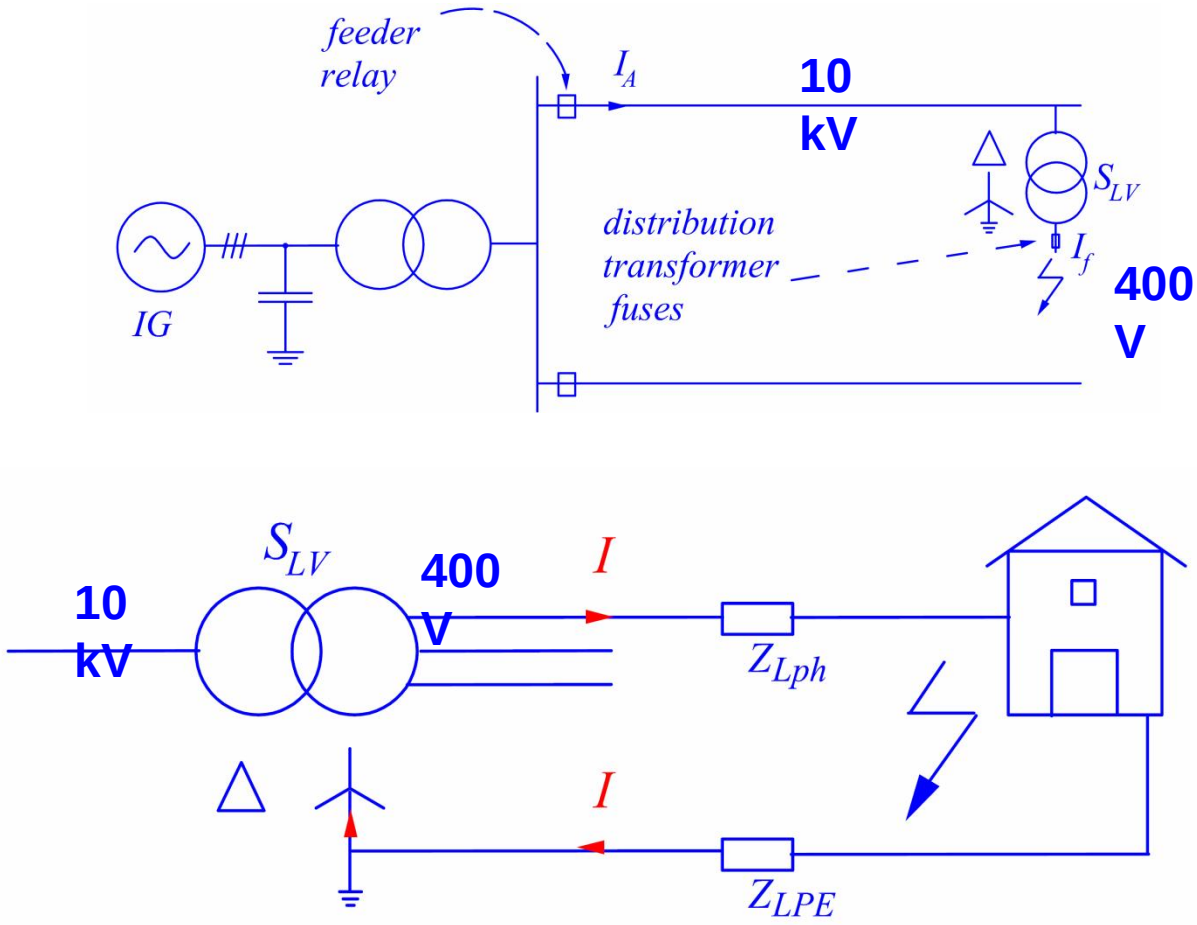
- IG does not demagnetize
- Selective protection possible
  - Normal settings
- Unselective protection
  - More cable reduces V0
  - Upper limit to cable length
  - New method gives V0 in network at IG with D/Y transformer

Self-excited IG behavior at short-circuit

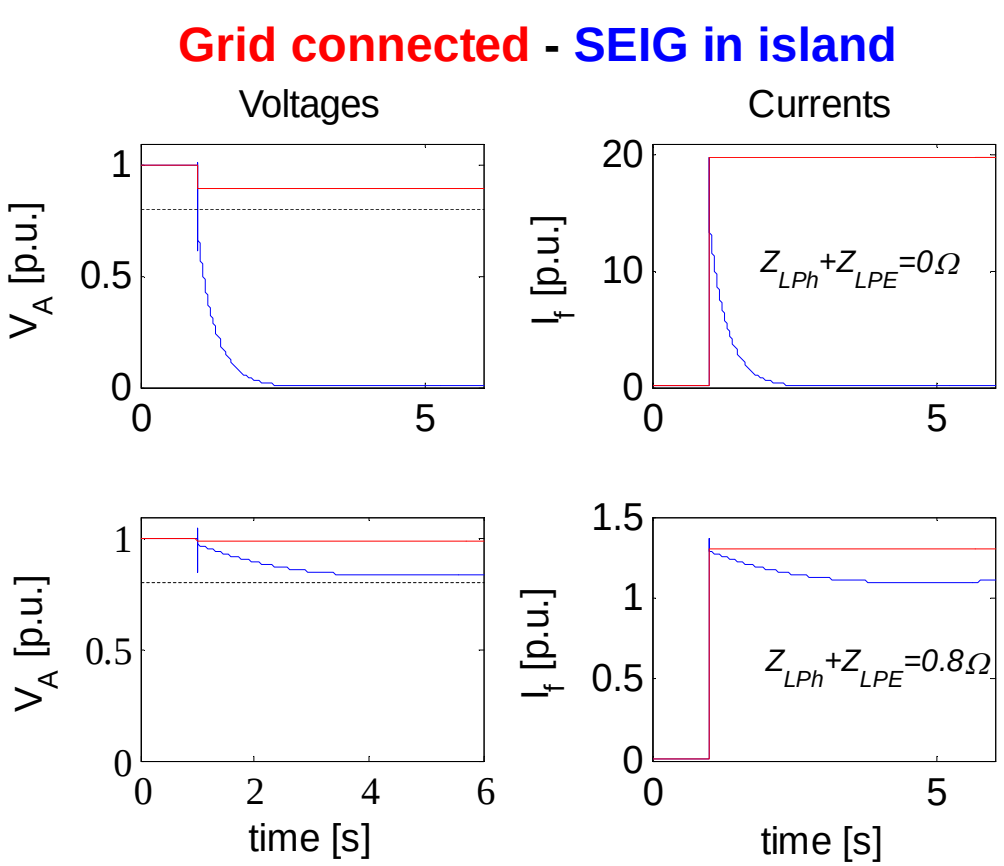
- IG demagnetizes at any short-circuit
- Fault current decays quickly – use undervoltage protection
- STATCOM does not affect short-circuit current much



Earth fault in LV network – normal situation



Earth fault in LV network – island operation



Reduced fault current

Longer melting time

Undervoltage relay may have time to trip

Unselective disconnection of SEIG for LV fault

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