TOV Issues in Renewable Plant Collectors and Application of Grounding Transformers

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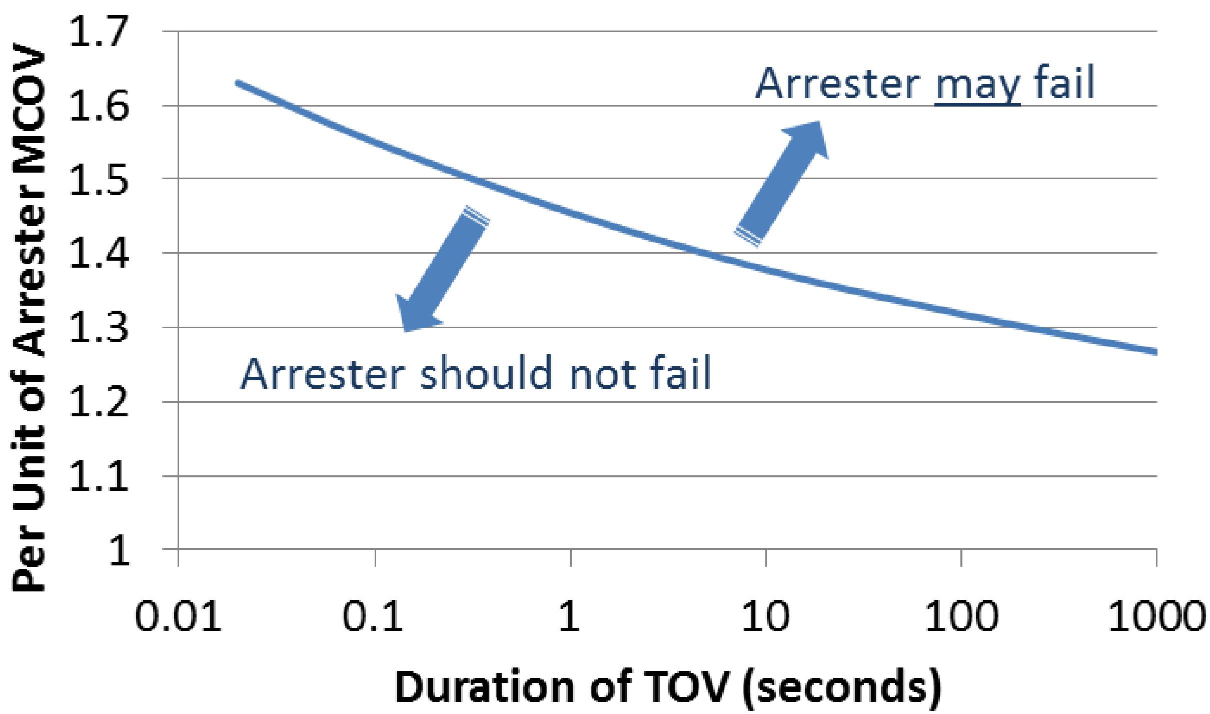
Overvoltage Definitions

- Transient overvoltage – impulses and supersynchronous oscillations lasting less than a couple of cycles
  - Examples: lightning, switching, etc.
- Temporary overvoltage – oscillatory overvoltage persisting for several cycles to seconds
  - Examples: load rejection, single-phase faults, ferroresonance, etc.

Impacts of Temporary Overvoltage

- Primary impact is on surge arresters
  - MV arresters are inexpensive
  - Arrester failures are not!

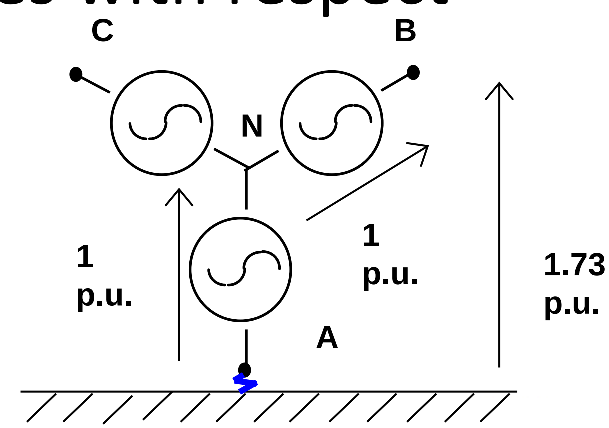


Surge Arresters

- Should be applied at open ends of collector feeders for impulse and switching surge protection
- Surge arresters are designed to limit transient overvoltages, not intended to limit TOV
- Surge arresters are the likely victims of TOV

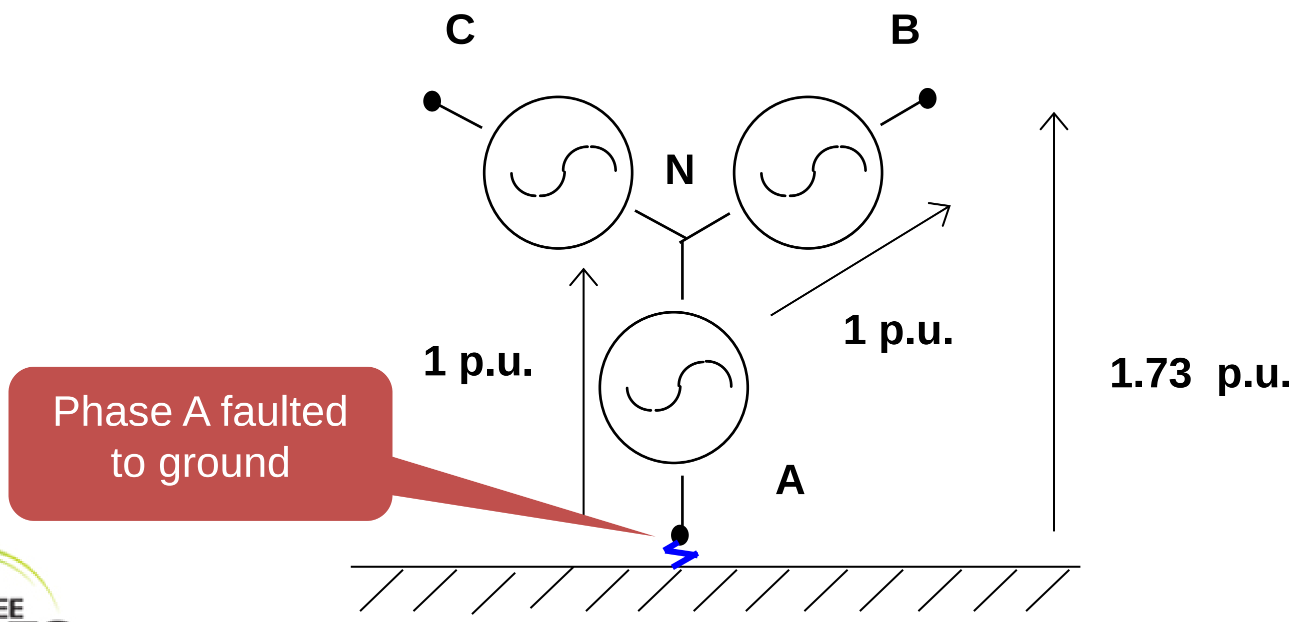
Grounding

- Two different uses of the term grounding in the power industry
  - Equipment or safety grounding
  - Bonding to provide a low impedance path between casing or other non-energized parts and local ground
- System grounding provides a reference point for the voltages on the three electrical phases with respect to ground
  - I.e., provide a defined zero-sequence admittance
  - Defines severity of unfaulted-phase voltage rise during ground faults



Loss of Ground Scenario

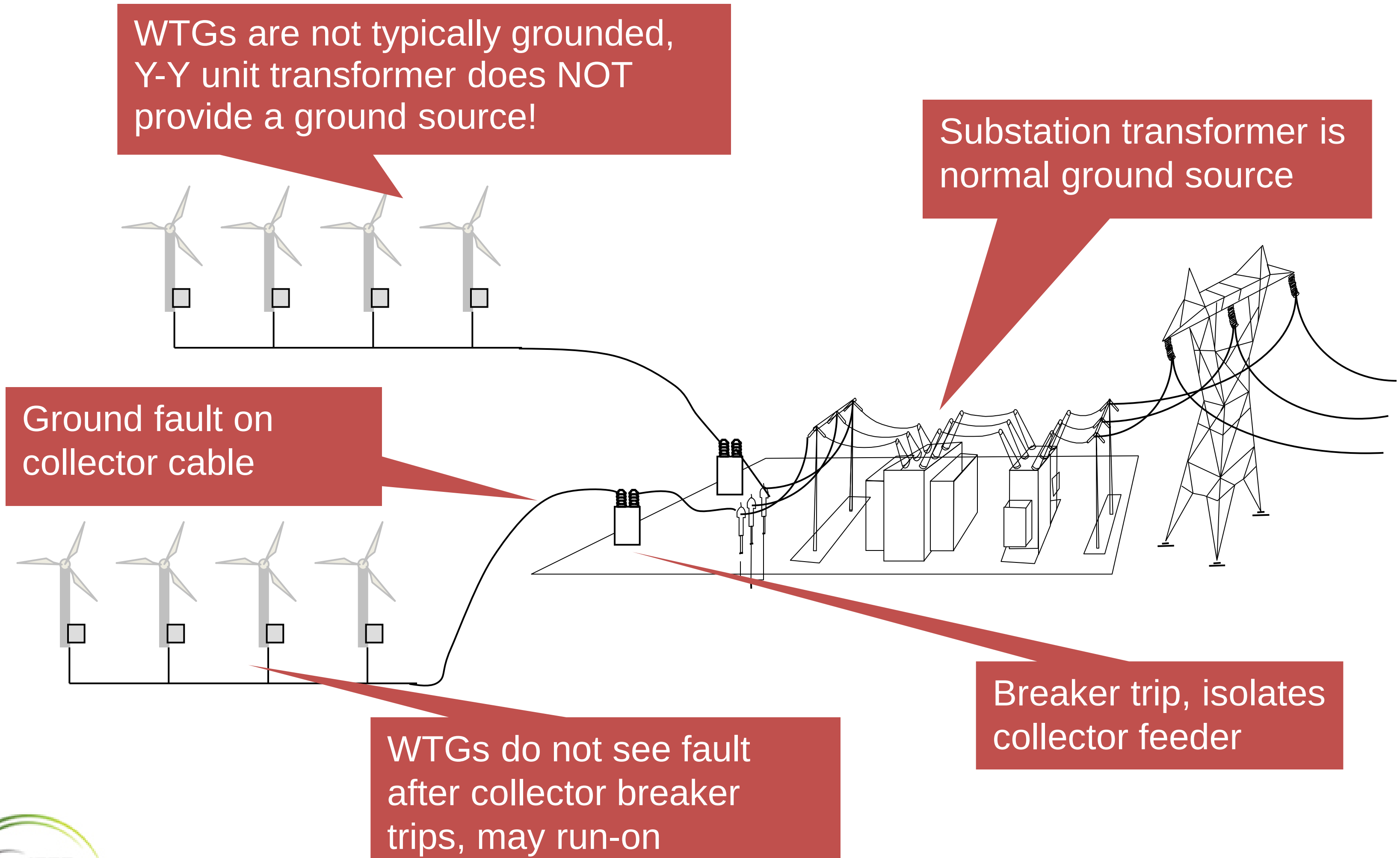
- Focus of utility concern regarding DG plants
  - Ground fault on feeder
  - Feeder breaker trips; losing normal ground source
  - DG doesn't trip immediately, continues to energize
  - If there is no ground source, high TOV may result



Effectively Grounded Systems

- Definition of effectively grounded system is where the COG < 0.8 (COG = TOV/V_{L-L})
  - $\therefore$ TOV < 1.39 p.u. in effectively grounded systems
- C62.91 states $X_0/X_1<3$ and $R_0/X_1<1$ generally results in COG<0.8
  - but is not the definition of effective grounding
- Arresters required to protect 150 kV BIL equipment on 34.5 kV feeders generally require effective grounding

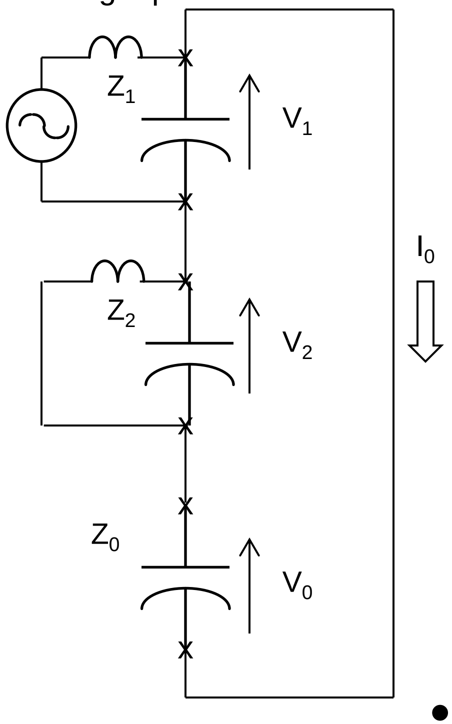
Loss of Grounding Scenario

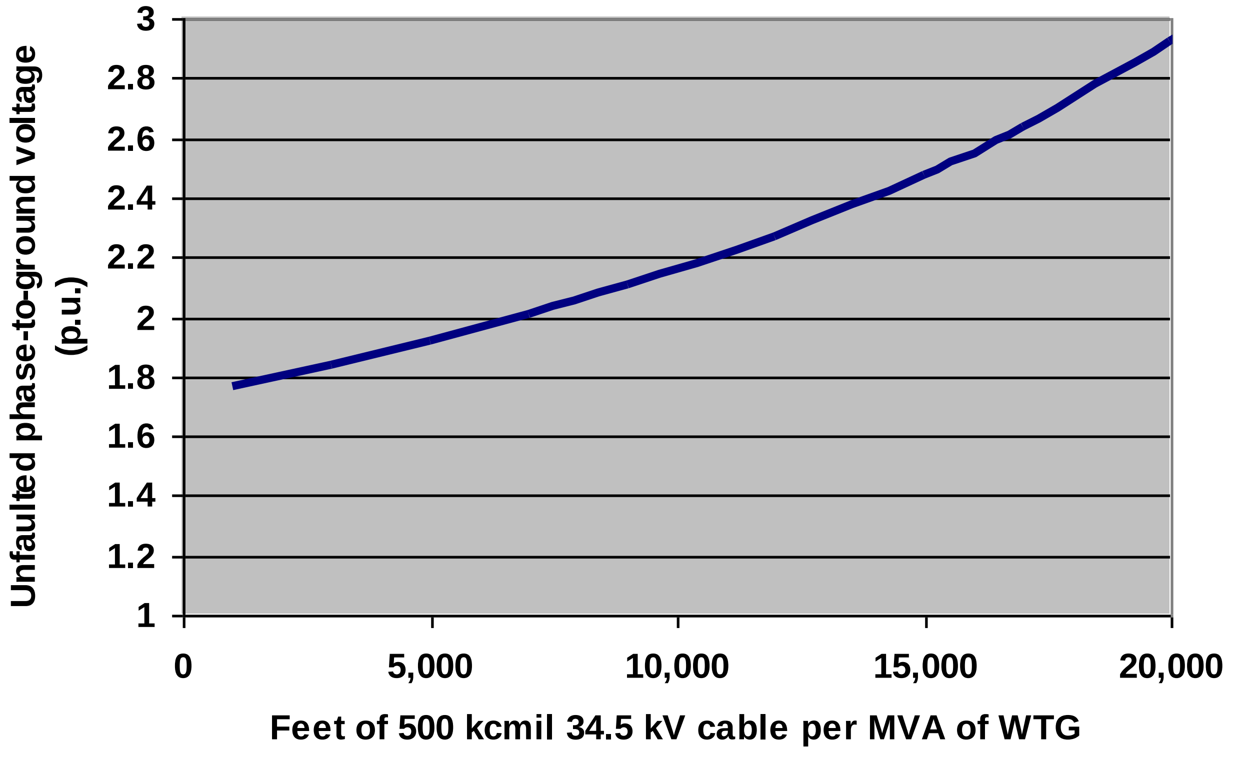


Feeder Isolation TOV

- Magnitude and character of TOV is highly dependent on the details of the "generators"
- Type 1 and 2 WTGs can be reasonably approximated as voltage sources behind impedance
  - Classical symmetrical component analysis applies
- Type 4 WTG and PV inverters behave more like current sources
  - Classical analysis and X_0/X_1 criteria do not apply
- Type 3 act like Type 1 & 2 if crowbarred, like Type 4 if not

Classic TOV Analysis





- Generators conventionally assumed to be voltage sources behind impedance
- Feeder cable capacitance can increase TOV > √3

Limitations of Conventional Analysis

- Voltage source representation only reasonable for Types 1 and 2 WTGs
- Inverters (Type 4 WTG and PV) designed to behave like positive-sequence current sources
  - Negative sequence may appear as a large impedance or as nonlinear impedance
  - Will not be able to drive ordered current into the high capacitive impedance of feeder
  - Modulation index is liked to be maxed out
  - Unstable control behavior may occur, generating complex non-sinusoidal waveforms

Type 3 (DFG) WTG Behavior

- Normal operating mode is similar to inverter
  - Constant power regulation
- If solidly crowbarred (rotor protectively shorted out), will behave like Type 1 & 2
  - Initial feeder fault is likely to initiate crowbar
- Controls designed for fault ride-through may attempt to recover from crowbar
  - Complex behavior may result

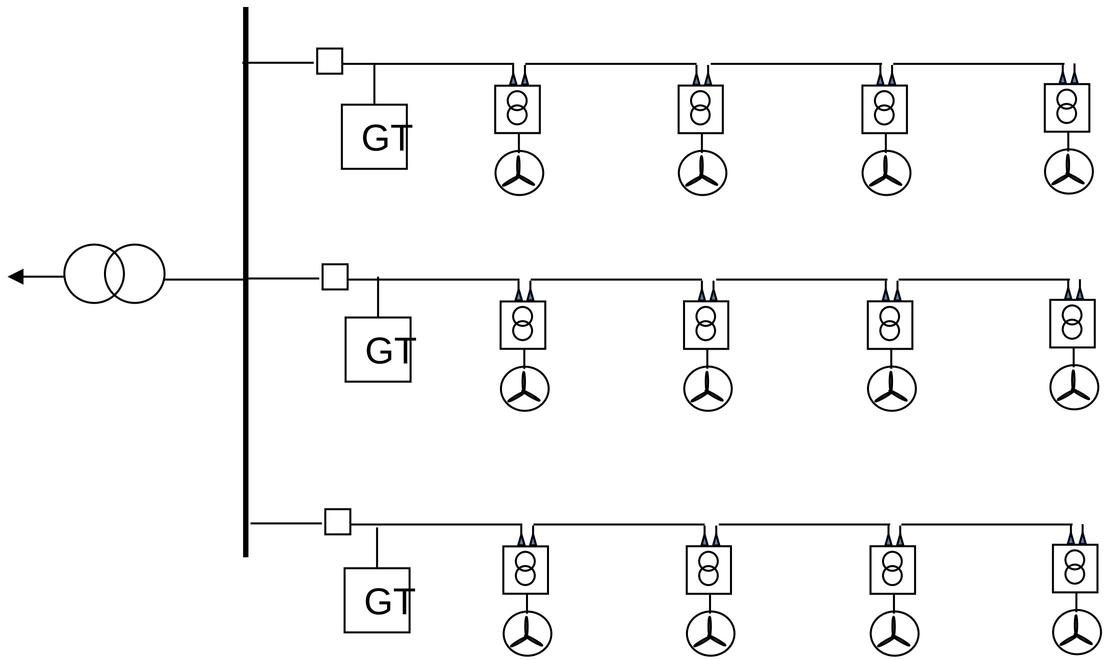
Analysis and Modeling of TOV and Grounding for Inverters and Type 3 WTG

- No analytical approach is even close
- EMT simulation is the only means to obtain adequate accuracy
- Detailed OEM-supplied model is essential:
  - Outer loop controls (i.e., power, ac voltage regulation)
  - Inner loop current regulators
  - Protective sequences
  - Protective tripping

TOV Mitigation

- Grounding transformers
- Grounding breakers
- Direct (fast) transfer trip

Grounding Transformers



- Grounding transformer on each collector feeder
  - Typically at the substation end
- Zig-zag or grounded-wye delta configuration

Grounding Transformer Application

- Zig-zag or Yg-delta – no functional difference
  - Zig-zag theoretically uses less copper and iron
  - Grounded-wye delta can be a commodity distribution xfmr
- Impedance – chosen to achieve acceptable TOV
  - Based on simulations, not calculations!
- Current ratings
  - Continuous – very little in a wind or solar plant
  - Temporary
    - Ground fault with feeder breaker closed
    - Sustained energization from WTGs/inverters after breaker opens
- Impact on feeder protection

Conclusions

- TOV mitigation is a critical element of wind and solar plant collector system design
- Grounding transformers are a popular solution to wind plant TOV issues
  - And what about large-scale PV plants?
- Detailed simulation is the only suitable approach to selection of grounding transformers for modern renewable plants