SOLAR INVERTER IMPACT ON COOP DISTRIBUTION GRIDS

FINLEY ENGINEERING

INTEGRITY INTO EVERYTHING

2020 TECHADVANTAGE® EXPERIENCE

FINLEY ENGINEERING

INTEGRITY INTO EVERYTHING

- Established in 1953
- Electric Power and Telecommunications Industries
- Ten Locations
- www.finleyusa.com
- If you have a need, we have a solution!

Impact

- Distributed generation influx
- Global Distributed Generation Market is to grow at healthy 10.21% CAGR by 2023.
- Global Distributed Generation Market by Technology (Geothermal, Solar, Wind, Biogas, Fuel Cells, and Others)

Courtesy of www.marketwatch.com, Aug 2019

Solar Growth

- Large number of residential systems
- Community scale and larger
- Most significant growth segment
- Market estimated to be at 680.22 GW in 2019. Fortune Business Insights has predicted that the market will reach 4766.82 GW by 2026, thereby exhibiting a CAGR of 30.7%

Courtesy of www.marketwatch.com, Nov 2019

Problem

- Is my distribution system ready for solar?

Distribution Systems today

- Many “smart” sub breakers
- Mostly OCRs downstream
- 1A-3C sub, 2A-2B feeders
- 1, 2, or 3 downstream feeder breakers
- Traditional coordination

Inductive and resistive loads dominate

U.S. residential sector electricity consumption by major end uses, 2018

- space heating
- space cooling
- water heating
- refrigerators and freezers
- lighting
- televisions and related equipment
- all other uses

U.S. commercial sector electricity consumption by major end uses, 2018

- computers and office equipment
- refrigeration
- space cooling
- ventilation
- lighting
- space and water heating
- all other uses

U.S. manufacturing electricity consumption by major end uses, 2014

- machine drive
- process and boiler heating
- facility heating, ventilation, air conditioning, ...
- electrochemical processes
- process cooling and refrigeration
- other processes and facility uses
- lighting

Courtesy of www.eia.gov, Apr 2019

Courtesy of www.nerc.com, March 2017

Typical fault currents on rural feeder

- 1-10 MVA transformers at substation
- 1-13 kA fault current available

Coordination Basics

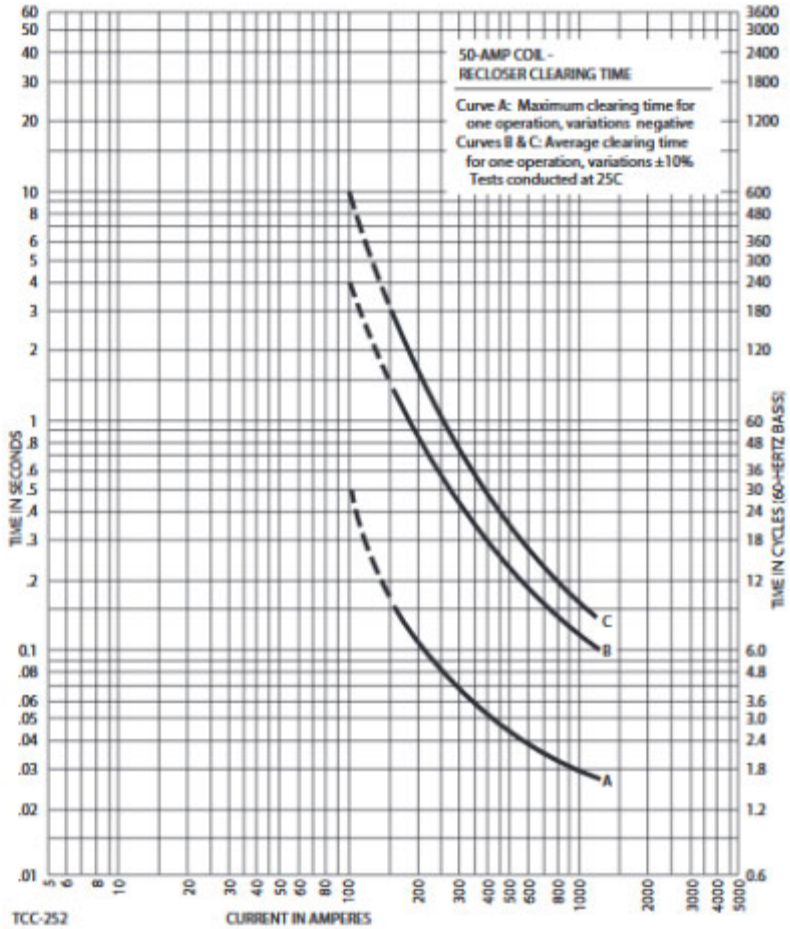
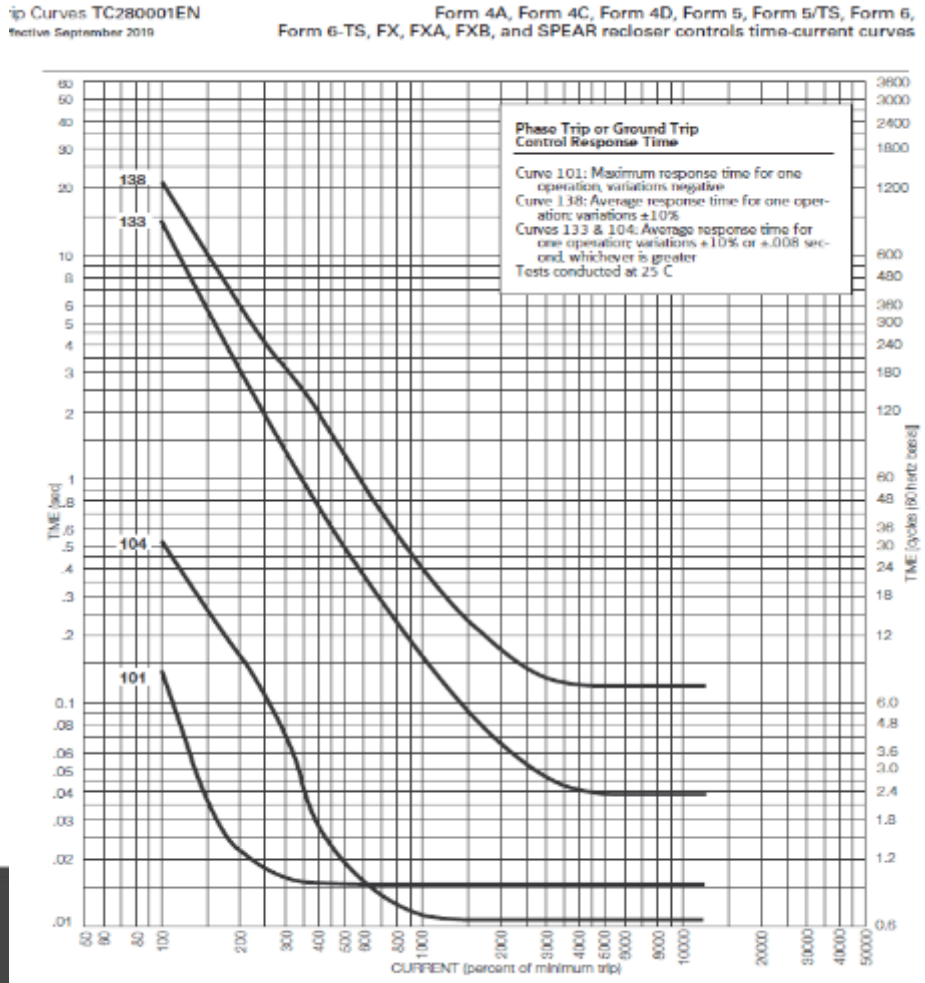


Figure 1. Type H time-current characteristics, 50 amp coil

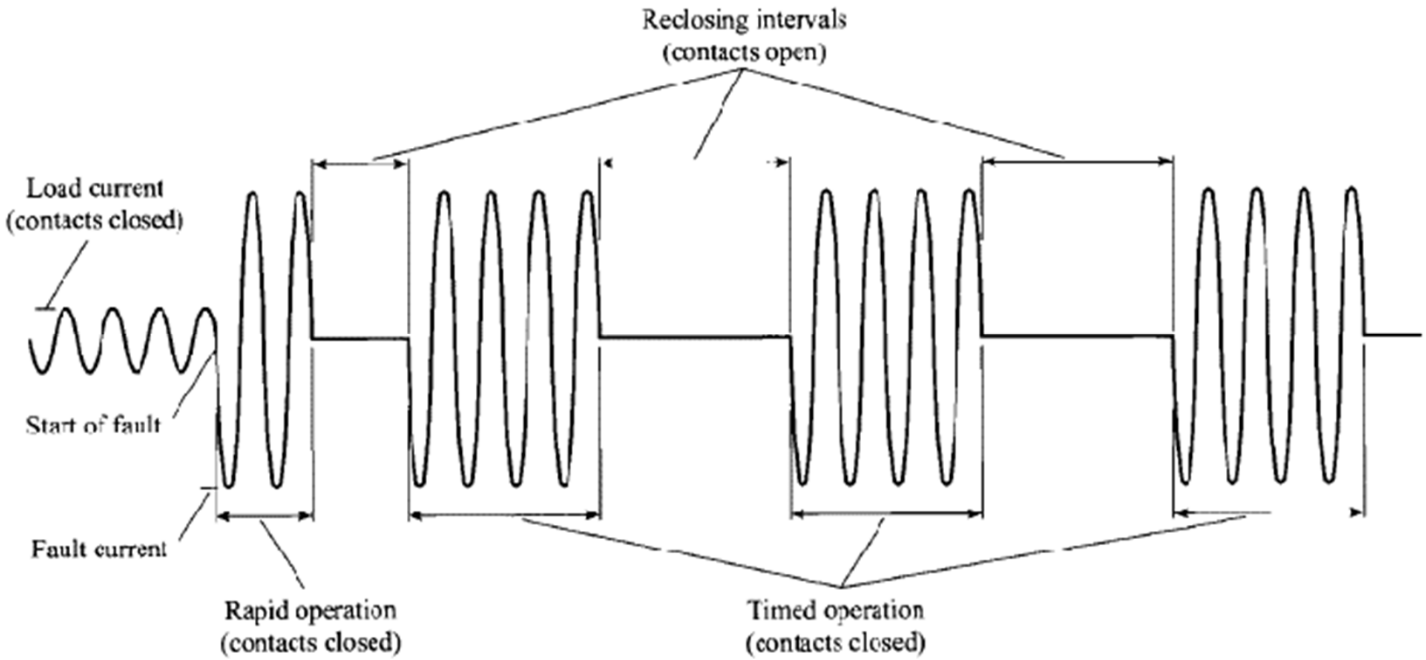
Courtesy of www.Eaton.com, May 2017

Coordination Basics



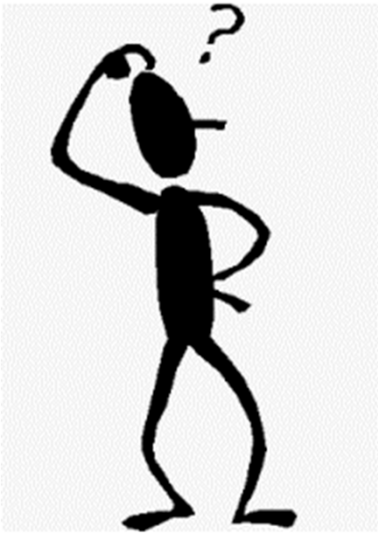
Courtesy of www.Eaton.com, Sept 2019

Traditional coordination



Courtesy of www.eng.uwo.ca, May 2008

Run throughs?



RATINGS

TABLE 14

Single- and Three-Phase Recloser Ratings

Trip-Coil Continuous Current (amps)	Minimum Trip Current (amps)	Interrupting Current (rms symmetrical amps)		
Type H Single-Phase; 50 Amps Maximum				
		@ 2.4 through 14.4 kV		
5	10	125		
10	20	250		
15	30	375		
25	50	625		
35	70	875		
50	100	1250		
Types 4H Single-Phase and 6H Three-Phase; 100 Amps Maximum				
		@ 4.8 kV	@ 8.32 kV	@ 14.4 kV
5	10	200	200	200
10	20	400	400	400
15	30	600	600	600
25	50	1000	1000	1000
35	70	1400	1400	1400
50	100	2000	2000	2000
70	140	2800	2500	2000
100	200	3000	2500	2000
Types V4H Single-Phase and V6H Three-Phase; 200 Amps Maximum				
5	10	200	200	200
10	20	400	400	400
15	30	600	600	600
25	50	1000	1000	1000
35	70	1400	1400	1400
50	100	2000	2000	2000
70	140	2800	2500	2000
100	200	3000	2500	2000
140	280	3000	2500	2000
200	400	3000	2500	2000
Type L Single-Phase; 280 Amps Maximum				
25	50	1500	1500	1500
35	70	2100	2100	2100
50	100	3000	3000	3000
70	140	4200	4200	4000
100	200	6000	5000	4000
140	280	6000	5000	4000
200	400	6000	5000	4000
280	560	6000	5000	4000

Courtesy of www.Eaton.com, Aug 2017

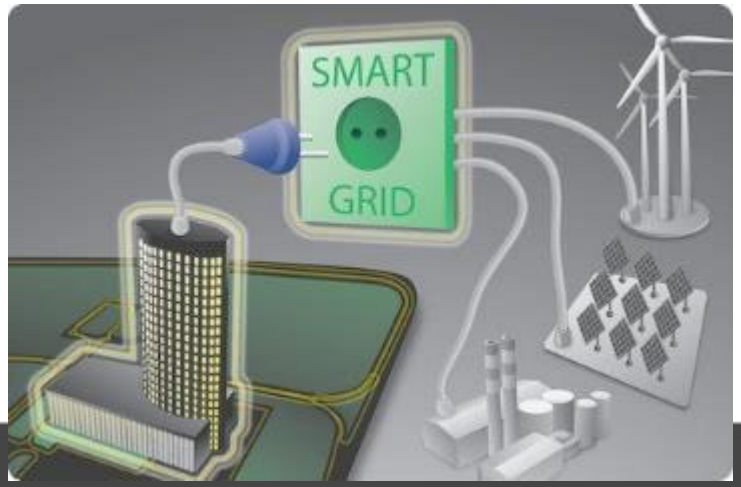
Hydraulic Reclosers

- Separation of the curves by less than two cycles (.033) always results in simultaneous operation
- Separation of the curves between two and 12 cycles (.2) could result in simultaneous operation
- Separation greater than 12 cycles ensures non-simultaneous operation
- i.e. rule of thumb - skip sizes

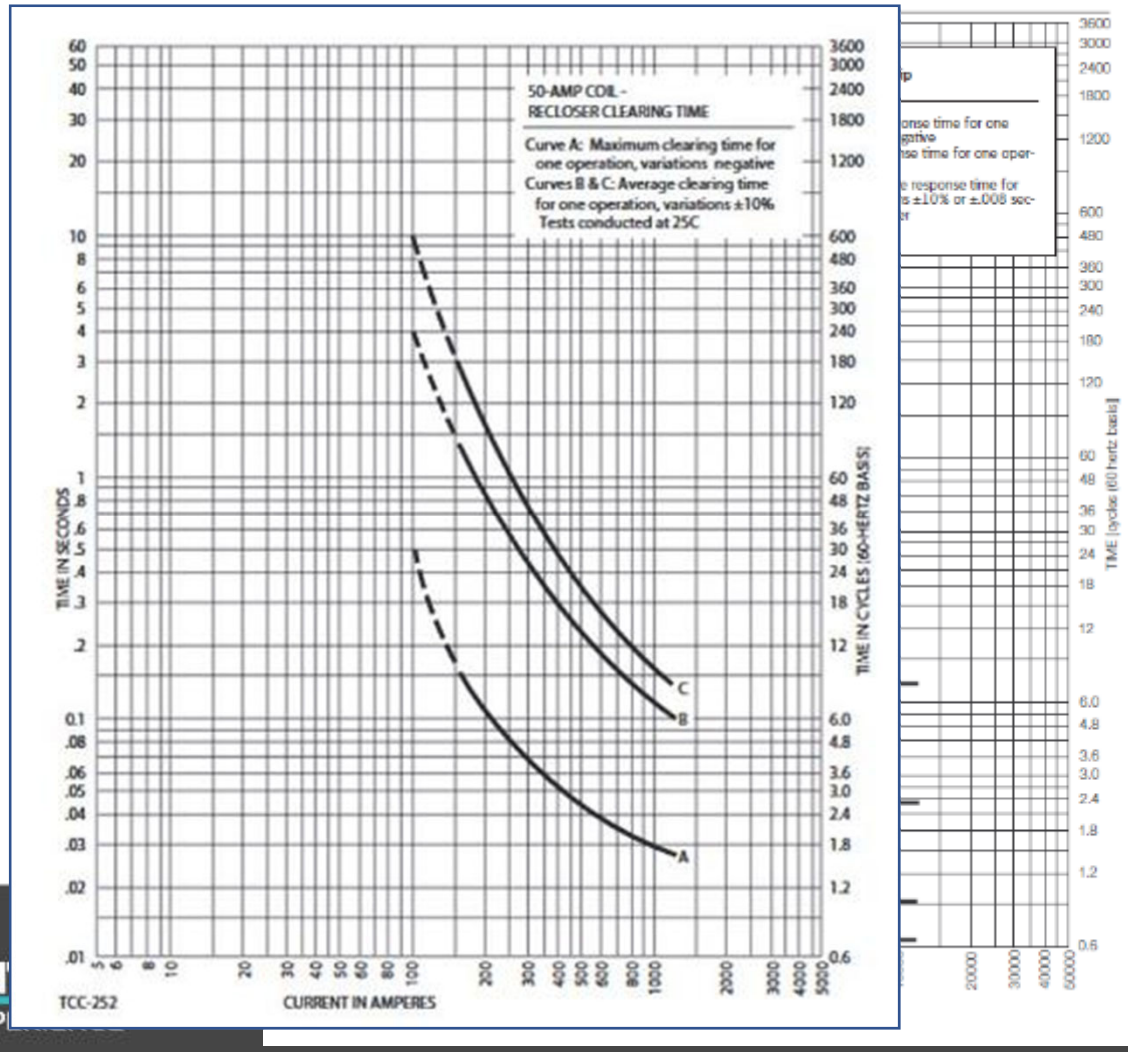
Courtesy of www.eng.uwo.ca, May 2008

Smart-Grid Feeder Coordination

- Faster tripping
- Ground trip and other intelligence
- Programmable, standardized equipment
- Triple-single
- SCADA control



Improved coordination



2020 TECHADVANTAGE EXPERIENCE
NRECA America's Electric Cooperatives

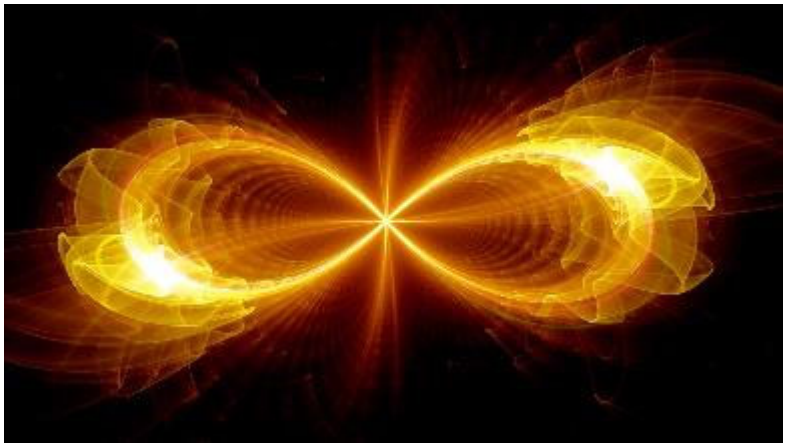
Faults?

- Symmetrical (2-5%, severe damage)
  - L-L-L-G
  - L-L-L
- Unsymmetrical (or unbalanced)
  - L-G (65-70%)
  - L-L (5-10%)
  - L-L-G (15-20%)

Courtesy of www.elprocus.com, May 2018

Distribution System Fault Magnitudes

- Infinite bus vs reality
- Rated current multiple
  - 10x, 20x, 30x
  - Impedance dictates



Fault Contribution

- What is the point of protection?
  - Isolate-trip
- Hi-Z or Lo-Z
- Impedances
  - Transformer
  - Primary line
  - Connected devices

Solar DG Enters the Picture
Inverter Characteristics

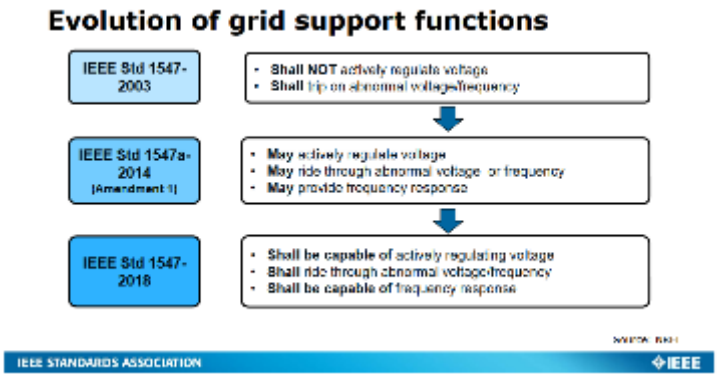
- Non-linear

Inverter Interfaced DG Challenges for Distribution Engineers

- What should we be mindful of?

IEEE 1547-2018 Std & UL 1741 Listing/ Cert.

- Large penetration of DG (goal)
- Increased islanding probability
- Inverter malfunction concerns?



Courtesy of www1.eere.energy.gov, Oct 2007 &

Courtesy of www.nerc.com, Jan 2019

System Regulation Concerns (ANSI C84.1)

- Reverse power flow
- Regulator settings
- DG system locations upstream or downstream from regulation exacerbates issue

Courtesy of www1.eere.energy.gov, Oct 2007

System Regulation Concerns (108v)

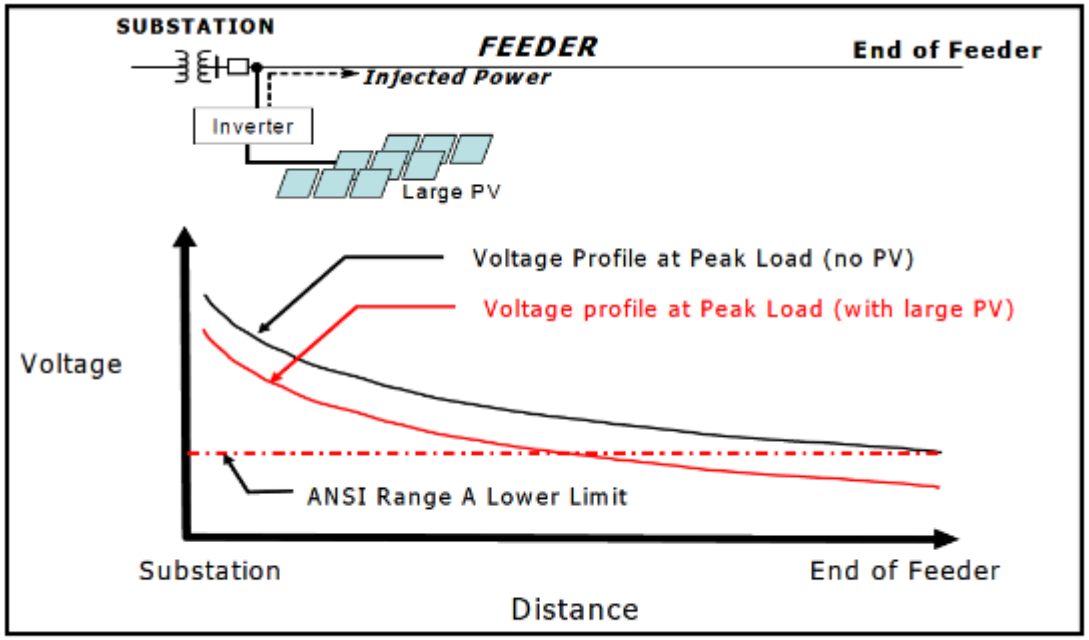


Figure 1. Line Drop Compensation Confused by a PV Generator near Front of Regulation Zone[3].

Courtesy of www1.eere.energy.gov, Oct 2007

System Regulation Concerns (108-126v)

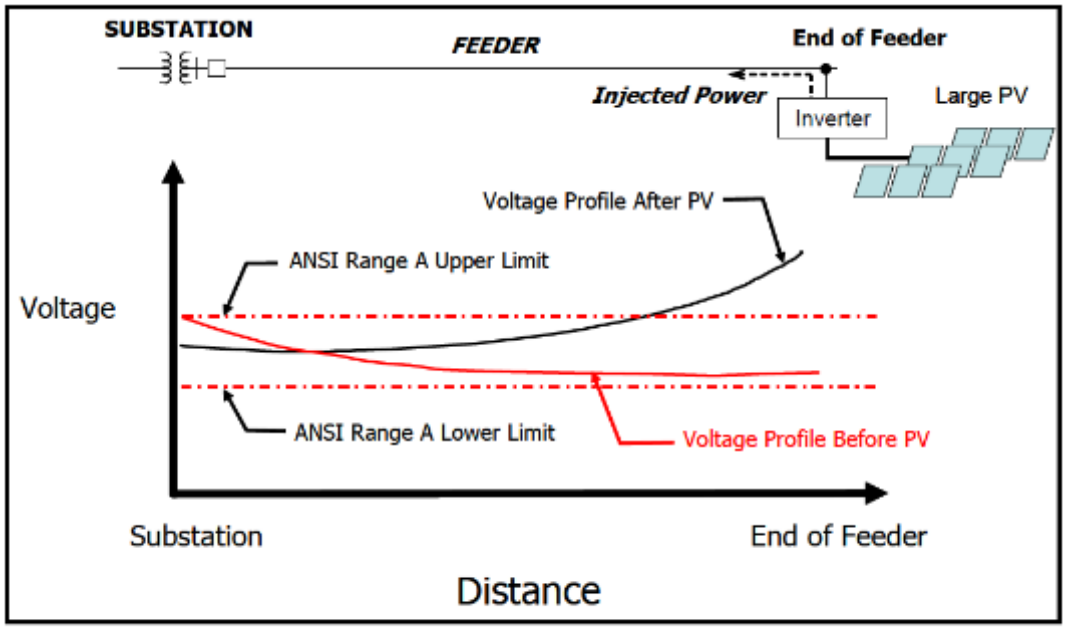


Figure 2 – Tail End of Regulation Zone Forced to High Voltage Due to Large Exporting PV System Located Near the End of the Feeder (or Regulation Zone)[3]

Courtesy of www1.eere.energy.gov, Oct 2007

DG injection point

- Impact on system protection device locations
- Inject after OCR leaves unprotected segment
- DG fault current supply – nuisance and sympathetic trip potential
- Traditional OCRs lack directional sensing

Courtesy of www1.eere.energy.gov, Oct 2007 &
Courtesy of prog-ng.sandia.gov, July 2016

Protection Under-Reach and Coordination Loss Example

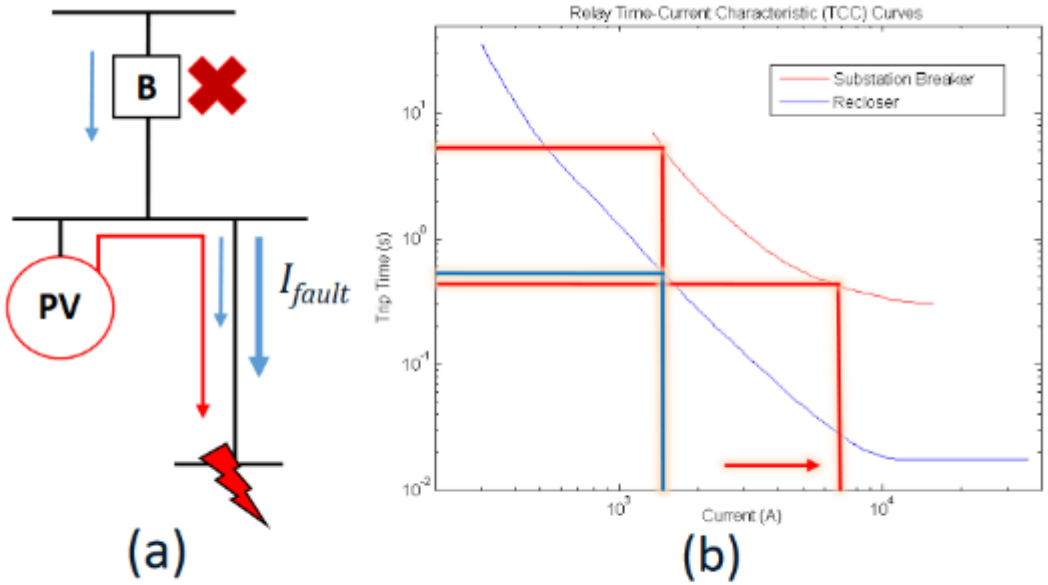


Figure 3. (a) Example of PV causing under-reach in breaker (b) Example of increased current seen by breaker causing coordination loss.

Courtesy of prog-ng.sandia.gov, July 2016

Sympathetic & Nuisance Trip Example

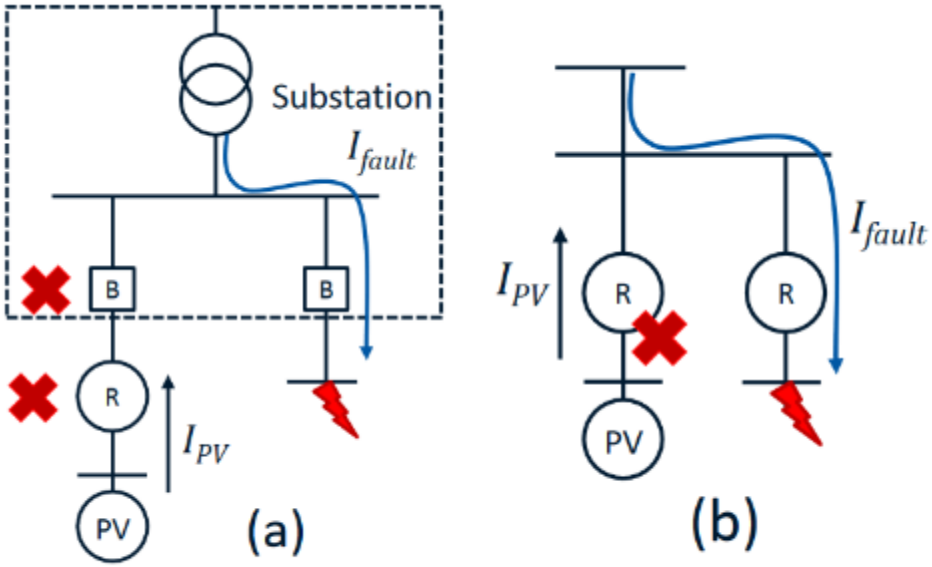
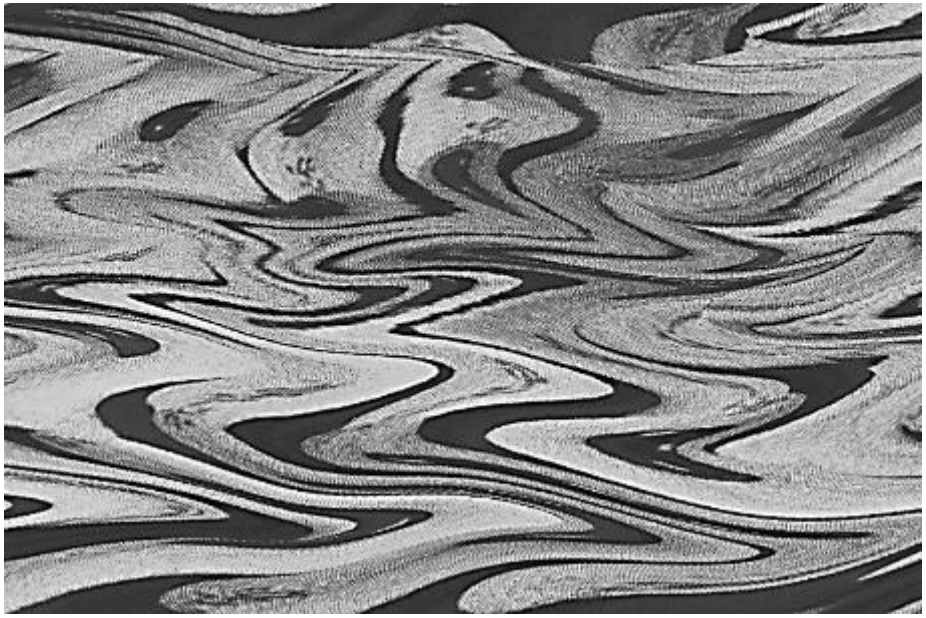


Figure 4. (a) Example of PV causing sympathetic tripping by back-feeding PDs to supply a nearby fault (b) Example of PV causing nuisance tripping by feeding a fault within its own network.

Courtesy of www1.eere.energy.gov, Oct 2007 &
Courtesy of prog-ng.sandia.gov, July 2016

Harmonic Distortions

- Frequency issues
- Caused by DC to AC conv.
- Amplified by quantity of units
- Impact to other consumers



Courtesy of www.apqi.org, Dec 2016

Lower Magnitude Fault Current

- How inverter interfaced DG feeds a fault
- Synchronous generator sustain higher fault current, longer periods of time
- DG inverter limited to 1.2-1.5 (2-3 former) times rated current
- Bounded by terminal voltage and DC side active power
- Min fault current imposter?

Courtesy of www.scirp.org/epe, Sept 2017

IEEE SPECTRUM Topics Reports Blogs Multimedia

24 Jul 2015 | 15:00 GMT

Zombie Coal Plants Reanimated to Stabilize the Grid

Old generators prop up voltage, helping grids soak up imported power and renewables

By **Peter Fairley**

Photo: FirstEnergy

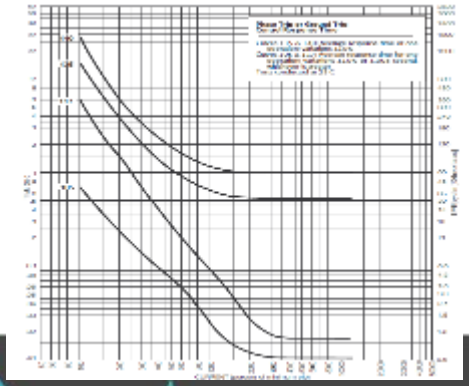
A New Life: Electricians work to turn a generator into a synchronous condenser. This conversion, at a decades-old coal plant in Ohio, is likely one of many to come

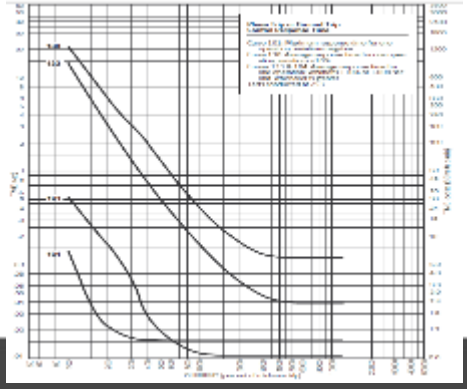
2020 TECHADVANTAGE® EXPERIENCE

NRECA America's Electric Cooperatives

Fast Initial Fault Contribution

- Fed by inverter control mode and integration circuits
- How quick?
- Impact on protection scheme
- Time-dependent coordination impact



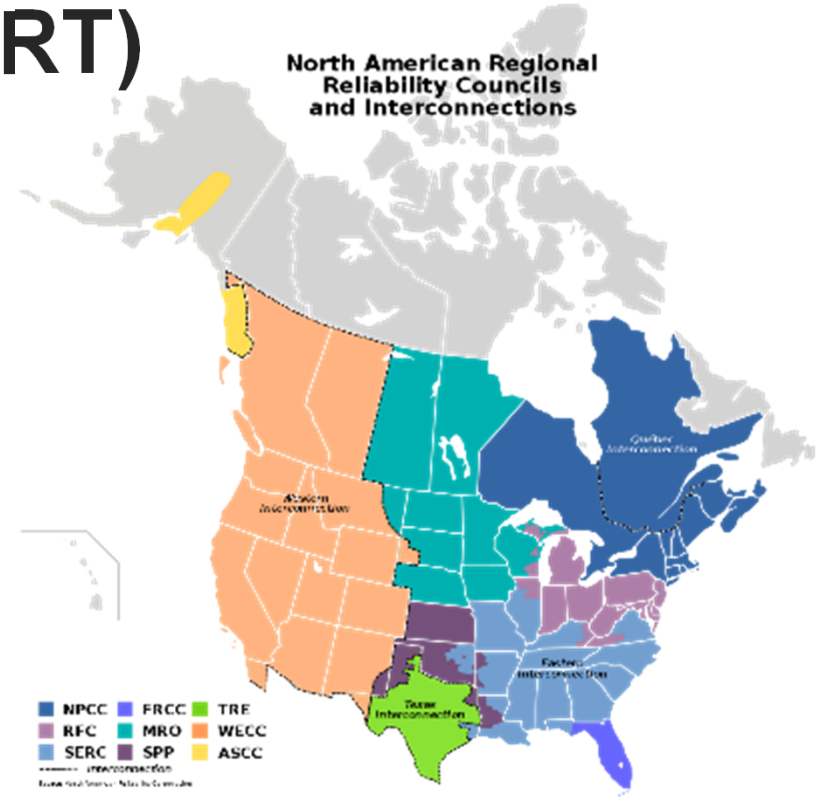


Courtesy of www.scirp.org/epe, Sept 2017 &

www.Eaton.com, Sept 2019

Fault Ride Through (FRT)

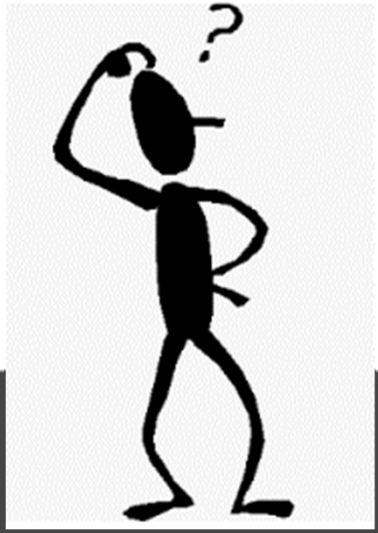
- Why?
- Code mandate - 2018 revision compared to 2014 Std
- Minimize large scale DG disconnection
- Impact on large scale grid reliability - System operator control areas



Courtesy of www.mdpi.com, Dec 2017

FRT Control Strategies

- Predictive techniques based on artificial intelligence and multi-loop feedback controllers (Synchronous faults)
- Single vector current controller with feed forward negative-sequence grid-side voltage (Asynchronous faults)
- Interested in some light reading?



Courtesy of www.mdpi.com, Dec 2017

FRT Implementation

- Max AC current disconnection threshold
- Voltage sag, inverter reactive power injection into fault
- Inverter attempts to maintain connection unless magnitude is excessive
- Based on limit of control scheme and power electronic capacity

Courtesy of www.pdfs.semanticscholar.org, Jun 2016

Bottom Line

- Our distribution systems were not designed for wide adoption of DG.
- They need some help!

Solution – Differential Protection Using Device External Communication

- Anti islanding control with growth
- Respond to real-time pricing and secure dispatch signals (weather, etc.)
- Spinning reserve, freq, area, and voltage regulation, peak shaving (demand response), backfeed control
- Cybersecurity concerns

Courtesy of www.scirp.org/epe, Sept 2017 &

Courtesy of www1.eere.energy.gov, Oct 2007

Solution – Differential Protection Using Device Internal Communication

- Method - fiber, cellular, microwave, partnership
- Smart device coordination
- Static Curve adjustment locally with faster initial response and dynamic modification based on DA

Courtesy of www.scirp.org/epe, Sept 2017 &

Courtesy of www1.eere.energy.gov, Oct 2007

Direct Transfer Trip

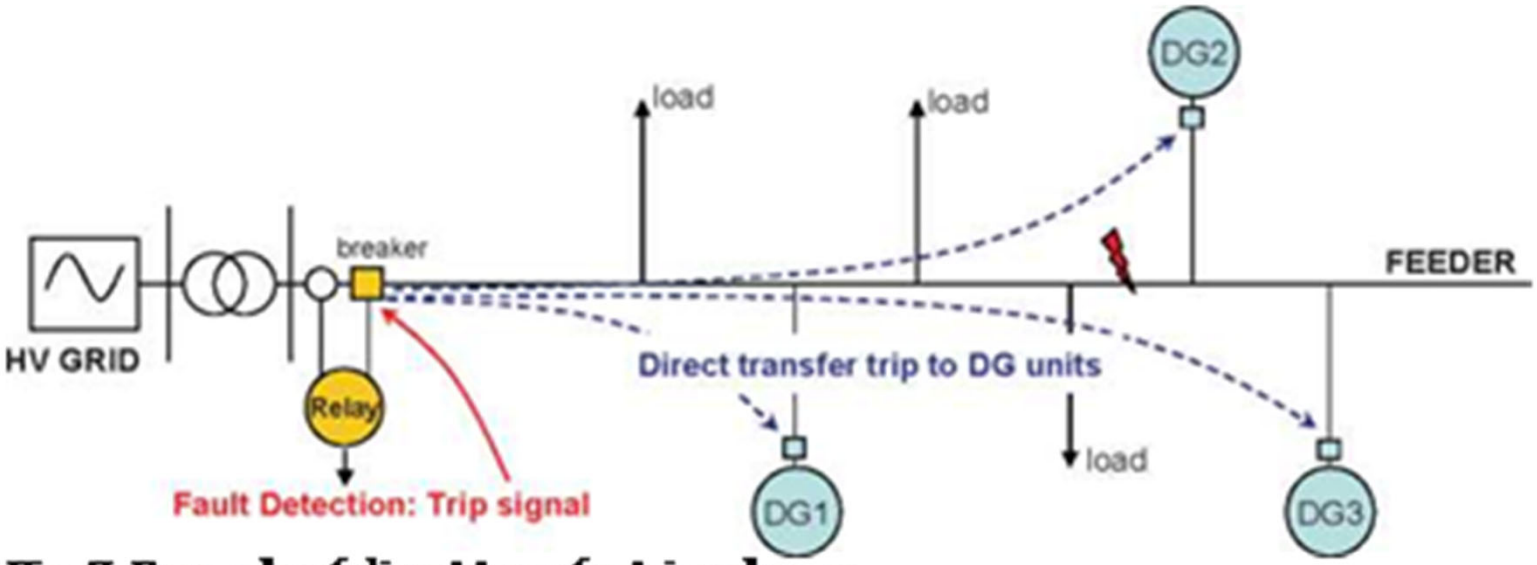


Fig. 7. Example of direct transfer trip scheme

Courtesy of www.energyprofessionalsymposium.com, Oct 2005

Solution – Inverter Development

- Dependent on manufacturers and code regulation
- Balance FRT with local operational control

Courtesy of www.scirp.org/epe, Sept 2017 &

Courtesy of www1.eere.energy.gov, Oct 2007

Solution – Others?

- Balance of synchronous generator and inverter loads
  - Define where dg connects (can we?)
- Permit listed equipment only
- Zero and negative sequence current component detection

Courtesy of www.scirp.org/epe, Sept 2017 &

Courtesy of www1.eere.energy.gov, Oct 2007

Questions?

Sean Middleton, P.E.
Director - Strategy and Operations
Finley Engineering Company, Inc.
Office: 217-993-7646
Direct: 217-473-6340
s.middleton@FinleyUSA.com
www.FinleyUSA.com

FINLEY ENGINEERING

INTEGRITY INTO EVERYTHING