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Impact of Inverter Based Resource (IBR) Negative Sequence Current Injection on Transmission System Protection

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Sandia National Laboratories

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Report on IBR Negative Sequence Current (I2)

- Investigates the IBR I2 impact to transmission relay security
- Use EMT simulation
- Sponsored by DOE/EERE

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Study Team

IBR OEMs, Consultants, Transmission Providers, Reliability Coordinators,

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Background and Problem Statement

Background

- Increasing Transmission IBR Penetration raises concern about protective relay practices

Problem Statement

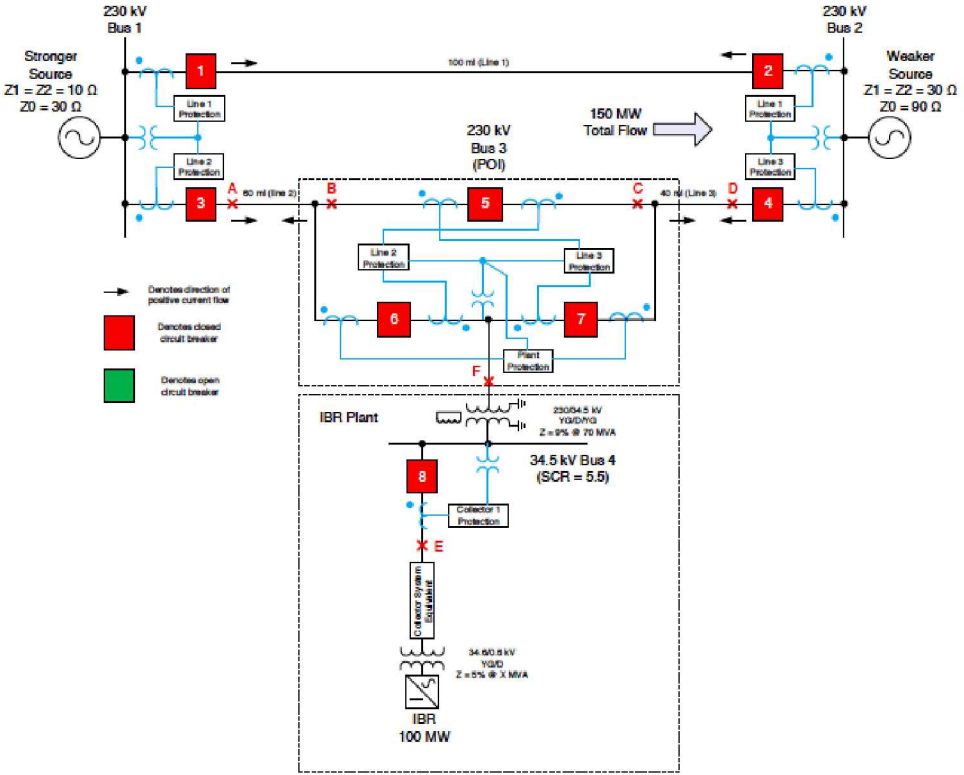
- IBR unbalanced fault response (specifically negative sequence current) is determined by embedded control codes, but has no industry standardization
- There have been known relay misoperations attributed to high IBR penetration
- Standard relaying practices (developed for conventional power sources) may not be adequate to protect systems with high IBR penetrations

Solution Approach

1. Simplified EMT grid system was developed, modeling several “real world” fault scenarios
2. The fault response of the system was characterized using four EMT ‘black box’ IBR models
3. Transient simulation outputs were sent to two protective relay manufacturers via COMTRADE files
    1. Transients were played back into the OEM’s relays
    2. The relays’ responses to the transient were analyzed
4. Conclusions were made regarding the adequacy of standard relay practices for systems with high IBR penetration

Four Bus Test System

- Initially built in PSS/E for system tuning
- Transitioned to PSCAD/ EMTDC for detailed analysis
- Busses 1 & 2 rated at 5.2 GVA and 1.8 GVA. They are represented by Thevenin equivalents in symmetrical components
- OEMs provided 'black box' models for IBRs (PV, Type 3, Type 4)



Test Scenarios

- 192 Scenarios were tested in all
  - 48 scenarios, duplicated for each of four IBR models
- Scenarios varied the following
  - Fault type (LG, LLG, LLLG, LL). All faults lasted 5 cycles
  - Fault Location (locations A-F)
  - Fault Resistance (0 Ohms, 5 Ohms)
  - Prior Outage (none, TL12, TL13)

Eight Key Scenarios

- The same eight cases shown for relay OEMs and IBR OEMs
- Green indicates no problem
- Red indicates that protection did not operate as expected

Scenario ID	Prior Outage	Fault Location	Fault Type (bolted)	Desired Line Trip	Negative Sequence Current from IBR During		Breakers expected to clear fault	Relay OEM1			Relay OEM 2			Results Reference in Appendix B
					Min	Max		Line Protected ?	Expected elements operation ?	Notes	Line Protected ?	Expected elements operation ?	Notes	
IBR OEM1														
1	None	B	LG	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 61 - 76
3	None	B	LLG	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 77 - 92
5	None	B	LLLG	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 93 - 108
7	None	B	LL	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 109 - 124
25	TL13	D	LG	TL23	20	60	BRK4, BRK7	Yes	No	Note 2	Yes	No	Note 4	Page 125 - 140
27	TL13	D	LLG	TL23	30	80	BRK4, BRK7	Yes	No	Note 2	Yes	No	Note 5	Page 141 - 156
29	TL13	D	LLLG	TL23	0	40	BRK4, BRK7	Yes	No	Note 2	Yes	No	Note 6	Page 157 - 172
31	TL13	D	LL	TL23	40	110	BRK4, BRK7	No	No	Note 3	No	No	Note 3	Page 173 - 188
IBR OEM2														
1	None	B	LG	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 61 - 76
3	None	B	LLG	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 77 - 92
5	None	B	LLLG	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 93 - 108
7	None	B	LL	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 109 - 124
25	TL13	D	LG	TL23	0	20	BRK4, BRK7	Yes	No	Note 2	Yes	No	Note 4	Page 125 - 140
27	TL13	D	LLG	TL23	0	50	BRK4, BRK7	Yes	No	Note 2	Yes	No	Note 4	Page 141 - 156
29	TL13	D	LLLG	TL23	0	25	BRK4, BRK7	Yes	No	Note 2	Yes	No	Note 5	Page 157 - 172
31	TL13	D	LL	TL23	20	50	BRK4, BRK7	Yes	No	Note 3	No	No	Note 3	Page 173 - 188
IBR OEM3														
1	None	B	LG	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 61 - 76
3	None	B	LLG	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 77 - 92
5	None	B	LLLG	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 93 - 108
7	None	B	LL	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 109 - 124
25	TL13	D	LG	TL23	50	90	BRK4, BRK7	Yes	No	Note 2	Yes	No	Note 4	Page 125 - 140
27	TL13	D	LLG	TL23	140	160	BRK4, BRK7	Yes	No	Note 2	Yes	No	Note 4	Page 141 - 156
29	TL13	D	LLLG	TL23	0	35	BRK4, BRK7	Yes	No	Note 2	No	No	Note 3	Page 157 - 172
31	TL13	D	LL	TL23	170	200	BRK4, BRK7	Yes	No	Note 3	Yes	No	Note 4	Page 173 - 188
IBR OEM4														
1	None	B	LG	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 61 - 76
3	None	B	LLG	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 77 - 92
5	None	B	LLLG	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 93 - 108
7	None	B	LL	TL13			BRK3, BRK5, BRK6	Yes	Yes	Note 1	Yes	Yes	Note 1	Page 109 - 124
25	TL13	D	LG	TL23	30	35	BRK4, BRK7	Yes	No	Note 2	Yes	No	Note 5	Page 125 - 140
27	TL13	D	LLG	TL23	70	75	BRK4, BRK7	Yes	No	Note 2	Yes	No	Note 5	Page 141 - 156
29	TL13	D	LLLG	TL23	0	0	BRK4, BRK7	Yes	No	Note 2	Yes	Yes	Note 1	Page 157 - 172
31	TL13	D	LL	TL23	90	97	BRK4, BRK7	Yes	No	Note 3	Yes	Yes	Note 1	Page 173 - 188

Conclusions

- The fault response of IBRs is not consistent
- There are further inconsistencies regarding negative-sequence current injection during unbalanced faults
- EMT studies are necessary to understand IBR fault response, but this is not practical.
- IBRs should standardize their fault response as much as possible
- As penetration of IBRs continue to grow, system fault currents are expected to fall with unknown consequences, and should be studied
- For unbalanced ground faults, and where zero sequence paths exist, zero-sequence quantities could be used to reliably detect faults, including direction and location
- There is a need to require IBRs to inject negative-sequence current and to control the frequency of the current during unbalanced faults to aid in detection of unbalanced faults, especially ones that do not involve ground.