

# ECEN 667

## Power System Stability

### Lecture 17: Protection Modeling in Dynamics

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Prof. Adam Birchfield

Dept. of Electrical and Computer Engineering

Texas A&M University

[abirchfield@tamu.edu](mailto:abirchfield@tamu.edu)



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# Announcements

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- HW #5 is on the website, due Nov 20<sup>th</sup> at 8 AM.
- Review the slides and PowerWorld examples
- **Exam 2 will be Tuesday, December 2<sup>nd</sup>, 2025**

# Blackouts Table (1965-2006) #1

Data from Vittal/McCalley  
book, Table 14.1



Location	Date	# Outaged Elements	Time Between Initiating and Secondary, Pre-collapse Events	Cause of Secondary, Pre-collapse Events
US-NE	9 Nov 1965	N-1	Few minutes	Proper protection operation
US-NE	13 July 1977	N-2	20-45 minutes	Lightning
France	19 Dec 1978		>30 mins	Proper protection operation
West Coast	22 Dec 1978	N-1	Fast	Protection and comms failure
Sweden	22 Dec 1982	N-2	50 s	Proper protection UFLS failure
Brazil	27 Dec 1983	N-1	9-10 min	Simultaneous tripping of 7 circuits and XFMRs
Brazil	18 Aug 1985	N-2		Protection failure (SPS setting)
Quebec	18 Apr 1988	N-3	2-3 s	Comms failure, load shedding protection failure
US-West	17 Jan 1994	N-2	Fast	Proper protection operation
Brazil	13 Dec 1994	N-1		Proper protection operation
US-West	2 July 1996	N-1	20 s	Proper protection operation, relay misoperation
US-West	10 Aug 1996	N-1	Fast	Relay misoperation
S. Francisco	8 Dec 1998		16 s	No load protection, delayed remote protection
Brazil	11 Mar 1999	>N-6	>30 s	Proper protection operation

# Blackouts Table (1965-2006) #2

Data from Vittal/McCalley  
book, Table 14.1



Location	Date	# Outaged Elements	Time Between Initiating and Secondary, Pre-collapse Events	Cause of Secondary, Pre-collapse Events
Brail	6 May 1999	Many		Inadvertent protection operation
India	1 Jan 2001		13 h	
Rome	26 Jun 2003			High load, low generation reduction in import
US-NE	14 Aug 2003	N-1	More than 2 hr	Proper protection operation
Denmark	13 Sept 2003	N-1	5 min	Switching device breaks, proper protection
Italy	28 Sept 2003	N-1	25 mins	Unsuccessful reclosing, loss of synch, volt. Collapse
Croatia	1 Dec 2003	N-1	30 s	Protection failure
Greece	12 July 2004	N-1	10 min	Proper protection operation
Moscow	24 May 2005		>12 hr	Six lines from HV sub tripped due to overloading
Europe	4 Nov 2006	Many	30 mins	Proper protection operation

What do you observe from these events?

# Protection and Stability

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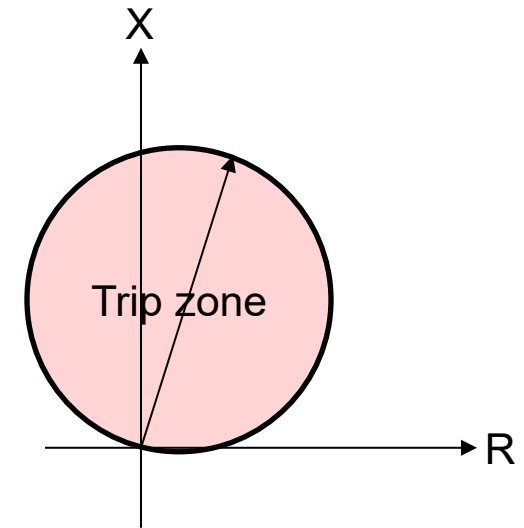


- A power system protection system is constantly monitoring the grid and will act quickly if adverse conditions are detected, to defend the grid and its components against undesired conditions
  - For example, fault detection in lines and transformers
- Traditionally, protection systems are not modeled in stability studies
  - Too much data, most of which will never be triggered
  - Fault events and associated assumed protection response are the “disturbance” from which the rest of the system response will be calculated
- However, recently that has been changing and more protection is being modeled in stability studies
  - Many blackouts are associated with the interaction between the protection system and stability phenomena

# Line Out-of-Step Protection



- In transient conditions, there may be wide “power swings” with current at levels that ordinarily would cause a line relay to trip.
- Protection zones
  - Zone 1 for primary protection of line (80-90% of branch)
  - Zone 2 for backup of line, primary of adjacent bus (>120% of branch)
  - Zone 3 for backup of adjacent branch
- Goal of out-of-step (OOS) protection
  - Block tripping if Z conditions are met only because of a stable power swing
  - Trip if swings are unstable
- Method of OOS protection – recognize that in swings, Z changes slowly
  - Blinders
  - Concentric characteristic



# Generator Out-of-Step Protection

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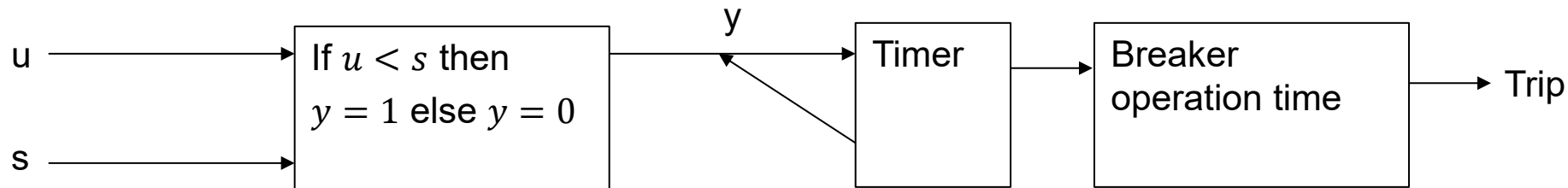


- Similarly, generators need to detect if there is the near potential for a loss-of-synchronism with the rest of the system
- It would generally be more desirable to use a line to prevent out-of-step conditions, but sometimes generator protection is needed.

# Undervoltage Load Shedding



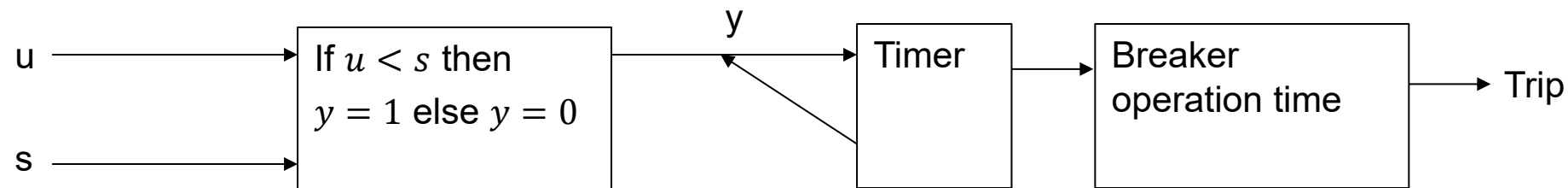
- Trips if the voltage magnitude at a bus is too low for too long. Two types:
  - Absolute voltage: voltage is below some threshold, say 0.7 per-unit
  - Relative voltage deviation: voltage is below initial value by some deviation, say 0.3 per-unit
- Purpose is to enhance voltage stability and avoid voltage collapse



# Underfrequency Load Shedding (UFLS)



- Trips if the frequency at a bus is too low for too long.
- Purpose is to enhance frequency stability and help keep load and generation in balance in extreme situations
- In simulation, calculation of frequency can be a challenge – need to set the lagging time delay for frequency calculation.



# UFLS in ERCOT



“Nodal Operating Guide Revision Request (NOGRR) 247 modifies the ERCOT automatic Under-Frequency Load Shed (UFLS) program by increasing the number of Load shed stages from three to five and changing the Transmission Operator (TO) Load relief amounts to uniform increments of 5% for each stage. NOGRR247 also adds a UFLS minimum time delay of six cycles (0.1 seconds).

On March 11, 2024, Nodal Operating Guide language associated with NOGRR247 Change UFLS Stages and Load Relief Amounts, was partially implemented. This partial implementation increased the number of Load shed stages from three to five.

No earlier than October 1, 2026, Nodal Operating Guide language associated with NOGRR247 Change UFLS Stages and Load Relief Amounts will be fully implemented. This implementation will change the Transmission Operator (TO) Load relief amounts to uniform increments of 5% for each stage, add a UFLS minimum time delay of six cycles (0.1 seconds), and require utilization of supplemental anti-stall UFLS Stages.”

Frequency Threshold	TO Load Relief	Delay to Trip
59.3 Hz	At least 5% of the TO Load	No more than 30 cycles
59.1 Hz	A total of at least 5% of the TO Load	No more than 30 cycles
58.9 Hz	A total of at least 15% of the TO Load	No more than 30 cycles
58.7 Hz	A total of at least 15% of the TO Load	No more than 30 cycles
58.5 Hz	A total of at least 25% of the TO Load	No more than 30 cycles

[https://www.ercot.com/services/comm/mkt\\_notices/M-A040825-01](https://www.ercot.com/services/comm/mkt_notices/M-A040825-01)

# Special Protection Schemes (SPS)

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- SPS are protection schemes designed for specific situations, to try to avoid system conditions that could lead to vulnerabilities
- Common SPS types are: generation rejection, load shedding, controlled islanding
- Generation rejection and load shedding
  - This may occur if, in transient conditions, there is significant flow across a transmission interface
  - A challenge is that generators are not designed to be frequently tripped offline completely and may have fatigue
- Controlled islanding
  - Transfer tripping of certain loads and generators to create contained stable islands
  - G. Xu, V. Vittal, A. Meklin and J. E. Thorman, "Controlled Islanding Demonstrations on the WECC System," in *IEEE Transactions on Power Systems*, vol. 26, no. 1, pp. 334-343, Feb. 2011

# Excitation Protection



- Generators cannot operate beyond upper and lower excitation limits for very long due to potential heating damage
- Over Excitation Limiters (OELs) are controllers that activate if the field current is too high for too long
- Under Excitation Limiters (UELs) are controllers that activate if the field current is too low for too long
- OEL and UEL are specialized controllers that generally give additional input to the exciter
  - When not near the limits, generally they do not have an effect.

