B5 – Protection & Automation

PS2 / Applications of Emerging Technolog for Protection, Automation and Control

Paper ID - 305

Optimizing Underfrequency Load Shedding Strategies to Improve System Reliability

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Motivation

- The power industry is endeavoring to achieve net-zero carbon emissions by replacing conventional synchronous generation with renewable energy.
- Less synchronous generation results in lower system inertia which can cause higher Rate-of-Change-of-Frequency (RoCoF) during a loss of generation event.

$$\frac{df}{dt} = \frac{-30 \cdot \Delta L}{H}$$

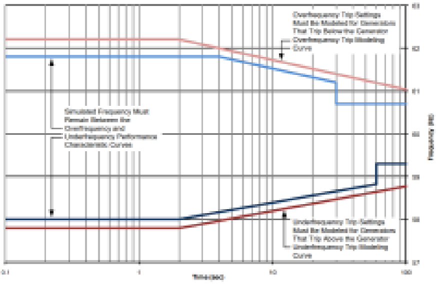
- Excessively high RoCoF can render an automatic UFLS program ineffective, possibly leading to a systemwide blackout. A recent example is the South Australian system blackout that occurred on September 28, 2016.

Challenges of IBR Penetration to Conventional UFLS Schemes

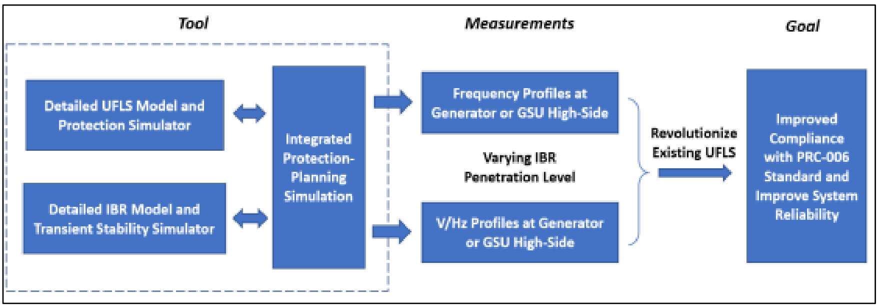
- The voltage-supervised and current-supervised UFLS relays are not sufficient to prevent misoperations at a motor load bus.
- Conventional UFLS increases the intentional time delay to 20 cycles or greater at heavy motor load buses to avoid mis-tripping.
- This existing approach unintentionally renders a UFLS program ineffective if too many relays have extended delays under high IBR penetration conditions.

Facilitating NERC PRC-006 Compliance Study with Integrated Protection-Planning Simulation (IPPS)

- NERC PRC-006-5 requirements:
  - Frequency shall remain between the UF and OF Performance Characteristic curves.
  - V/Hz shall not exceed 1.18/1.10 p.u. for longer than 2/45 sec cumulatively per simulated event.



- The IPPS is an emerging technology that integrates detailed protection modeling with the conventional transient stability simulation environment.
- The main features of IPPS include:
  - Thousands of highly-detailed relay models that protection engineers utilize to develop settings.
  - Transient stability model that planning engineers utilize to perform stability studies.
  - Simulates the planning and protection models simultaneously so that the effect of protective relay operations on the dynamic behavior of the system and cascading failures can be studied. Relay operation times are determined by simulation and not assumed.
  - Provides a platform for developing and testing special protection schemes and their associated wide-area protection/control algorithms.



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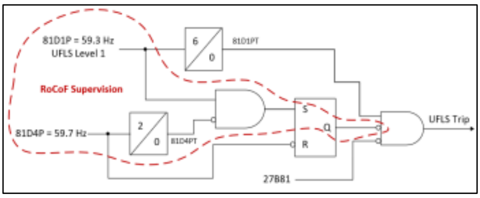
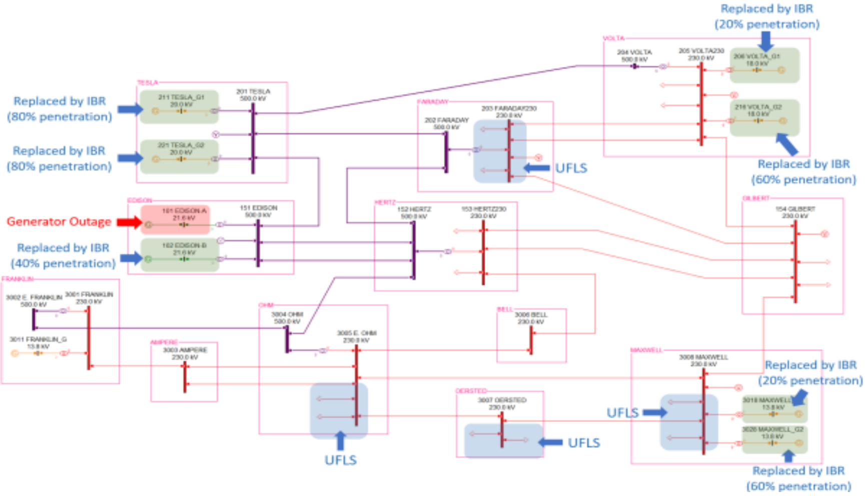
New UFLS Logic with RoCoF Supervision

- To tackle the UFLS challenges imposed by high IBR penetration, an innovative UFLS relay algorithm with RoCoF supervision was developed.
- This logic employs two underfrequency relay elements with a difference of 0.4 Hz and a 2-cycle timer to create a RoCoF supervisor.



Simulation Validation

- The UFLS relays modeled in IPPS are deployed at the eight load locations as marked in the one-line diagram of the 23-bus system.
- The entire UFLS program is set to shed 11.0% of the system load at three frequency levels: 59.3 Hz, 59.0 Hz, and 58.7 Hz.
- UFLS time delays are set as a combination of 6 cycles and 30 cycles to represent a typical UFLS scheme with large amounts of industrial motor loads.
- A generation-load imbalance condition was created by suddenly disconnecting the synchronous generator at Bus 101 from the system. The amount of generation tripped represented 23.4% of the total system load.
- Synchronous generation was incrementally replaced by IBRs to study various IBR penetration levels.



IBR Penetration Level	Worst-Case Bus	RoCoF (Hz/sec)	Frequency Nadir (Hz)	
			Conventional UFLS	Innovative UFLS
Zero	3018	1.117	58.852	59.074
20%	211	1.292	58.725	58.984
40%	211	1.966	58.093	58.794
60%	211	2.485	57.619	58.637
80%	211	4.496	56.469	58.165

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Frequency Evaluation

- Using the IPPS tool, both the traditional UFLS and the innovative RoCoF-supervised UFLS were studied for comparison purposes.
- Compared to the conventional UFLS results, the new scheme clearly demonstrated better frequency performance. The Level 1 and Level 2 load shedding were initiated earlier, and the frequency recovered faster. More importantly, the 60% IBR penetration case did not violate PRC-006-5 requirement R3.
- It can also be observed for the 80% penetration case, Mitigation actions such as adding synchronous condensers to the system must be taken to replace lost inertia above 60% IBR penetration to maintain frequency stability.

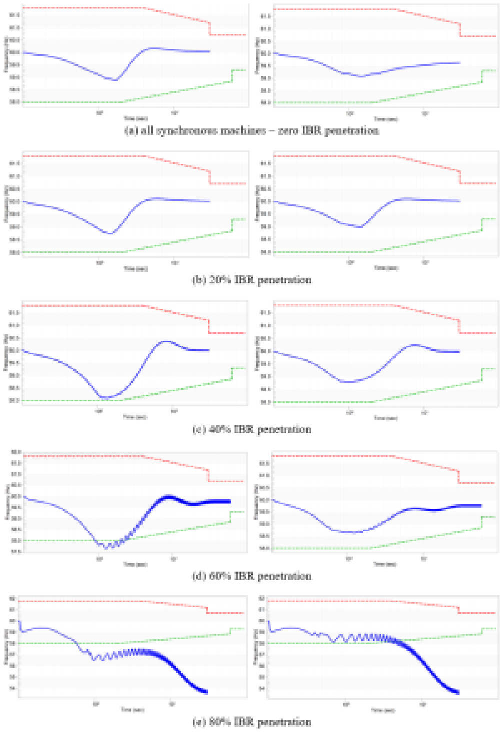
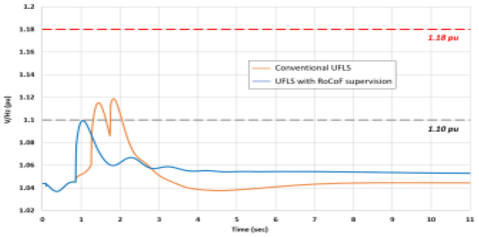


Figure: Simulation Results Under Various IBR Penetration Levels.
Left: Conventional UFLS with Mixed Operation Time;
Right: RoCoF-Supervised UFLS with Reduced Operation Time.

Volts Per Hz Evaluation

- The PRC-006-5 standard also requires an evaluation of the V/Hz performance at generation sites.
- The below figure shows a comparison of the V/Hz performance between conventional and new UFLS schemes at Maxwell generation bus 3018 when all generators are synchronous machines.
- The table below lists the simulation results of all 5 scenarios.



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Conclusions

- The IPPS tool provides a suitable platform for designing and testing highly detailed UFLS relay algorithms in a transient stability study.
- The RoCoF-supervised UFLS relay allows reduced intentional time delay.
- Implementation of faster UFLS tripping in the IPPS test system showed promising performance improvements with IBR penetration up to 80%.
- The frequency nadir was reduced and recovery to nominal frequency was faster. The frequency response plot fit within the PRC-006-5 OF/UF performance characteristic margins much better.
- The Volts per Hertz performance at generator buses was also improved with less cumulative time over the 1.10 p.u. and 1.18 p.u. thresholds.