Frequency Response and Its Enhancement Using Synchronous Condensers in Presence of High Wind Penetration

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Introduction

- Substantial wind penetration in the South Australian grid
- Presence of few synchronous machines results reduced inertia
- A big contingency may produce severe frequency excursion
- South Australian system may face significant under frequency load shedding (UFLS)

Objectives

- To investigate frequency response of a low inertia power system, which loosely represents South Australian network
- To determine the amount of UFLS after a major disturbance
- To propose a solution to improve frequency response and reduce UFLS

Simulation Network

- Based on South East Australian 14-Generator Model

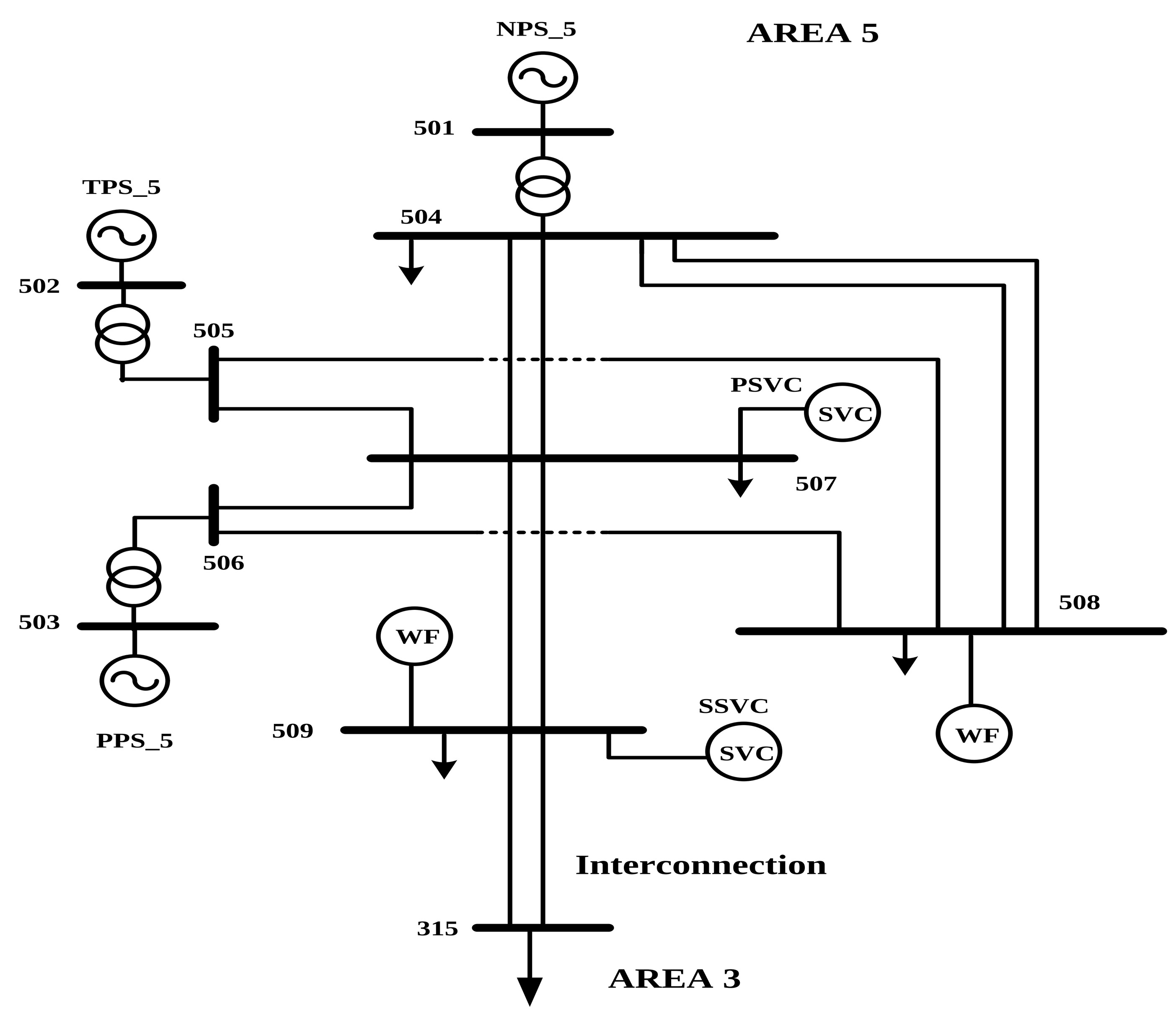

Fig. 1: The studied power system

Simulation Methods and Cases

- Dynamic studies: PSS®E and Python
- Equivalent system frequency: $f_{eq} = [\sum_{i=1}^{i=n}(H_i \times S_i \times \omega_i)]/[\sum_{i=1}^{i=n}(H_i \times S_i)]$
- Rate of change of frequency: $ROCOF = \frac{1}{2} \times \frac{\Delta P}{IR} f_0$
- Contingency: 460 MW interconnection trip

Table 1: Simulation scenarios

No. of synchronous generators	P_{sync} (MW)	P_{wind} (MW)	IR (MWs)	HR (MW)	WPL (%)
5	570	220	5575	765	18
4	470	320	4575	615	26
3	320	470	3400	430	38
2	165	660	2245	250	52
1	90	770	1000	160	59

Simulation Results

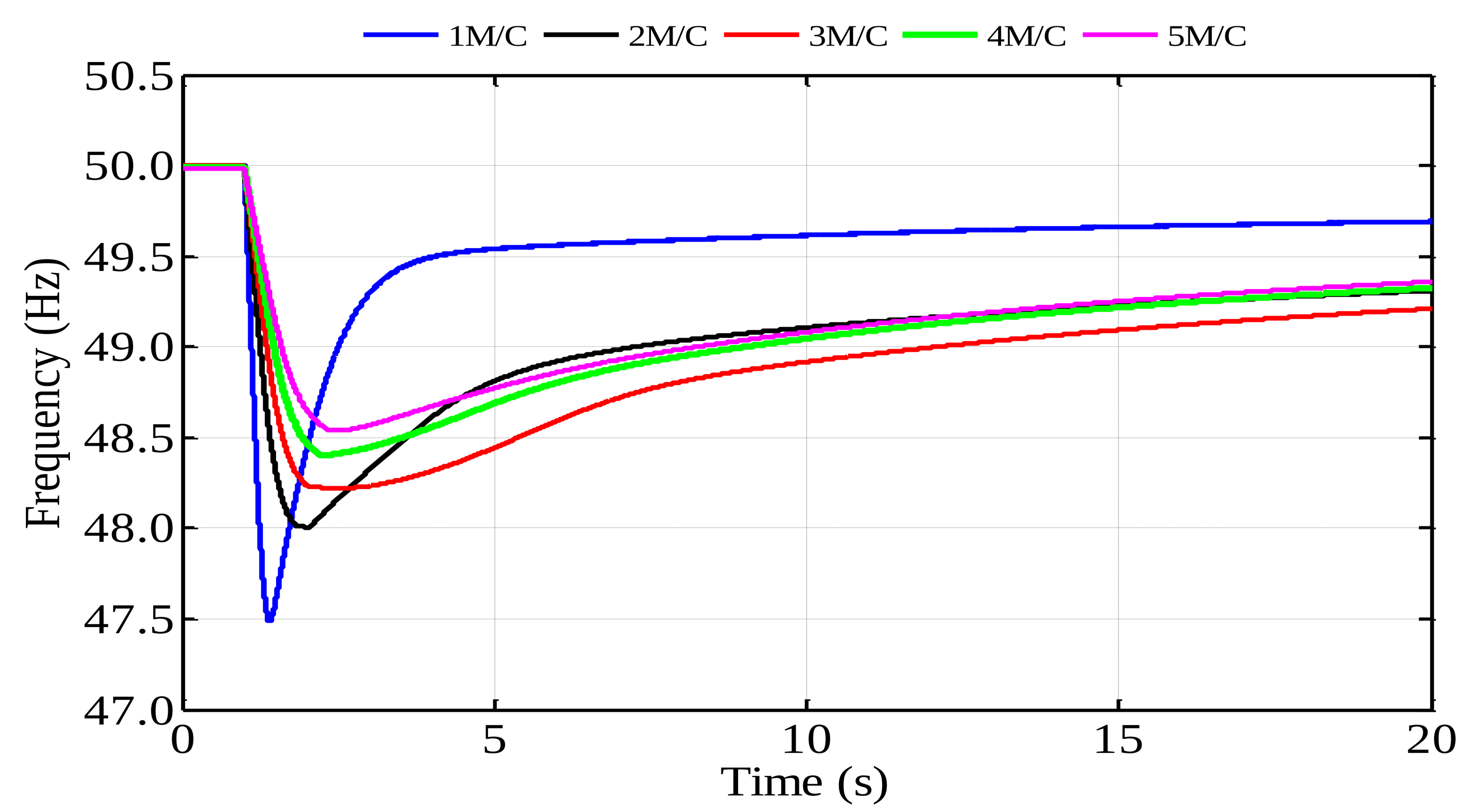

Fig. 2: Frequency response

Table 2: UFLS and ROCOF

No. of synchronous generators	UFLS (%)	Load shed (MW)	ROCOF (Hz/s)
5	12%	144	2
4	15%	180	2.45
3	18%	216	3.3
2	24%	288	5
1	30%	360	11.25

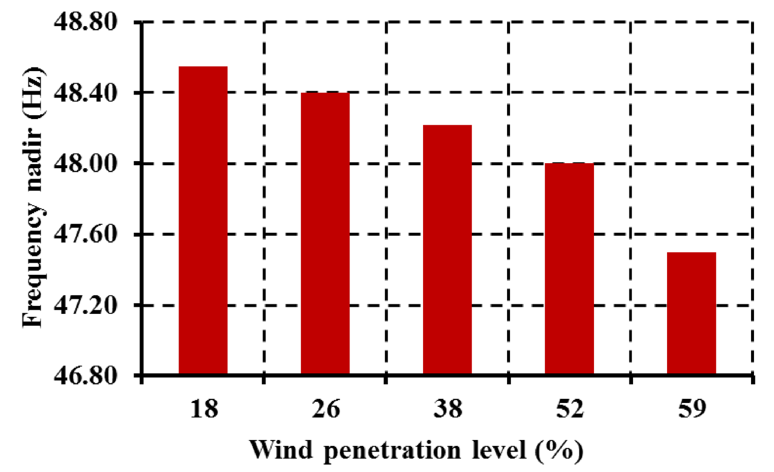

Fig. 3: Frequency nadir vs. wind penetration level

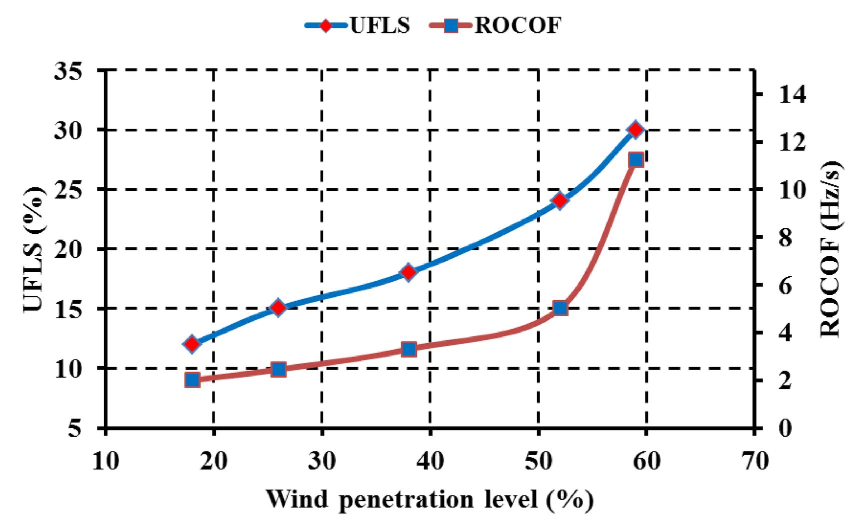

Fig. 4: Effects of wind penetration level on UFLS and ROCOF

- Enhancement of system performance: Synchronous condensers

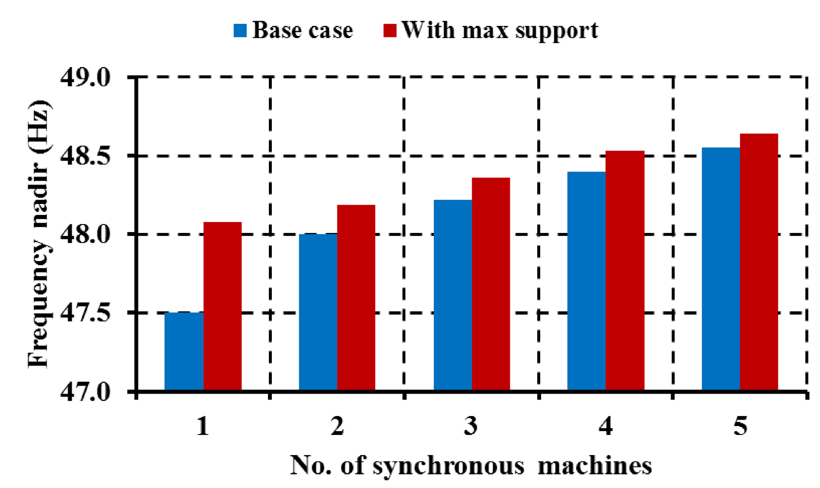

Fig. 5: Improvement of frequency nadir

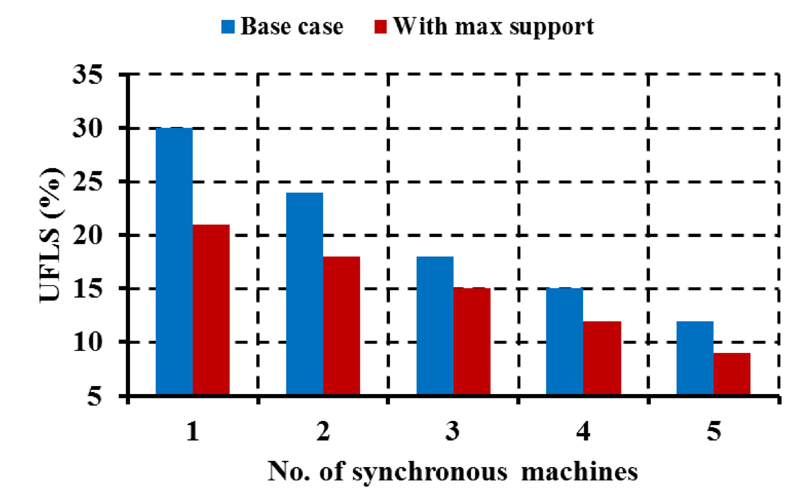

Fig. 6: Reduction of UFLS

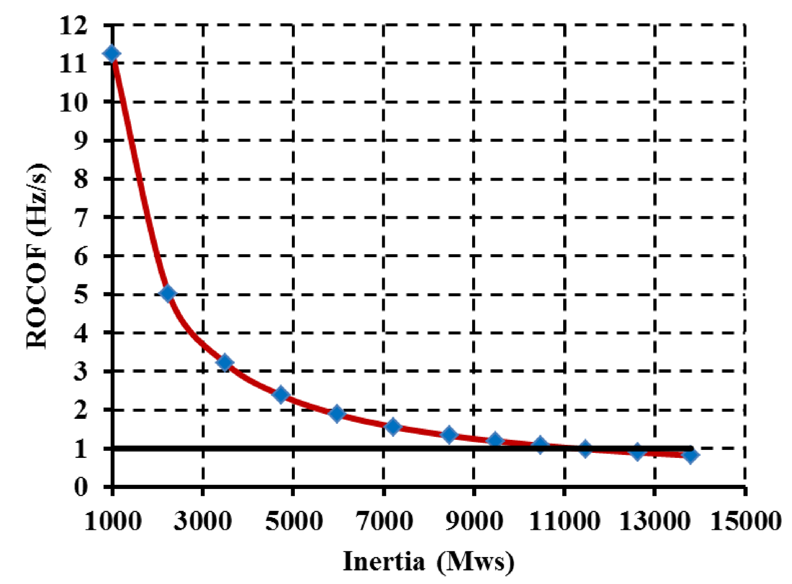

Fig. 7: ROCOF vs. inertia for single machine case

Table 3: Minimum number of synchronous condensers to ensure an acceptable ROCOF

No. of synchronous generators	Minimum no. of synchronous condensers
5	5
4	6
3	7
2	8
1	9

Conclusions

- Due to UFLS, system can be rescued after a severe contingency
- Frequency response depends on wind penetration level, inertia, reserve, interconnection flow and contingency size
- Synchronous condensers improve frequency response, reduce ROCOF and UFLS
- Minimum number of synchronous condensers to maintain an acceptable ROCOF depends on committed system inertia

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