Impact of Renewables on Transmission System Protection

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1. Introduction

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*"One major challenge related to the integration of renewables into power systems is the **impact of renewables on system protection** taken into consideration the complex fault response characteristics of these devices."*

- The first aspect related to this challenge is the ***reliable modeling of the converter interfaced renewable resources used for protection studies.*** (accurate evaluation of the short circuit contribution of these devices to the system fault).

- The second aspect is the *performance of protection schemes* of systems with high levels of renewables.

2. Objectives

2. Objectives

- Investigating the ***impact of renewable sources on*** the performance of transmission line distance protection ***(R21)***.

- The studies analyzed the performance of R21 ***during unbalanced faults*** for the following different cases:

  1- System configurations. ***2-*** Fault locations.

  3-Wind park generation capacity ***4-*** WTG types.

  5- WTG connections (directly tapped - equipped with complete protection system).

- Wind parks are also ***replaced by conventional generators*** to differentiate the performance of distance protection with respect to the fault response characteristics of the converter interfaced renewables compared to synchronous generators

3. Distance Protection of Transmission Lines Incorporated Wind Parks

3.1 Factors controlling the impact of Wind Park on (R21):

3.1.1 Wind park capacity:

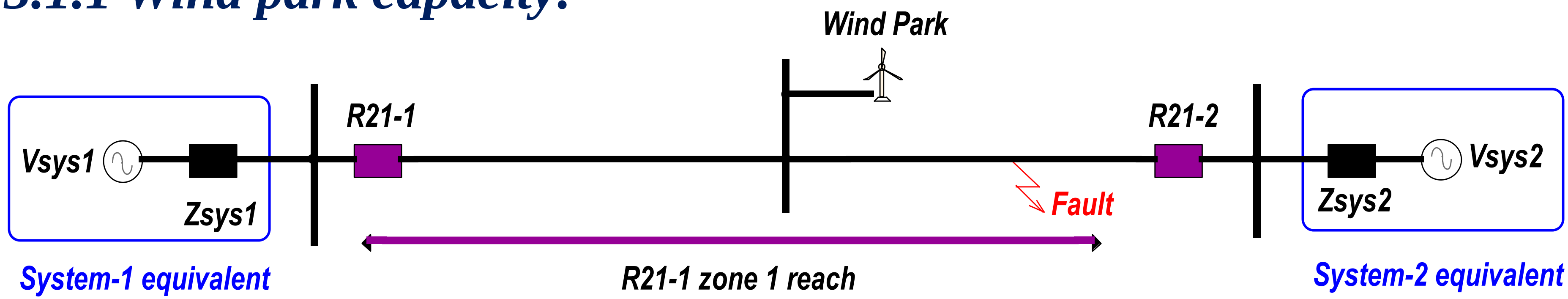

Fig. 1.

$$SCR = \frac{MVA_{SC}}{P_{WP}} = \frac{\left(V_{POI}^{2}\right)/\left(Z_{s}\right)}{P_{WP}} \qquad (1)$$

$$Error(\%) = \frac{\left|Z_{with\,wind\,park}\right| - \left|Z_{without\,wind\,park}\right|}{\left|Z_{without\,wind\,park}\right|} \times 100$$

4.1 Benchmark 1 (Wind park is tapped to the Busbar on the T.L)

Table 1: Benchmark-1 Strong External System Scenarios

Case	R_1 (Ω)	X_1 (Ω)	X_1/R_1	R_{TL} (Ω)	X_{TL} (Ω)	R_s (Ω)	X_s (Ω)	Z_s (Ω)	X_s/R_s	Generation Capacity	SCR
S1	0.2	6	30	7.4	73.4	3.8	39.7	39.9	8.4	100 MW / 111.1 MVA	29.8
S2										300 MW / 333.3 MVA	9.9

Table 2: Benchmark-1 Weak External System Scenarios

Case	R_1 (Ω)	X_1 (Ω)	X_1/R_1	R_{TL} (Ω)	X_{TL} (Ω)	R_s (Ω)	X_s (Ω)	Z_s (Ω)	X_s/R_s	Generation Capacity	SCR
W1	30	40	0.75	7.4	73.4	18.7	66.7	69.3	3.6	100 MW / 111.1 MVA	17.2
W2										300 MW / 333.3 MVA	5.7

Table 3: Benchmark-1 R21 (Zone 1) Performance in Strong External System

Case	Generation Type	Fault Location: 95% of reach, Distance from R21-1 = 304 km		Fault Location: 100% of reach, Distance from R21-1 = 320 km	
		Error %	Relay Operation	Error %	Relay Operation
S1	Type III	3.8	D (2cycles)	5	F
	Type IV	2.5	D (2cycles)	3.5	F
	Synchronous	7.3	F	8.4	F
S2	Type III	6	F	8.8	F
	Type IV	5.6	D (2cycles)	6.3	F
	Synchronous	22	F	23.8	F

Table 4: Benchmark-1 R21 (Zone 1) Performance in Weak External System

Case	Generation Type	Fault Location			
		95% of reach Distance from R21-1 = 304 km		100% of reach Distance from R21-1 = 320 km	
		Error %	Relay Operation	Error %	Relay Operation
W1	Type III	4.2	D (2cycles)	6.2	F
	Type IV	3.6	D (2cycles)	4.3	F
	Synchronous	12.2	F	13.4	F
W2	Type III	11.5	F	15.3	F
	Type IV	11	F	13	F
	Synchronous	31.6	F	36.4	F

4. Benchmark Systems and Simulation Results

4.2 Benchmark 2 (Wind park is equipped with protection scheme)

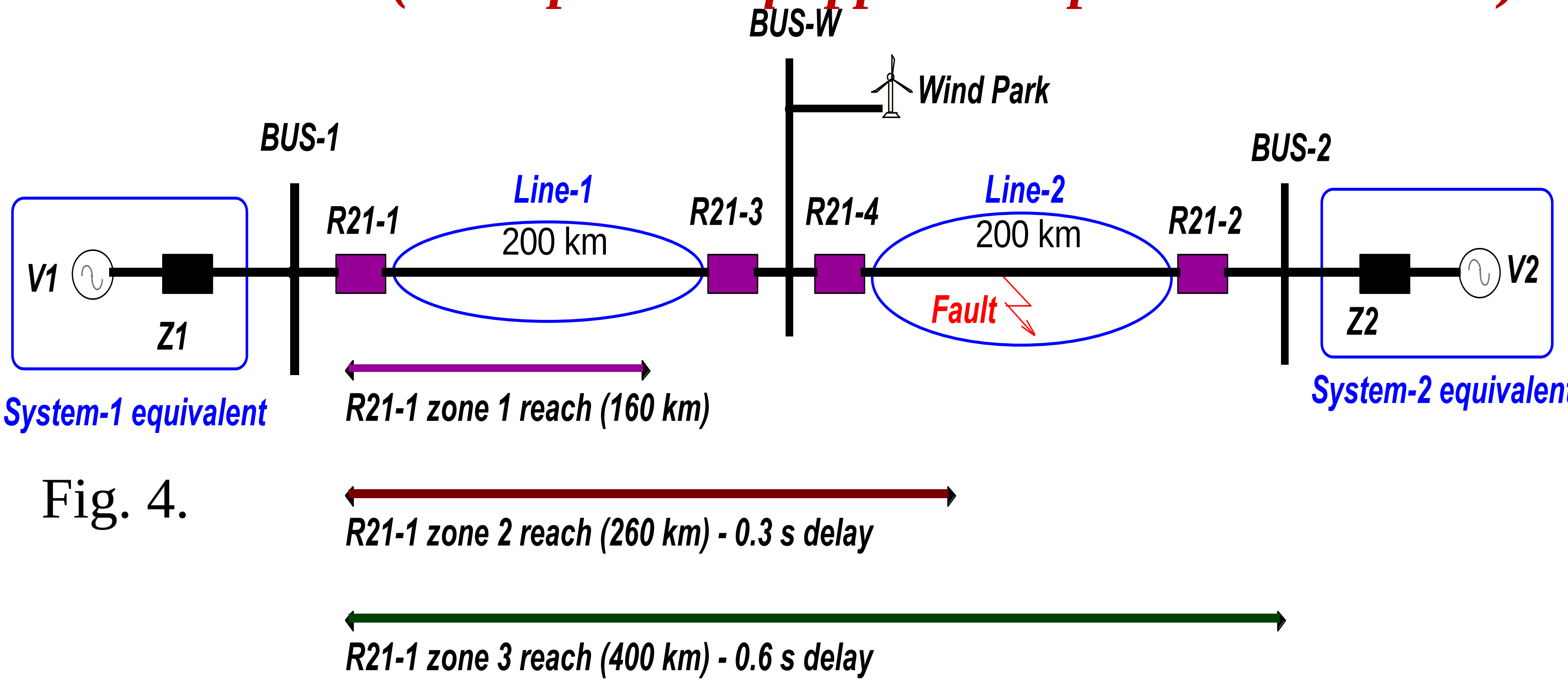

Fig. 4.

Table 5: Fault locations

Fault Scenario	Fault Location
F1	92% of Zone 2 reach (Distance from R21-1 = 240 km)
F2	80% of Zone 3 reach (Distance from R21-1 = 320 km)
F3	90% of Zone 3 reach (Distance from R21-1 = 360 km)

4. Benchmark Systems and Simulation Results

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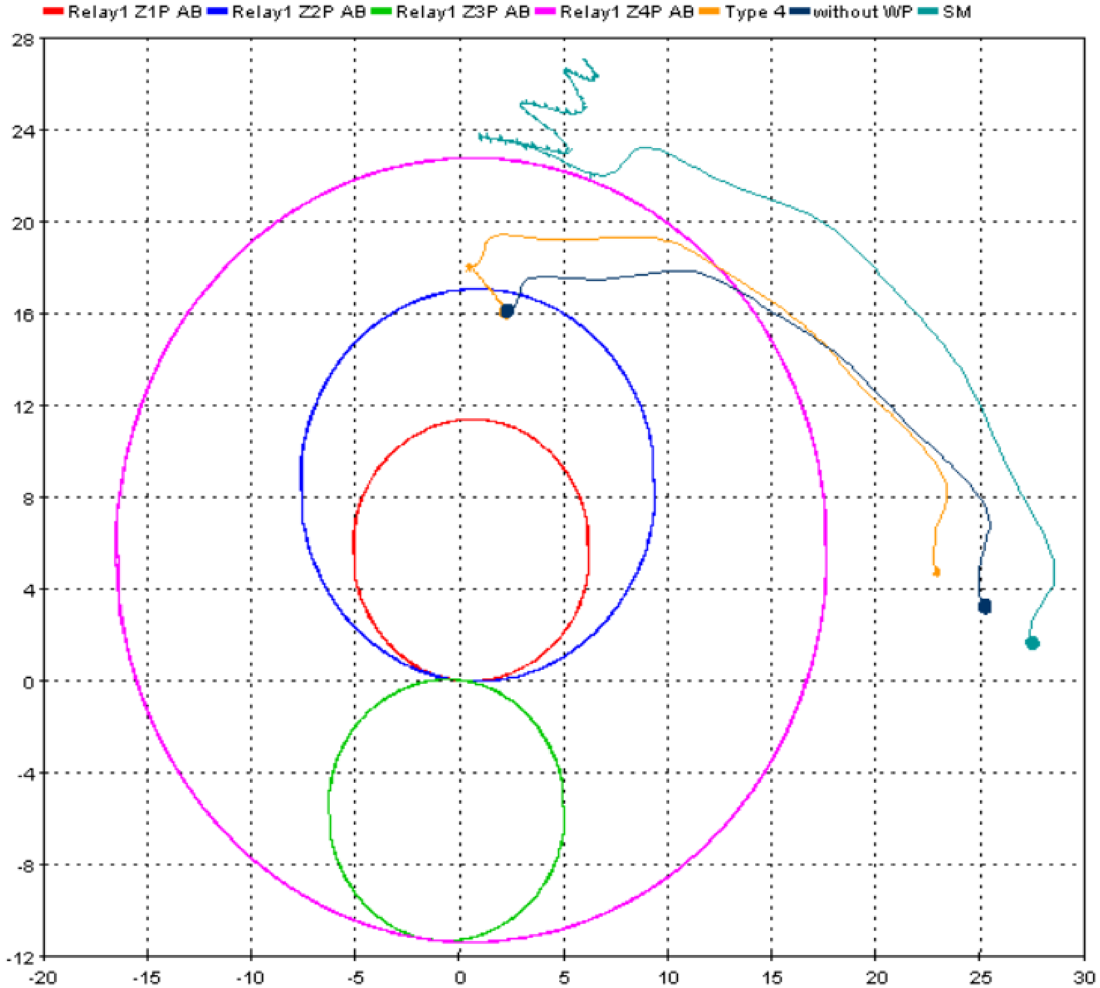


$$Error(\%) = \frac{|Z_{with\,wind\ park}| - |Z_{without\,wind\ park}|}{|Z_{without\,wind\ park}|} \times 100$$

4.2 Benchmark 2 (Wind park is equipped with protection scheme)

Table 6: Benchmark-2 R21 Zone 2 Performance in Strong External System

Case	Generation Type	Scenario F3 (Fault Location 92% of relay reach)	
		Error %	Relay Operation
S1	Type III	1.7	D (3 cycles)
	Type IV	1.1	D (3 cycles)
	Synchronous	1.7	D (4 cycles)
S2	Type III	5.1	D (7.5 cycles)
	Type IV	3.4	D (4 cycles)
	Synchronous	17.3	D (18 cycles)

4.2 Benchmark 2 (Wind park is equipped with protection scheme)

Table 7: Benchmark-3 R21 Zone 2 Performance in Weak External System

Case	Generation Type	Scenario F3 (Fault Location 92% of relay reach)	
		Error %	Relay Operation
W1	Type III	3.4	D (4 cycles)
	Type IV	1.7	D (2 cycles)
	Synchronous	8.6	D (10 cycles)
W2	Type III	7.4	F
	Type IV	5.6	D (2 cycles)
	Synchronous	14.4	F

4.2 Benchmark 2 (Wind park is equipped with protection scheme)

Table 8: Benchmark-3 R21 Zone 3 Performance in Strong External System

Case	Generation Type	Fault Location			
		80% of reach		90% of reach	
		Error %	Relay Operation	Error %	Relay Operation
S1	Type III	--	--	5.5	F
	Type IV	--	--	4	F
	Synchronous	6.7	D (2 cycles)	8.8	F
S2	Type III	9.6	D (3 cycles)	10.5	F
	Type IV	5.8	D (2 cycles)	6.6	F
	Synchronous	14.6	F	15	F

4.2 Benchmark 2 (Wind park is equipped with protection scheme)

Table 9: Benchmark-2 R21 Zone 3 Performance in Weak External System

Case	Generation Type	Fault Location			
		80% of reach		90% of reach	
		Error %	Relay Operation	Error %	Relay Operation
W1	Type III	9.2	D (2 cycles)	11.3	F
	Type IV	--	--	7.7	F
	Synchronous	11.7	D (2 cycles)	12	F
W2	Type III	21.5	F	23	F
	Type IV	13.4	D (2 cycles)	15	F
	Synchronous	29.2	F	29.6	F

4.2 Benchmark 2 (Wind park is equipped with protection scheme)

Table 10: Benchmark-2 Fault Current Contributions from Generation in Strong External System

Case	Generation Type	Fault Current Contribution from Generation (A)	
		Positive Sequence	Negative Sequence
S1	Type III	353	165
	Type IV	315	20.5
	Synchronous	564	294
S2	Type III	992	443
	Type IV	936	68
	Synchronous	1658	707

4.2 Benchmark 2 (Wind park is equipped with protection scheme)

Table 11: Benchmark-3 Fault Current Contributions from Generation in Weak External System

Case	Generation Type	Fault Current Contribution from Generation (A)	
		Positive Sequence	Negative Sequence
W1	Type III	360	164
	Type IV	311	21
	Synchronous	671	250
W2	Type III	1011	400
	Type IV	880	65
	Synchronous	1680	410

5. Conclusions and Future work

5.1 Conclusions

- The studies ***evaluate the settings of R21 through calculating the error in the impedance measured by the relay*** for different fault types, generation levels, fault locations and generation types.

- Potential problems are demonstrated when the settings of R21 are kept intact following the integration of generation into the transmission system. ***The necessity of revising R21 reach based on correct models of wind parks is highlighted***.

- Three benchmark systems are studied, and the results show that the wind parks have an impact on the operation of distance protection. The ***impact varies according to the wind park type, fault type, fault location and wind generation level.***

5.1 Conclusions

- ***The impact is more pronounced for Type III WTGs*** and especially when the wind park is tapped at the line without installing additional relays at both sides of the connection point. ***The impact varies from delayed operation to a failure in operation***.

- For all generation types, ***there is a strong correlation between the SCR*** (system short circuit MVA versus generation capacity) and the relay ***Error%***. The errors increases with the decrease in SCR.

- When the generation types are considered, the measurement ***errors are largest in conventional generating unit (synchronous machine)*** as its short circuit current contribution and voltage support capability are much higher compared to wind parks (both Type III and Type IV WTGs).

5.1 Conclusions

- In the WTGs, the short circuit current contribution is limited by their controllers. However, the induction generator of ***Type III WTG provides a path for negative sequence currents and this results in*** larger distance relay impedance measurement ***errors compared to Type IV WTG.***

5.2 Other Works

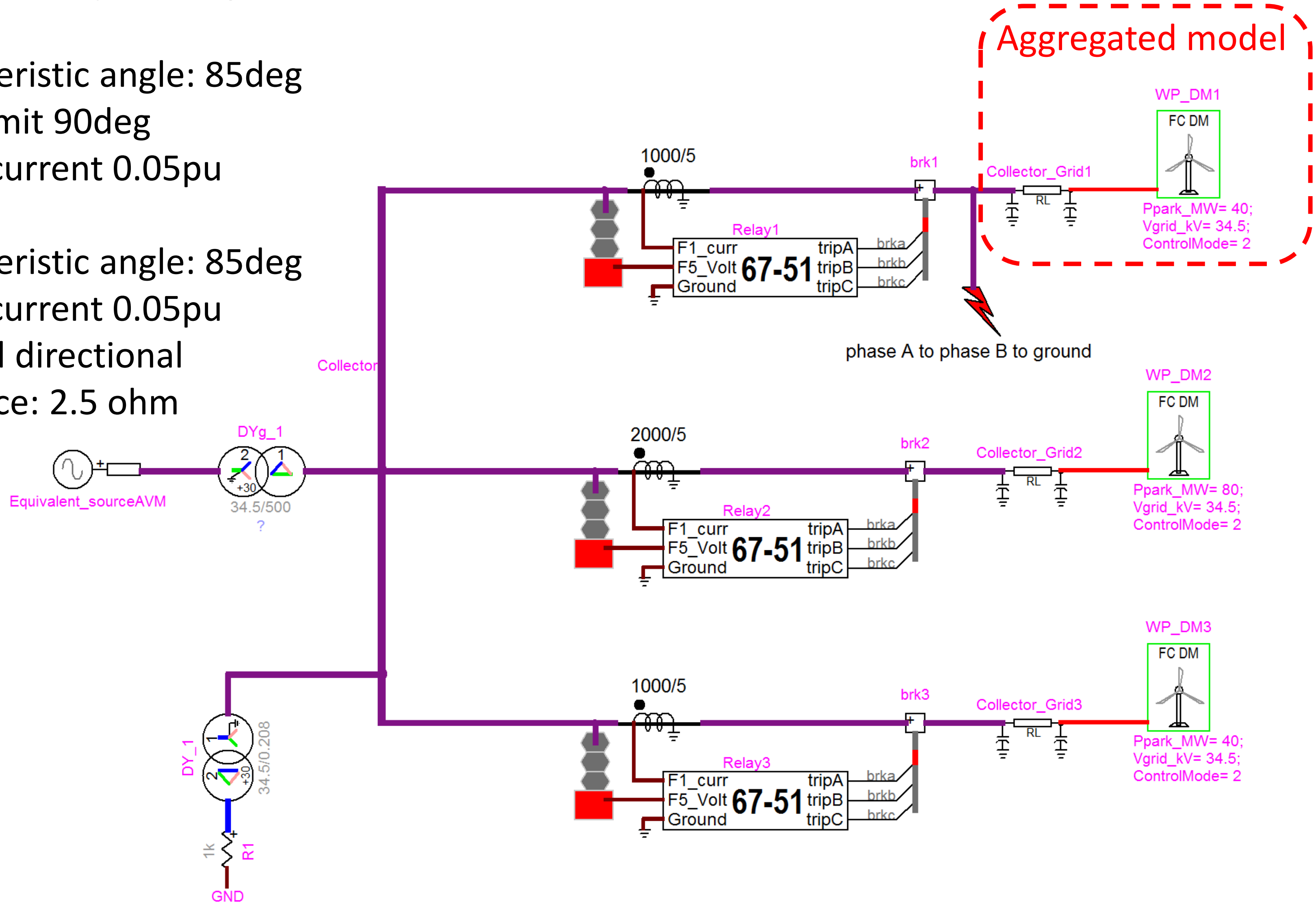
Negative sequence directional relays setting :

- GE:

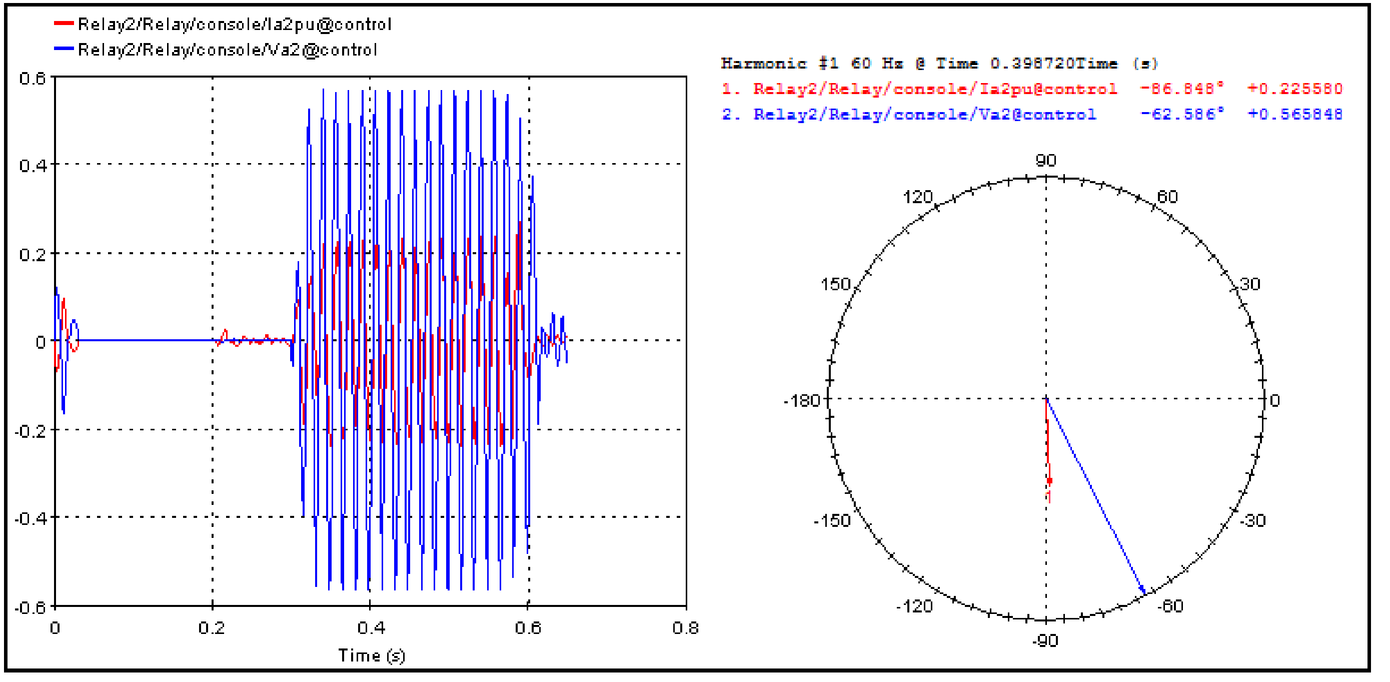
- Characteristic angle: 85deg
- Angle limit 90deg
- Pickup current 0.05pu

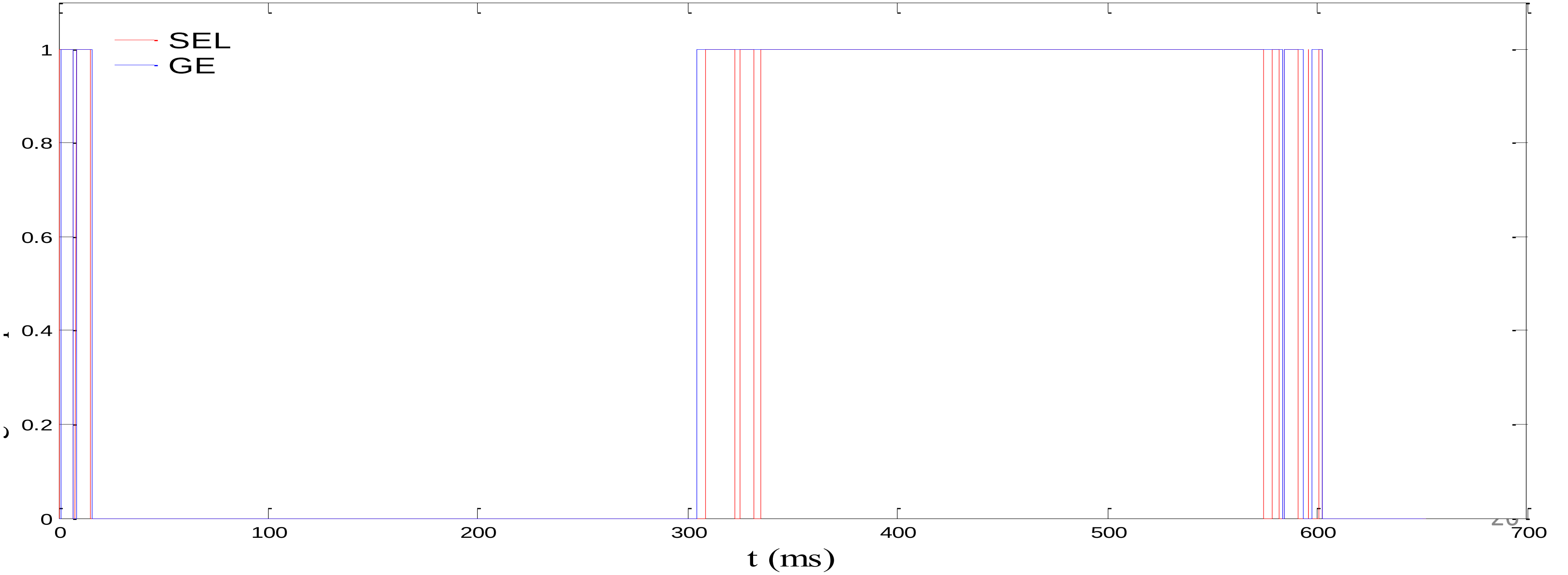
- SEL:

- Characteristic angle: 85deg
- Pickup current 0.05pu
- Forward directional impedance: 2.5 ohm



5.2 Other Works





5.3 Future Works

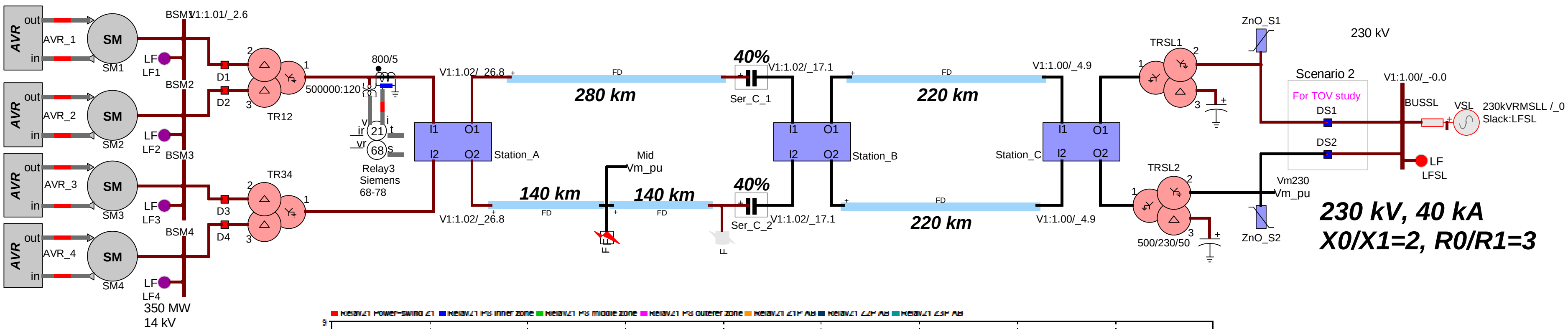
- Development of an extensive and portable short circuit model library for phasor domain tools by taking into account different control modes, topologies and points of control.

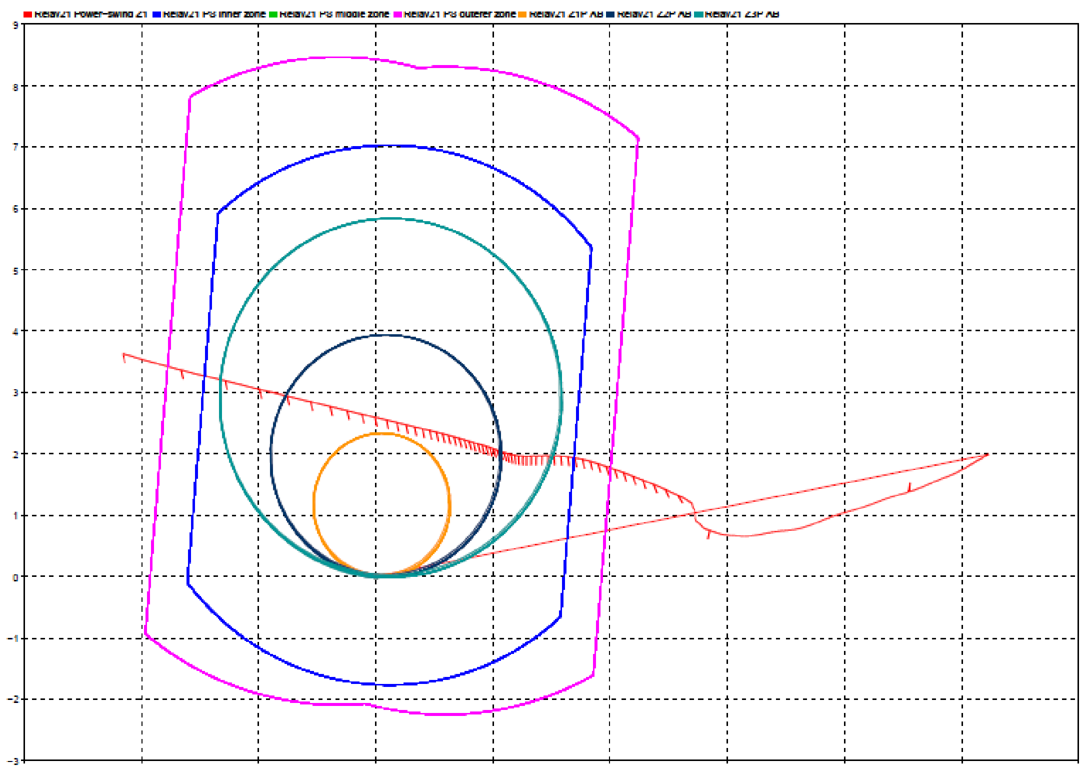
- Implementation of such models is fault and protection analysis platforms.

- Further improvement of Type III model by considering the negative sequence decoupling options provided by some WTG manufacturers.

- Development of new benchmark cases and evaluation of the performance of other protection functions such as line/transformer differential protection, directional elements, overcurrent protection, interactions with existing generation plants etc.

5.2 Future Works: Powerswing / Out-of-step





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