CIGRE SC B5. Workshop

EFFECT OF GENERATOR CONTROLS ON PROTECTIVE RELAY SETTINGS

Juan M Gers

Oct 22nd, 2019

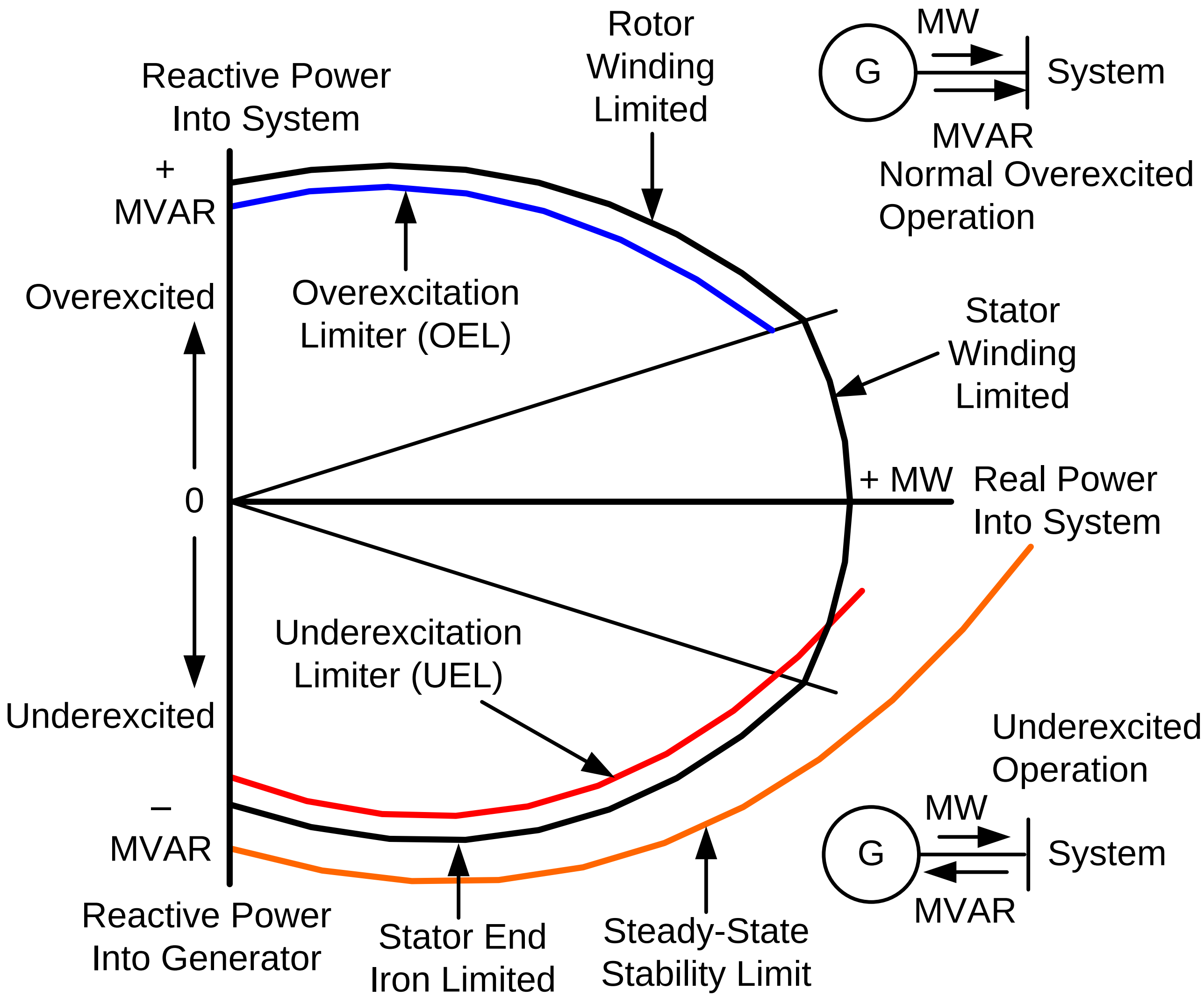
GERS

Content

- Fundamentals
- Protection schemes and setting criteria suggested by IEEE Std C37.102-2006
- NERC Regulations 019, 024, 025 and 026
- Case Study

GERS

Typical Generator Capability Curve P-Q Diagram



GERS

Typical Settings of Generator Relays

Table 1 - Recommended Settings			
IEEE No.	**FUNCTION**	**Per IEEE C37.102**	
		SECTION	**DESCRIPTION**
21	Distance	4.6.1.1 & A.2.3	Zone-1 = smaller of the two following criteria: 1. 120% of unit transformer 2. 80% of Zone 1 reach setting of the line relay on the shortest line (neglecting in-feed); time = 0.5 s
			Zone-2 = the smaller of the three following criteria: A. 120% of longest line (with in-feed). If the unit is connected to a breaker and a half bus, this would be the length of the adjacent line. B. 50% to 66.7% of load impedance (150% to 200% of the generator capability curve) at the RPFA C. 80% to 90% of load impedance (111% to 125% of the generator capability curve) at the maximum torque angle; time > 60 cycles
			<u>Note</u>**:** Maximum load impedance at rated power factor does not encroach into the reach. A value of 150% to 200% is recommended to avoid tripping during normal load. Zone2<2Zmax_load @ RPF
24	Overexcitation	4.5.4.2 & A.2.10	Single relay: PU = 110% p.u. time = 6 s
			Two stages relay: alarm pu = 110%; 45< t < 60 s trip pu = 118% - 120%, 2< t < 6s
25	Sync-check	5.7	Breaker closing angle: within ± 10 elect. Degrees
			Voltage matching: 0 to +5%
			Frequency difference < 0.067 Hz
27	Undervoltage	4.5.7 & A.2.13	*Relays with inverse time charac and instantaneous* Pickup: 90%Vn; t= 9.0 s at 90% of pickup setting Inst : 70% Vn
			Relays with definite time charac and 2 stages FS - Alarm pickup: 90%Vn; 10< t < 15 s SS - Trip pickup: 80% Vn; time: 2s

GERS

Typical Settings of Generator Relays

Table 1 - Recommended Settings			
IEEE No.	FUNCTION	Per IEEE C37.102	
		SECTION	DESCRIPTION
32	Reverse Power	4.5.5.3 & A.2.9	Pickup setting should be below the following motoring limits: Gas : 50% rated power; time < 60 s Diesel : 25% rated power; time < 60 s Hydro turbines : 0.2% - 2% rated power; time < 60 s Steam turbines : 0.5% - 3% rated power; time < 30 s
40	Loss-of-field Approach # 1	4.5.1.3 & A.2.1	UNIT 1 Offset: $X'_d/2$; Diameter: 1.0 pu; time: 0.1 s UNIT 2 Offset: $X'_d/2$; Diameter: X_d; time: 0.5 to 0.6 s
	Loss-of-field Approach # 2		UNIT 1 Offset: $X'_d/2$; Diameter: 1.1 X_d - X'_d /2 or 1.25X_d - X'_d /2 ; Time: 0.25 s UNIT 2 Offset: X_{TG} + $X_{min\ SG1}$; Diameter: 1.1 X_d + X_{TG} + $X_{min\ SG1}$ or 1.25 X_d + X_{TG} + $X_{min\ SG1}$ Time: 1.0 s < t < 60 s. Angle of directional element = -13^o

Typical Settings of Generator Relays

Table 1 - Recommended Settings			
IEEE No.	FUNCTION	Per IEEE C37.102	
		SECTION	DESCRIPTION
46	Negative Sequence Overcurrent	4.5.2 & A.2.8	Pickup setting should be below the permissible I_2 percent expressed in percent of rated current, which are indicated below: *Salient pole: 10%* With connected amortisseur windings : 10% With non-connected amortisseur windings : 5% *Cilindrical rotor* Indirectly cooled : 10% Directly cooled - Up to 350 : 8% - 351 MVA TO 1250 MVA : 8% (MVA-350)/300 - 1251MVA TO 1600 MVA : 5% Permissible K (I^2_2 t) Salient pole generator : 40 Synchronous condenser : 30 Cylindrical rotor indirectly cooled : 30 Cylindrical rotor directly cooled (0 MVA to 800 MVA) : 10 Directly cooled (801 MVA -1600 MVA) : See Figure 4-39
50/87	Differential via flux summation CTs or split-phase protection	4.3.2.5.1	The pickup of the instantaneous unit should be set above the CT error currents that may occur during external faults. The resulting settings offers little turn fault protection.
50/27	Inadvertent Energization Overcurrent with 27, 81 Supervision	5.4.2.4 & A.2.4	50: pickup ≤ 50% of the worst-case current value and should be > 125% generator rated current. 27: 50% Vn, time: 1.5 s

GERS

Typical Settings of Generator Relays

Table 1 - Recommended Settings			
IEEE No.	FUNCTION	Per IEEE C37.102	
		SECTION	DESCRIPTION
50 BF	Generator Breaker Failure Protection	4.7 & A.2.11	Current detector: picku should be more sensitive than the lowest current present during fault involving currents. Timer > Generator breaker interrupt time + Curr det. dropout time + safety margin
51N	Stator Ground Over-current (Low,Med Z Gnd,Phase CT Residual)	4.3.3.2	The grounding resistor is selected to limit the generator's contribution to a single phase-to-ground fault at its terminals to a range of current between 200 A and 150% rated full load current
50/51N	Stator Ground Over-current (Low, Med Z Gnd, Neutral CT or Flux Summation CT)		
51GN, 51N	Stator Ground Over-current (High Z Gnd)	4.3.3.1.1	Typically, the overvoltage relay has minimum pickup setting of approximately 5 V. With this setting and with typical distribution transformar ratios, this scheme is capable of detecting faults to within 2% to 5% of the stator neutral.
50/51	Time overcurrent protection (against overloads)	4.1.1.2	51 pickup: 75-100% FLC, time: 7 s at 218% FLC. FLC means full load current. 50 pickup: 115% FLC, time: instantaneous unit is set to pick up at 115% of full-load current and is used to torque control the time-overcurrent unit. The instantaneous unit dropout should be 95% of higher of pickup setting.

GERS

Typical Settings of Generator Relays

Table 1 - Recommended Settings			
IEEE No.	FUNCTION	Per IEEE C37.102	
		SECTION	DESCRIPTION
51VC	Voltage Controlled Overcurrent	4.6.1.2 & A.2.6	Overcurrent pickup: 50% FLC Control voltage: 75%Vn. Inverse time curve and dial settings should be set to coordinate with system line relays for close-in faults on the transmission lines at the plant.
51VR	Voltage Restrained Overcurrent	4.6.1.2 & A.2.6	Overcurrent pickup: 150% FLC at rated voltage Inverse time curve and dial settings should be set to coordinate with system line relays for close-in faults on the transmission lines at the plant.
59	Overvoltage	4.5.6. & A.2.12	*Relays with inverse time charac and instantaneous* Pickup: 110%Vn; t= 2.5 s at 140% of pickup setting Inst : 130 - 150% Vn *Relays with definite time charac and 2 stages* Alarm pickup : 110%Vn; 10< t < 15 s Trip pickup : 150% Vn; time: 2 cycles<t<5 cycles
59N, 27-TH, 59P	100% Stator Gound protection (for high impedance grounding generators)	4.3.3.1.1 & A.2.7	59G element: Pickup = 5 V; t = 5 s Time setting must be selected to provide coordination with other system protective devices. 27TH element: Pickup = 50% neutral third harmonic voltage, time = 5 s
64F	Generator Rotor Field protection (rotor ground faults)	4.4.1	Field ground detection using DC a source: 1< t <3 s Field ground detection for Brushless Machines with telemetry infrared LED communications: time up to 10 s Field ground detection using low frequency square wave voltage injection: ALARM = 20 kOhm TRIP = 5 kOhm

GERS

Typical Settings of Generator Relays

Table 1 - Recommended Settings			
IEEE No.	FUNCTION	Per IEEE C37.102	
		SECTION	DESCRIPTION
67IE	Directional O/C for Inadvertent Energization		
78	Out of Step	4.5.3 & A.2.2	Mho Diameter : $2X'_d + 1.5\ X_{TG}$ Blinder distance (d) = ((X'd + XTG + XmaxSG1)/2) x tan (90-(d/2)); d: angular separation between generator and the system which the relay determines instability. <u>If there is not stability study available</u> d = 120º t = as per transient stability study Typically 40 < t < 100 ms
81	Over/under frequency (60 Hz systems)	4.5.8 & A.2.14	Typical Setting 81U ALARM: 59.5 Hz Time: 10 s. The underfrequency load shedding setting in the systems is given as 59.3 Hz with a delay of 14 cycles. 81U TRIP: The generator 81U relay should be set below the pick-up of underfrequency load shedding relay set-point and above the off frequency operating limits of steam turbine. 81O ALARM:Pick-up: 60.6 Hz, Time Delay 5 sec.

GERS

Typical Settings of Generator Relays

Table 1 - Recommended Settings			
IEEE No.	FUNCTION	Per IEEE C37.102	
		SECTION	DESCRIPTION
87G	Generator Phase Differential	4.3.3.2 & A.2.5	Pickup : 0.3 A Slope : 10% time: instantaneous
87GN	Generator Ground Differential	4.3.2	
87UD	Unit Differential	4.3.2.6	

NERC Standards

NERC Standards have to be considered and in particular the following:

- Standard PRC-019-2 — Coordination of Generating Unit or Plant Capabilities, Voltage Regulating Controls, and Protection
- Standard PRC-024-1 — Generator Frequency and Voltage Protective Relay Settings
- Standard PRC-025-1— Generator Relay Loadability
- Standard PRC-026-1 – Relay Performance During Stable Power Swings

GERS

NERC PRC-019-2

Standard PRC-019-2 — Coordination of Generating Unit or Plant Capabilities, Voltage Regulating Controls, and Protection

A. Introduction

1. **Title:** Coordination of Generating Unit or Plant Capabilities, Voltage Regulating Controls, and Protection
2. **Number:** PRC-019-2
3. **Purpose:** To verify coordination of generating unit Facility or synchronous condenser voltage regulating controls, limit functions, equipment capabilities and Protection System settings.

GERS

NERC PRC-019-2

- The use of a transient stability study is required to demonstrate this coordination.

- NERC PRC-019-2 requires the generator owner to verify the following coordination items:

  – The in-service limiters (field over and under-excitation limiters) are set to operate before the Protection System (Function 40) to avoid disconnecting the generator unnecessarily.

  – The generator protection system devices (Functions 40 and 78) are set to operate to isolate equipment in order to limit the extent of damage when operating conditions exceed equipment capabilities or stability limits (steady and transient).

NERC PRC-019-2

- Per NERC PRC-019-2, the diagram should include the equipment capabilities and the operating region for the limiters and protection functions. The following are typical:
  - Generator Capability Curve (under and over-excited operation)
  - Over Excitation Limiter (OEL) and Over Excitation Trip (OEP)
  - Under Excitation Limiter (UEL) and Minimum Excitation Trip (MEP)
  - System Steady-State Stability Limit (SSSL)
  - Zone 1 and 2 of Loss of Field Protection (40)
- The Steady State Stability Limit (SSSL) is the limit to synchronous stability in the under-excited region with fixed field current. It can be calculated using generator reactance parameters and system impedances.

NERC PRC-024-1

Standard PRC-024-1 — Generator Frequency and Voltage Protective Relay Settings

A. Introduction

1. **Title:** Generator Frequency and Voltage Protective Relay Settings
2. **Number:** **PRC-024-1**
3. **Purpose:** Ensure Generator Owners set their generator protective relays such that generating units remain connected during defined frequency and voltage excursions.
4. **Applicability:**

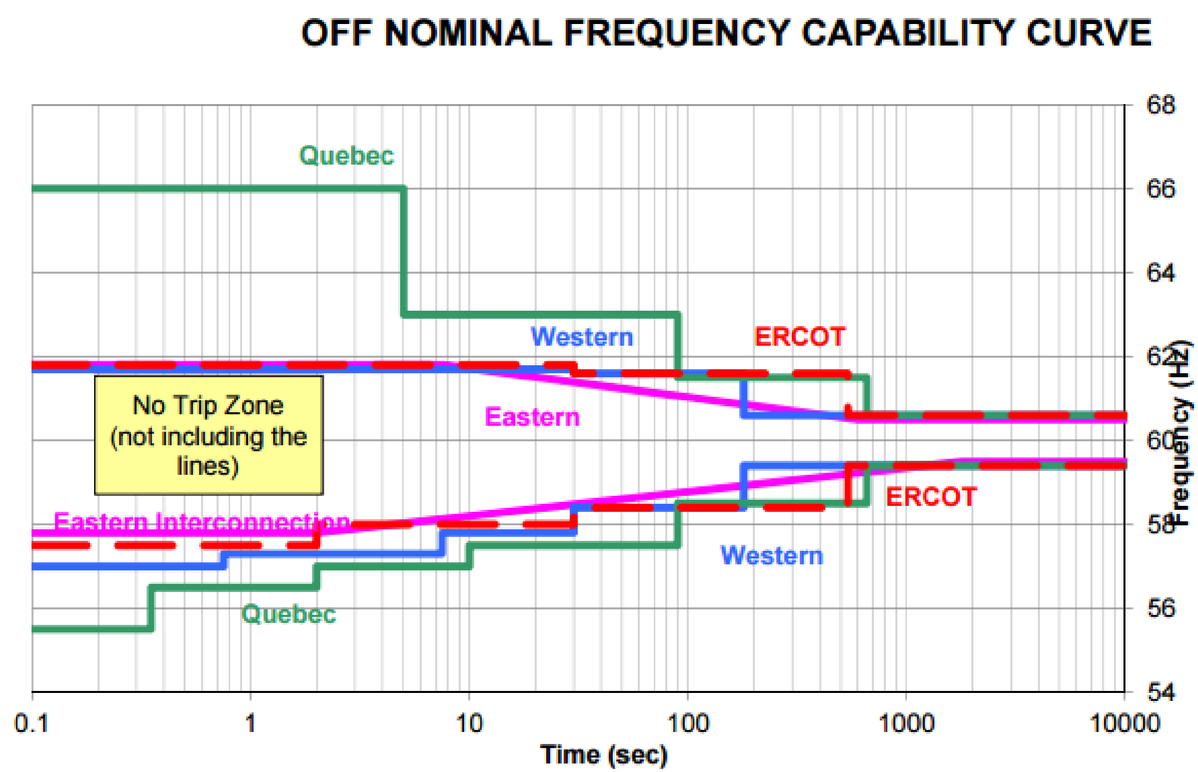
   4.1. Generator Owner

GERS

NERC PRC-024-1

Standard PRC-024-1 — Generator Frequency and Voltage Protective Relay Settings

PRC-024 — Attachment 1

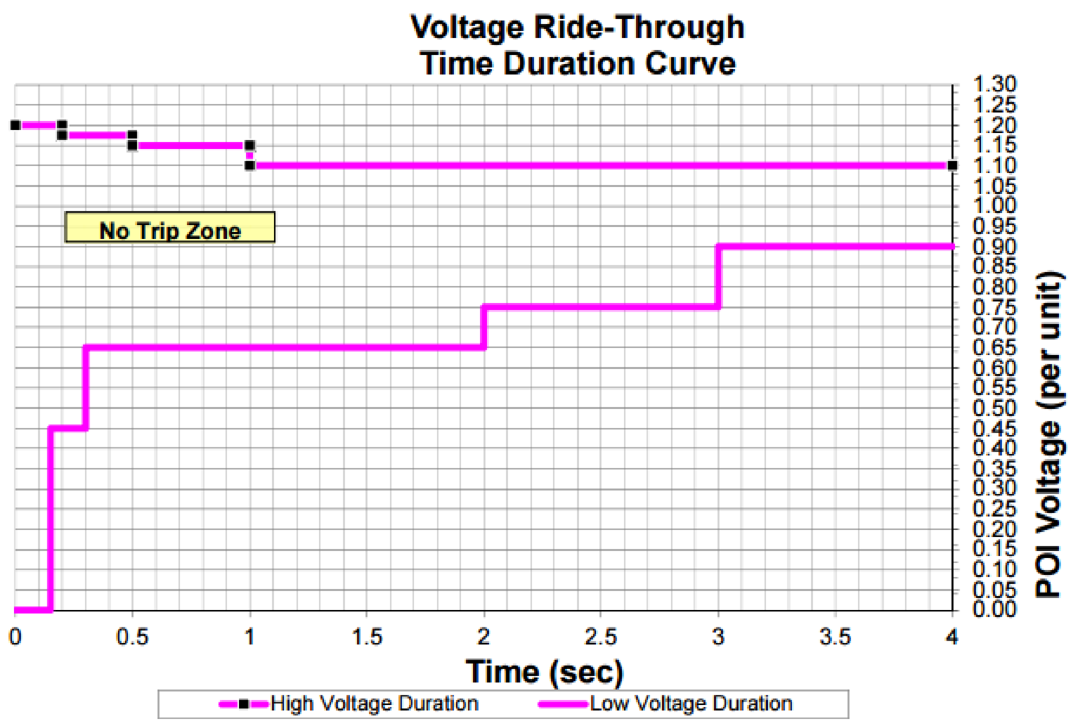


GERS

NERC PRC-024-1

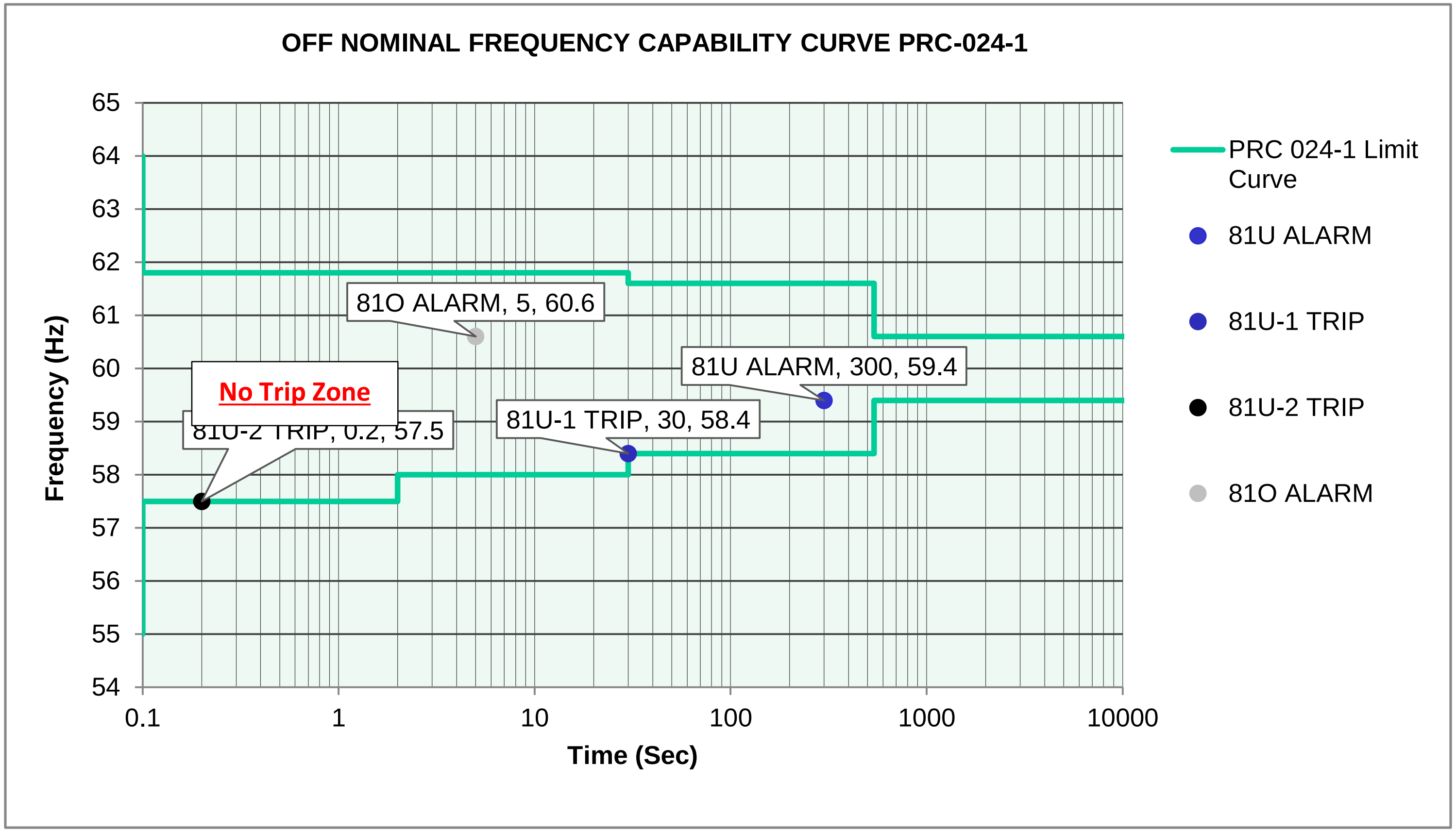
Standard PRC-024-1 — Generator Frequency and Voltage Protective Relay Settings

PRC-024— Attachment 2



GERS

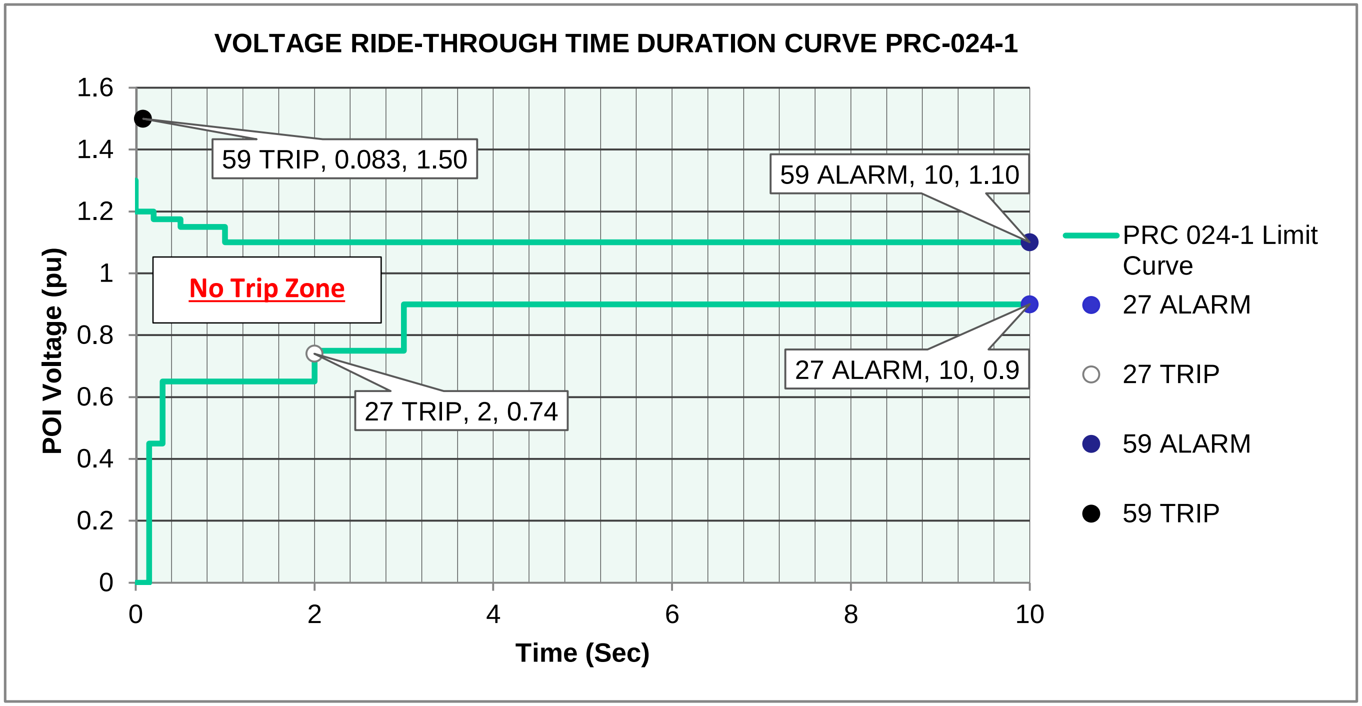
NERC PRC-024-1 – Case Study



Graphical Verification of Coordination per Standard PRC-024-1 – Frequency (ERCOT Interconnection)

GERS

NERC PRC-024-1 – Case Study



Graphical Verification of Coordination per Standard PRC-024-1 - Voltage

NERC PRC-025-1

PRC-025-1— Generator Relay Loadability

A. Introduction

1. **Title:** **Generator Relay Loadability**

2. **Number:** **PRC-025-1**

Purpose: To set load-responsive protective relays associated with generation Facilities at a level to prevent unnecessary tripping of generators during a system disturbance for conditions that do not pose a risk of damage to the associated equipment.

GERS

NERC PRC-025-1

Example Calculations: Option 1a

$$Z_{sec} = 0.321\angle 58.7°\ \Omega \times \frac{\frac{25000}{5}}{\frac{200}{1}}$$

$$Z_{sec} = 0.321\angle 58.7°\ \Omega \times 25$$

$$Z_{sec} = 8.035\angle 58.7°\ \Omega$$

To satisfy the 115% margin in Option 1a:

Eq. (7) $$Z_{sec\,limit} = \frac{Z_{sec}}{115\%}$$

$$Z_{sec\,limit} = \frac{8.035\angle 58.7°\ \Omega}{1.15}$$

$$Z_{sec\,limit} = 6.9873\angle 58.7°\ \Omega$$

$$\theta_{transient\ load\ angle} = 58.7°$$

NERC PRC-026-1

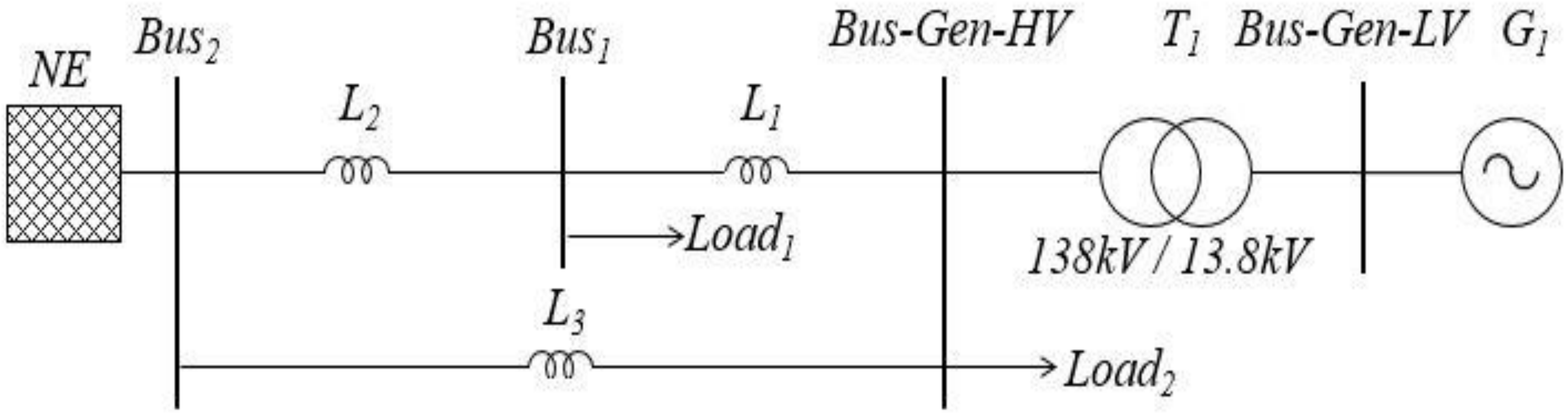
PRC-026-1 — Relay Performance During Stable Power Swings

A. Introduction

1. **Title:** **Relay Performance During Stable Power Swings**
2. **Number:** **PRC-026-1**
3. **Purpose:** To ensure that load-responsive protective relays are expected to not trip in response to stable power swings during non-Fault conditions.

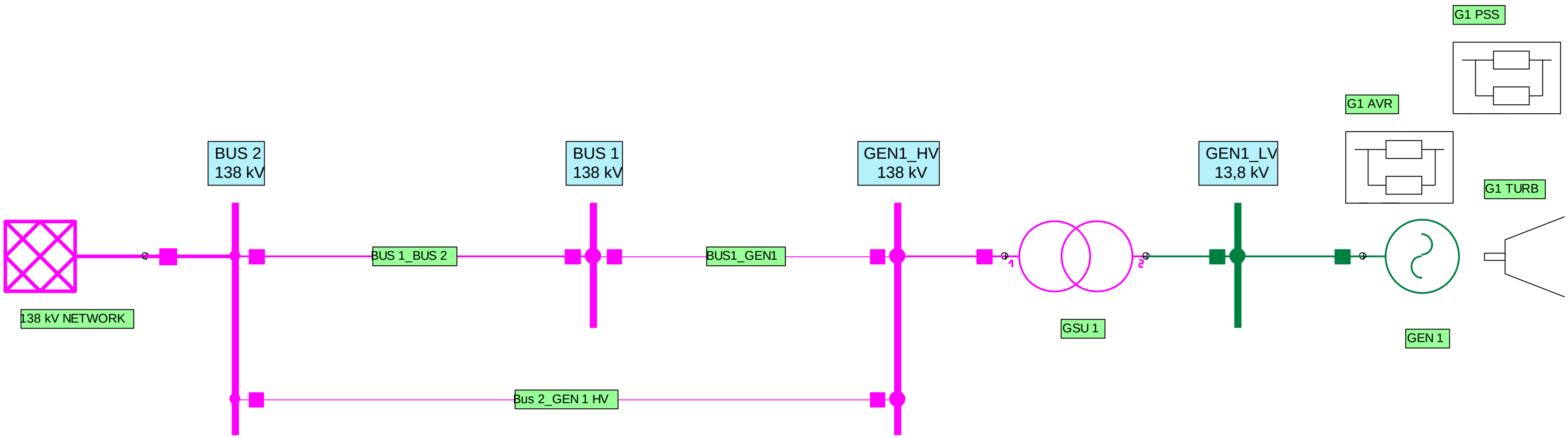
GERS

Case Example - Single line drawing



GERS

Case Example Modeling



Case Example Data

System Data

Equivalent System	Data
3 Phase Short Circuit	2.19 kA
Rated Voltage	138 kV
Xs	35.245 Ohm
Rs	9.022 Ohm

Generator Data

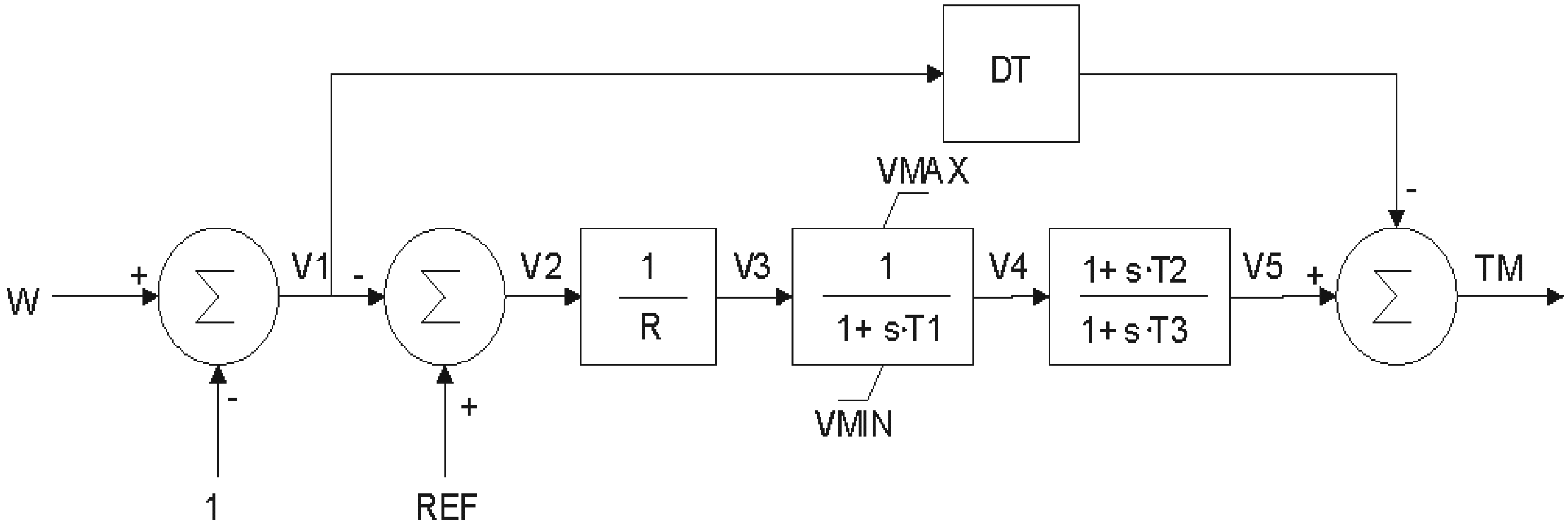
Generator	Data
Rated Power	101.8 MVA
Rated Current	4259
Xd”	11.7 %
Xd´	16.3 %
Xd	198 %
Turbine	TGOV1
AVR	IEEE T1
PSS	IEEE PSS 1A
Turbine	TGOV1
AVR	IEEE T1
PSS	IEEE PSS 1A

Transformer Data

Transformer	Data
Rated Power	100 MVA
Voltage	138/13.8 kV
Xt	9.27 %

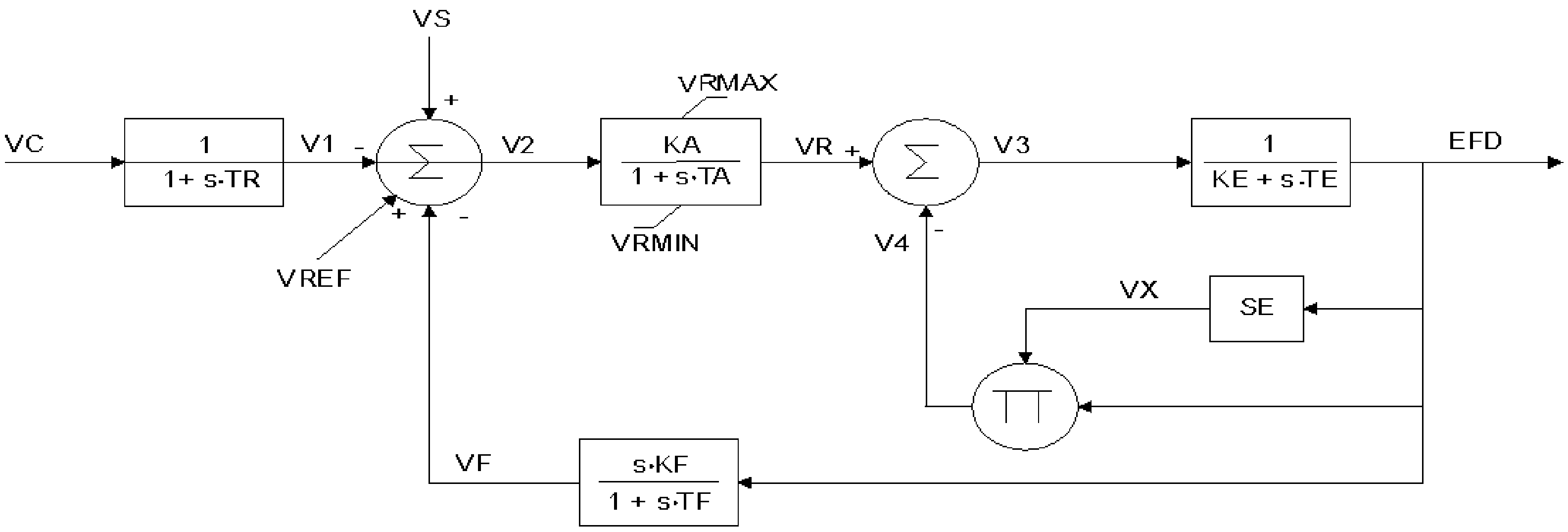
GERS

Governor Control



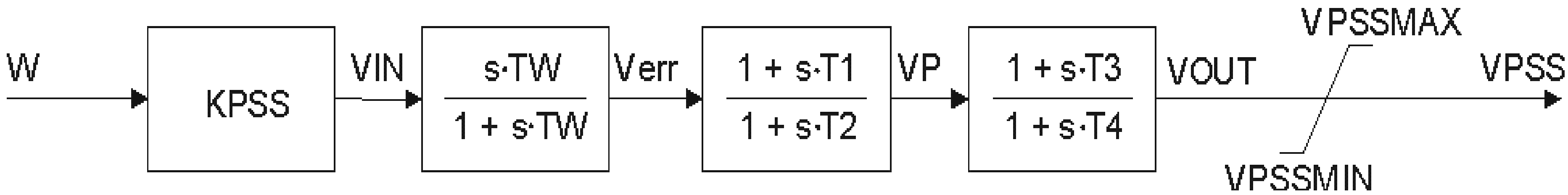
The governor control model is TGOV1

AVR Control



The AVR control System is IEEET1

PSS Control



The PSS control System corresponds to IEEE PSS1A

GERS

Stability Runs

NEPLAN - [Results Dynamic Simulation]

File Edit Format Grid Settings View Window Help

Variants	State
Illustrative Example J13.n...	
Rootnet	Checke...
Without Cont...	

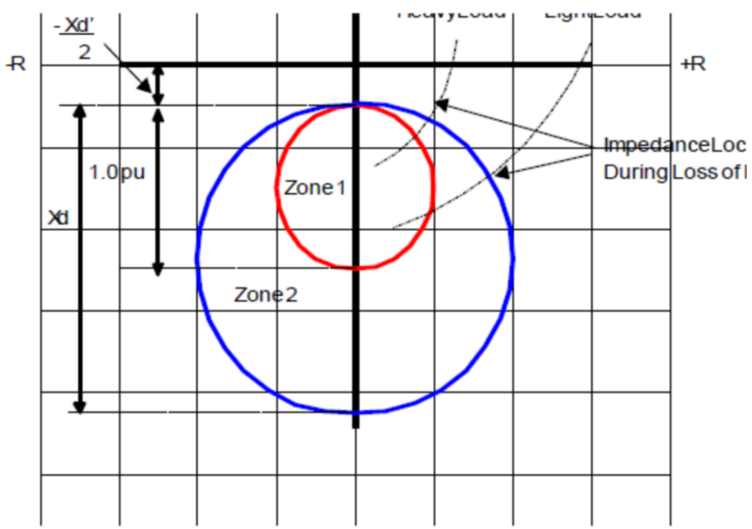
Variants | Diagrams | All Elements | Elements

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Time	VT	W	VT	W	VT	W	VT	W	ROTORANG	P1	Q1	R	X	R	X
2		BUS 1	BUS 1	BUS 2	BUS 2	GEN1_HV	GEN1_HV	GEN1_LV	GEN1_LV	GEN 1	GEN 1	GEN 1	GEN 1	GEN 1	GSU 1	GSU 1
3	0	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
4	0.005	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
5	0.01	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
6	0.015	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
7	0.02	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
8	0.025	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
9	0.03	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
10	0.035	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
11	0.04	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
12	0.045	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
13	0.05	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
14	0.055	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
15	0.06	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
16	0.065	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
17	0.07	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
18	0.075	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
19	0.08	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
20	0.085	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
21	0.09	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
22	0.095	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
23	0.1	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
24	0.105	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
25	0.11	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
26	0.115	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
27	0.12	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
28	0.125	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
29	0.13	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
30	0.135	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
31	0.14	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
32	0.145	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
33	0.15	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
34	0.155	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
35	0.16	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
36	0.165	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
37	0.17	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
38	0.175	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
39	0.18	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
40	0.185	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
41	0.19	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
42	0.195	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
43	0.2	0.941174126	60	1	60	0.973520363	60	1.02	60	38.07213978	98	53.42568538	1.558567704	0.849668855	1.558567704	0.849668855
44	0.205	0.854711959	59.93095459	0.973350980	59.97217266	0.849411805	59.89709990	0.843084989	59.81977126	38.14369433	23.46540013	-5.67187013	5.487549638	-1.66878968	5.487549638	-1.66878968
45	0.21	0.849954623	59.93025859	0.971851862	59.97196074	0.842582271	59.89596646	0.833312412	59.81721394	38.36394275	20.11415345	-8.47117423	5.569222548	-2.39787032	5.569222548	-2.39787032
46	0.215	0.846890356	59.93172699	0.970860715	59.97256557	0.838150135	59.89802031	0.826780315	59.81995758	38.75472341	18.55435279	-10.2918791	5.325911322	-2.98424980	5.325911322	-2.98424980
47	0.22	0.844042977	59.93372275	0.969930064	59.97335506	0.834013195	59.90084418	0.820581884	59.82392508	39.23088850	17.33389714	-12.0559336	4.983966267	-3.46717720	4.983966267	-3.46717720
48	0.225	0.841573090	59.93677169	0.969101745	59.97450665	0.830382902	59.90520564	0.814913088	59.83032190	39.90163976	16.77116632	-13.7631307	4.505414872	-3.69251895	4.505414872	-3.69251895

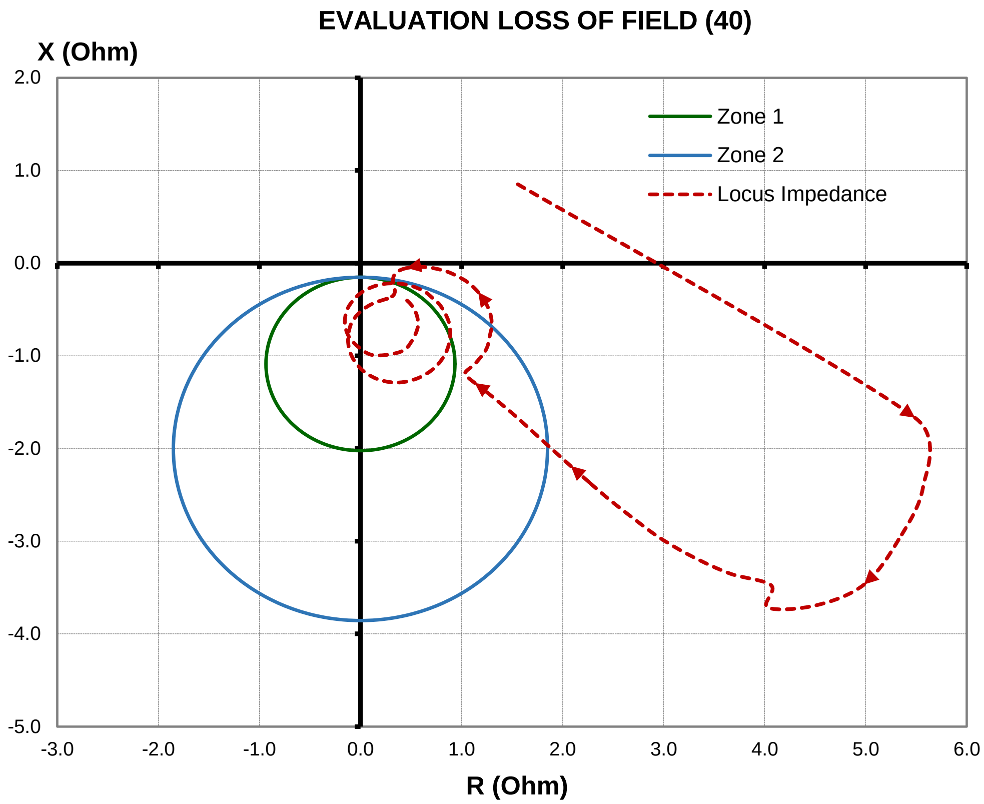
```
Assigning initial values to blocks .........completed
Simulation started
  Number of dynamic states = 56
  Number of algebraic states = 347
  Checking of the model limits succeeded
  Time            model                             parameter          changed to
  ----            -----                             ---------          ----------
  0.200000        GEN 1 (ID=1229744593)             ExcitationON       0.000000   R=0.000000 X=0.000000
Simulation done in 14.210000 seconds
Dynamic analysis done in 15.880000 seconds
```

Calculation of Function 40 Settings

Impedance Characteristic			
	Setting	Un	Criterion
Characteristic 1			
Diameter 1 (Ohm) primary	1.87	ohm	1.0 pu
Offset1 (Ohm) primary	0.15	ohm	Xd' / 2
Center 1 (Ohm) primary	1.09	ohm	
Time 1 (s)	0.5	s	
Characteristic 2			
Diameter 2 (Ohm) primary	3.70	ohm	
Offset2 (Ohm) primary	0.15	ohm	Xd' / 2
Center 2 (Ohm) primary	2.00	ohm	
Time 2 (s)	1.0	s	
Reduction Factor Characteristic 2	1.00		
Generator Data			
S base (MVA)	101.8		
Vbase (kV)	13.8		
Xd (%)	198.0%		
Xd' (%)	16.3%		
Z.base gen (Ohm) (1.0 pu)	1.87		
Xd (Ohm)	3.70		
Xd' (Ohm)	0.30		



Calculation of Function 40 Settings



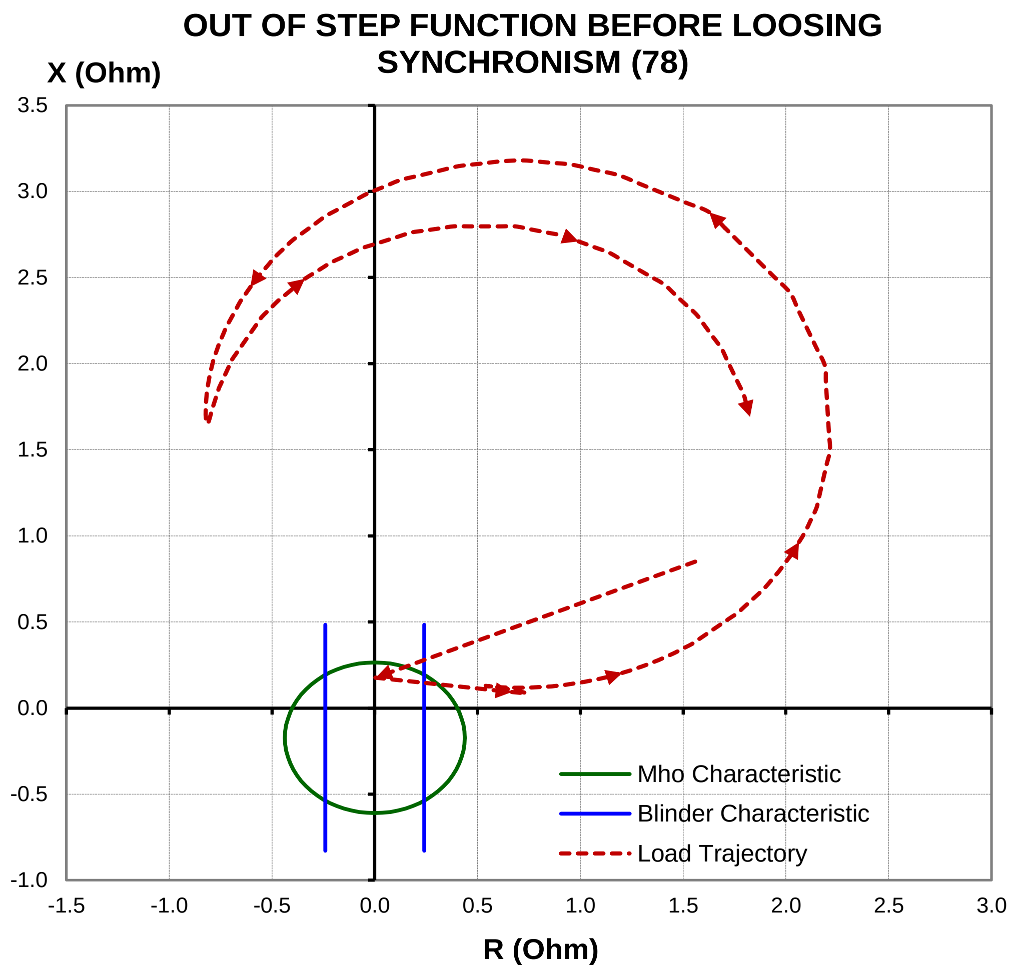
Characteristic 1	X	Y
Center	0.00	-1.09
Radius	0.94	
Characteristic 2		
Center	0.00	-2.00
Radius	1.85	

	Zone 1		Zone 2		Locus Impedance		
Angle	X	Y	X	Y	time	X(R)	Y(X)
0	0.935	-1.088	1.852	-2.004	0.000	1.559	0.850
5	0.932	-1.006	1.845	-1.843	0.005	1.559	0.850
10	0.921	-0.925	1.824	-1.683	0.010	1.559	0.850
15	0.903	-0.846	1.789	-1.525	0.015	1.559	0.850
20	0.879	-0.768	1.740	-1.371	0.020	1.559	0.850
25	0.848	-0.693	1.678	-1.222	0.025	1.559	0.850
30	0.810	-0.620	1.604	-1.078	0.030	1.559	0.850
35	0.766	-0.551	1.517	-0.942	0.035	1.559	0.850
40	0.717	-0.487	1.419	-0.814	0.040	1.559	0.850
45	0.661	-0.426	1.310	-0.695	0.045	1.559	0.850
50	0.601	-0.371	1.190	-0.586	0.050	1.559	0.850
55	0.537	-0.322	1.062	-0.487	0.055	1.559	0.850
60	0.468	-0.278	0.926	-0.401	0.060	1.559	0.850
65	0.395	-0.240	0.783	-0.326	0.065	1.559	0.850
70	0.320	-0.209	0.633	-0.264	0.070	1.559	0.850
75	0.242	-0.184	0.479	-0.216	0.075	1.559	0.850
80	0.162	-0.167	0.322	-0.181	0.080	1.559	0.850

GERS

Calculation of Function 78 Settings

Case 1: Before losing synchronism



Mho Characteristic

	X	Y
Center	0.000	-0.173
Radius	0.437	
Forward	0.265	
Reverse	0.610	

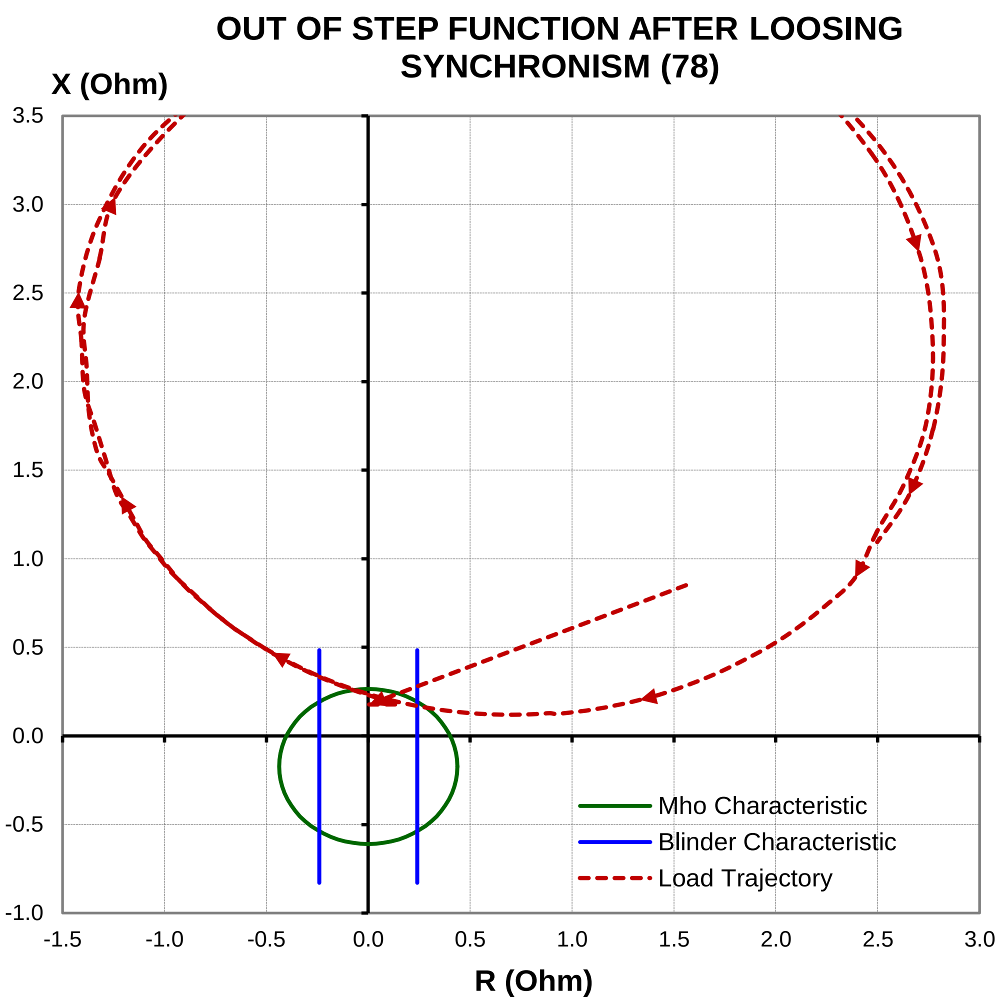
Blinder Characteristic

	d	l
	0.241	0.656
Angle	90	
Offset	0.000	

	Mho Characteristic		Blinder Characteristic		Load Trajectory		
Angle	X	Y	X	Y	t	X(R)	Y(X)
0	0.437	-0.173	0.241	0.483	0.000	1.559	0.850
5	0.436	-0.134	0.241	-0.829	0.001	1.559	0.850
10	0.431	-0.097			0.002	1.559	0.850
15	0.422	-0.059	-0.241	0.483	0.003	1.559	0.850
20	0.411	-0.023	-0.241	-0.829	0.004	1.559	0.850
25	0.396	0.012			0.005	1.559	0.850
30	0.379	0.046			0.006	1.559	0.850
35	0.358	0.078			0.007	1.559	0.850
40	0.335	0.109			0.008	1.559	0.850
45	0.309	0.137			0.009	1.559	0.850
50	0.281	0.162			0.010	1.559	0.850
55	0.251	0.186			0.011	1.559	0.850
60	0.219	0.206			0.012	1.559	0.850
65	0.185	0.224			0.013	1.559	0.850
70	0.150	0.238			0.014	1.559	0.850
75	0.113	0.250			0.015	1.559	0.850
80	0.076	0.258			0.016	1.559	0.850
85	0.038	0.263			0.017	1.559	0.850
90	0.000	0.265			0.018	1.559	0.850
95	-0.038	0.263			0.019	1.559	0.850

Calculation of Function 78 Settings

Case 2: After losing synchronism



Mho Characteristic

	X	Y
Center	0.000	-0.173
Radius	0.437	
Forward	0.265	
Reverse	0.610	

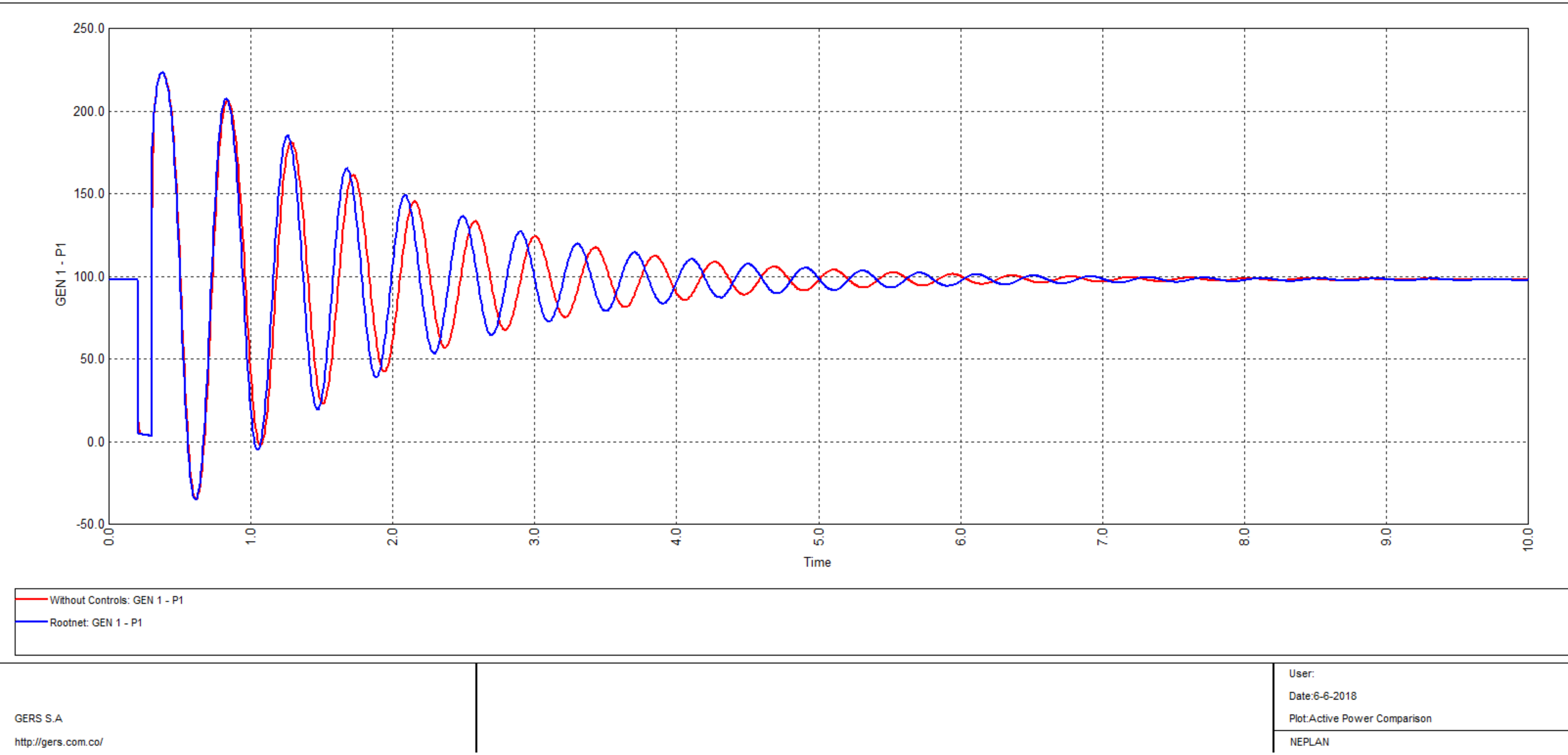
Blinder Characteristic

	d	l
	0.241	0.656
Angle	90	
Offset	0.000	

Mho Characteristic			Blinder Characteristic		Load Trajectory		
Angle	X	Y	X	Y	t	X(R)	Y(X)
0	0.437	-0.173	0.241	0.483	0.000	1.559	0.850
5	0.436	-0.134	0.241	-0.829	0.001	1.559	0.850
10	0.431	-0.097			0.002	1.559	0.850
15	0.422	-0.059	-0.241	0.483	0.003	1.559	0.850
20	0.411	-0.023	-0.241	-0.829	0.004	1.559	0.850
25	0.396	0.012			0.005	1.559	0.850
30	0.379	0.046			0.006	1.559	0.850
35	0.358	0.078			0.007	1.559	0.850
40	0.335	0.109			0.008	1.559	0.850
45	0.309	0.137			0.009	1.559	0.850
50	0.281	0.162			0.010	1.559	0.850
55	0.251	0.186			0.011	1.559	0.850
60	0.219	0.206			0.012	1.559	0.850
65	0.185	0.224			0.013	1.559	0.850
70	0.150	0.238			0.014	1.559	0.850
75	0.113	0.250			0.015	1.559	0.850
80	0.076	0.258			0.016	1.559	0.850
85	0.038	0.263			0.017	1.559	0.850
90	0.000	0.265			0.018	1.559	0.850
95	-0.038	0.263			0.019	1.559	0.850

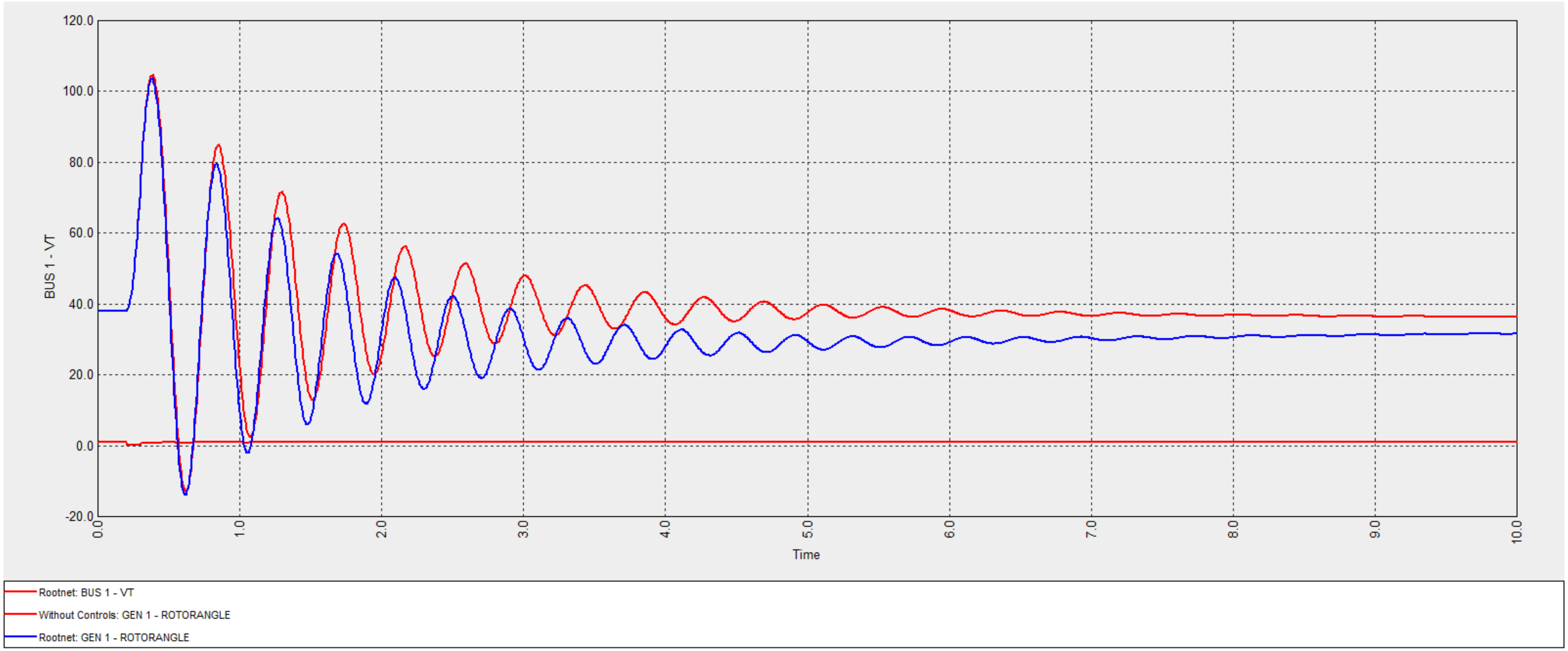
GERS

Power comparison before losing synchronism



The active power recovers faster thanks to the controls

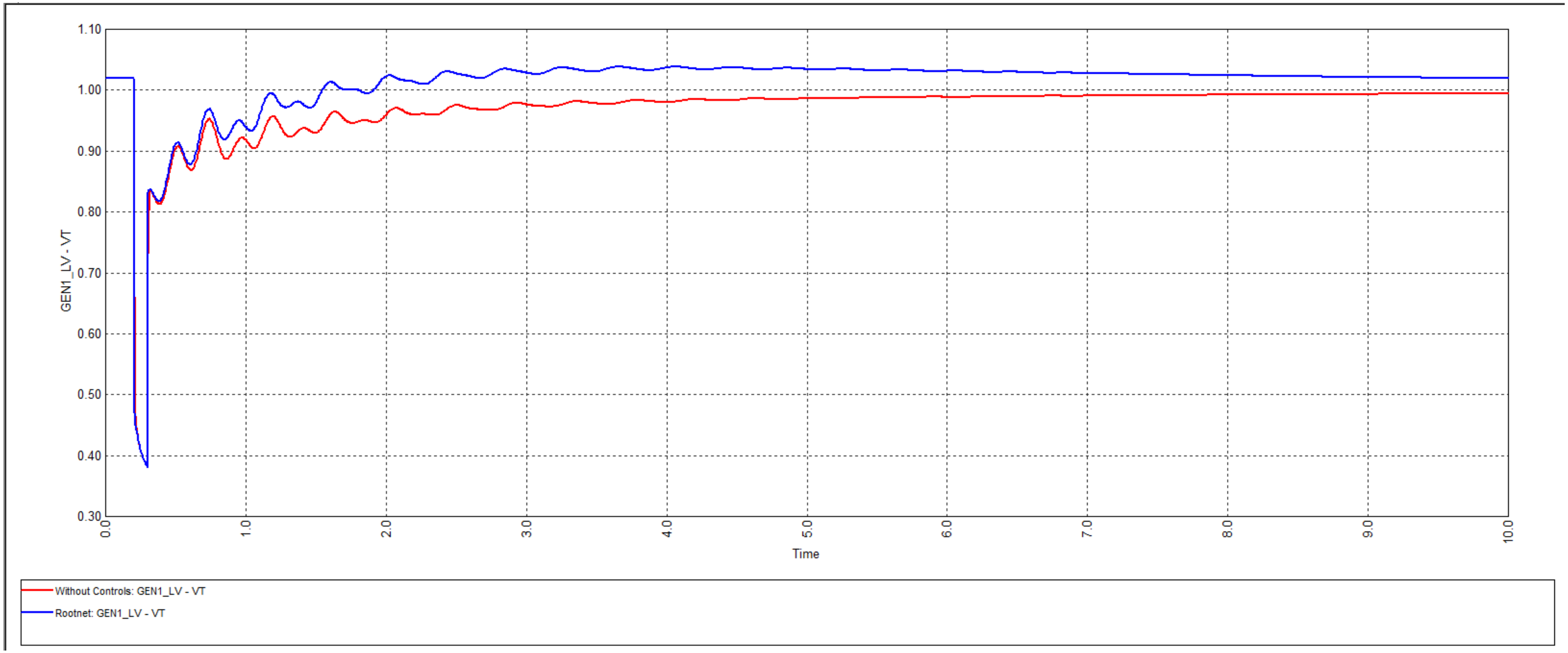
Angle comparison before losing synchronism



The angle adjusts to a different value thanks to the controls

GERS

Voltage comparison before losing synchronism



The voltage recovers the initial value thanks to the controls

GERS

Calculation of Function 78 Settings

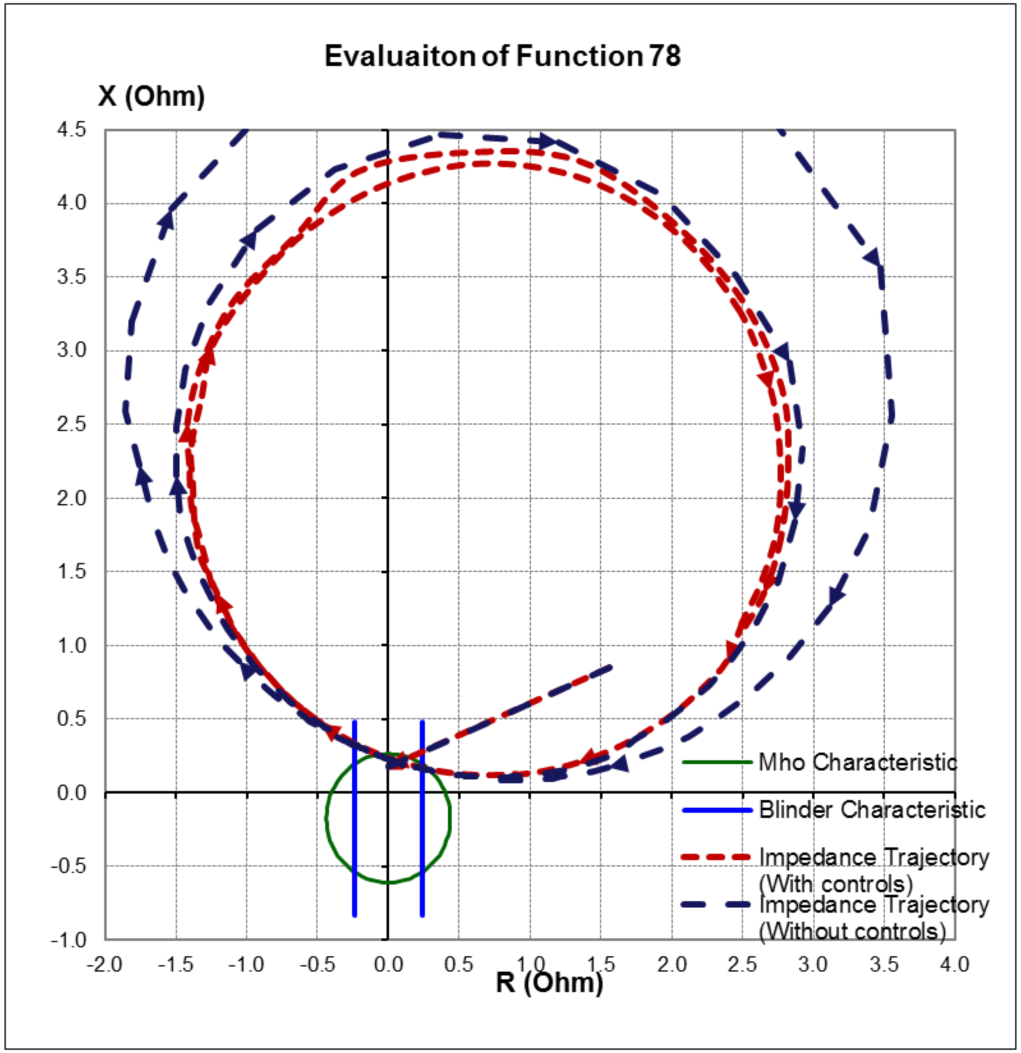
After losing synchronism with and without controls

Mho Characteristic		
	X	Y
Center	0.000	-0.173
Radio	0.437	
Forward	0.265	
Reverse	0.610	
Blinder Characteristic		
	d	l
	0.241	0.656
Angle	90	
Offset	0.000	

Mho Characteristic			Blinder Characteristic		Impedance Trajectory (With controls)			Impedance Trajectory (Without controls)		
Angle	X	Y	X	Y	t	X(R)	Y(X)	t	X(R)	Y(X)
0	0.437	-0.173	0.241	0.483	0.000	1.559	0.850	0.000	1.559	0.850
5	0.436	-0.134	0.241	-0.829	0.001	1.559	0.850	0.001	1.559	0.850
10	0.431	-0.097			0.002	1.559	0.850	0.002	1.559	0.850
15	0.422	-0.059	-0.241	0.483	0.003	1.559	0.850	0.003	1.559	0.850
20	0.411	-0.023	-0.241	-0.829	0.004	1.559	0.850	0.004	1.559	0.850
25	0.396	0.012			0.005	1.559	0.850	0.005	1.559	0.850
30	0.379	0.046			0.006	1.559	0.850	0.006	1.559	0.850
35	0.358	0.078			0.007	1.559	0.850	0.007	1.559	0.850
40	0.335	0.109			0.008	1.559	0.850	0.008	1.559	0.850
45	0.309	0.137			0.009	1.559	0.850	0.009	1.559	0.850
50	0.281	0.162			0.010	1.559	0.850	0.010	1.559	0.850
55	0.251	0.186			0.011	1.559	0.850	0.011	1.559	0.850
60	0.219	0.206			0.012	1.559	0.850	0.012	1.559	0.850
65	0.185	0.224			0.013	1.559	0.850	0.013	1.559	0.850
70	0.150	0.238			0.014	1.559	0.850	0.014	1.559	0.850
75	0.113	0.250			0.015	1.559	0.850	0.015	1.559	0.850
80	0.076	0.258			0.016	1.559	0.850	0.016	1.559	0.850
85	0.038	0.263			0.017	1.559	0.850	0.017	1.559	0.850
90	0.000	0.265			0.018	1.559	0.850	0.018	1.559	0.850
95	-0.038	0.263			0.019	1.559	0.850	0.019	1.559	0.850
100	-0.076	0.258			0.020	1.559	0.850	0.020	1.559	0.850
105	-0.113	0.250			0.021	1.559	0.850	0.021	1.559	0.850

Calculation of Function 78 Settings

After losing synchronism with and without controls



Conclusions

- The interaction of governor, AVR and PSS controls in the generators and protective relays strongly determine the stability of a power system.
- Modeling of dynamic of the power system and protection devices permit studying with depth those conditions that may affect the integrity of the power system.
- For stability simulation, the representation of generator protection is necessary.
- Computational collaboration of transient stability programs with specialized protective relay model software is possible.
- Relay models may be used to justify compliance with NERC standards (PRC-019, PRC-024, PRC-025, PRC-026, and others).
- Relay settings included in the models could be used to present graphical results of coordination of generator controls with loss of field, voltage, frequency and other generator protection functions.

GERS

Questions?