Circulating Currents in Parallel Generator Applications (Rev. A13)

Quantities are per unit percentage unless otherwise specified
All units assumed to have the same base voltage

Project data:

Project Name: Sample DPNL Simulation
Project Description: 2 x 800kW existing 0.8667 pitch, 1 x 800kW new 0.6667 pitch
Prepared by:
Date:

Comments:

Base Values:

Frequency:	60	Hz
Generator base voltage (L-L):	480	V
phase voltage (L-N):	**277**	V
Total kVA:	**3750.0**	kVA
Current:	**4510.5**	A (bus)

Similar pitch parallel machines ("Y" side)

	Ratings					
	Generator Pitch	**Power kW**	**PF**	**Apparent kVA**	**Voltage V**	**Current A**	**Z_base ohm**
Gen 1:	2/3	800	0.800	1000.0	480	**1202.8**	**0.2304**
Gen 3:							
Gen 5:							
Gen 7:							
Gen 9:							
Gen 11:							

	Reactances at fundamental frequency ("Y" side)											
	Zero Sequence X0				Negative Sequence X2				Subtransient X''d			
	Unsaturated		Saturated		Unsaturated		Saturated		Unsaturated		Saturated	
	%p.u.	ohm	%p.u.	ohm	%p.u.	ohm	%p.u.	ohm	%p.u.	ohm	%p.u.	ohm
Gen 1:	0.95%	**0.0022**	0.95%	**0.0022**	11.41%	**0.0263**	11.41%	**0.0263**	10.94%	**0.0252**	10.94%	**0.0252**
Gen 3:												
Gen 5:												
Gen 7:												
Gen 9:												
Gen 11:												
		0.0022		**0.0022**		**0.0263**		**0.0263**		**0.0252**		**0.0252**
3 x fund:		0.0066				0.0789				0.0756		

	Equivalent Reactances "Y" side			
	Unsaturated (X0+X2+X''d)/3		Saturated (X0+X2+X''d)/3	
	%p.u.	ohm	%p.u.	ohm
	7.77%	**0.0179**	7.77%	**0.0179**
at fund freq		**0.0179**	at fund freq	**0.0179**
at 3 x fund		0.0537	at 3 x fund	

Bus kVA:	**1000.0**	**kVA**
Isc:		**kA**
Isc_3Ph:		kA

SOURCE Calculation

Second set of similar pitch parallel machines or other Source (different than the above) ("Z" side). Only this side can be used as solidly grounded Utility Transformer!

	Ratings					
	Generator Pitch	**Power kW**	**PF**	**Apparent kVA**	**Voltage V**	**Current A**	**Z_base ohm**
Gen 2:	13/15	800	0.800	1000.0	480	**1202.8**	**0.2304**
Gen 4:	13/15	800	0.800	1000.0	480	**1202.8**	**0.2304**
Gen 6:							
Gen 8:							
Gen 10:							
Gen 12:							

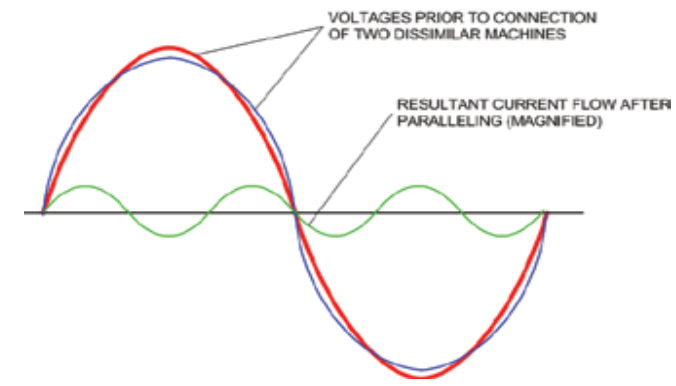
	Reactances at fundamental frequency ("Z" side)											
	Zero Sequence X0				Negative Sequence X2				Subtransient X''d (***)			
	Unsaturated		Saturated		Unsaturated		Saturated		Unsaturated		Saturated	
	%p.u.	ohm	%p.u.	ohm	%p.u.	ohm	%p.u.	ohm	%p.u.	ohm	%p.u.	ohm
Gen 2:	10.33%	**0.0238**	10.33%	**0.0238**	15.67%	**0.0361**	15.67%	**0.0361**	15.49%	**0.0357**	15.49%	**0.0357**
Gen 4:	10.33%	**0.0238**	10.33%	**0.0238**	15.67%	**0.0361**	15.67%	**0.0361**	15.49%	**0.0357**	15.49%	**0.0357**
Gen 6:												
Gen 8:												
Gen 10:												
Gen 12:												
		0.0119		**0.0119**		**0.0181**		**0.0181**		**0.0178**		**0.0178**
3 x fundamental:		0.0357				0.0542				0.0535		
("Y"||"Z"):		**0.0018**		**0.0018**		**0.0107**		**0.0107**		**0.0104**		**0.0104**
		0.0055				0.0321				0.0313		

(***) For Transormer as a parallel source the Subtransient Reactance value is used as the Positive-Sequence Reactance X1

Equivalent reactances "Z" side			
Unsaturated (X0+X2+X''d)/3		Saturated (X0+X2+X''d)/3	
%p.u.	ohm	%p.u.	ohm
13.83%	**0.0319**	13.83%	**0.0319**
13.83%	**0.0319**	13.83%	**0.0319**
at fund freq	**0.0159**	at fund freq	**0.0159**
at 3 x fund	0.0478	at 3 x fund	
Parallel imp:	**0.0077**	Parallel imp:	**0.0077**
at 3 x fund:	0.0230	at 3 x fund:	
	0.0084		**0.0084**
	0.0253		

Bus kVA:	**2000.0**	**kVA**
Isc:		**kA**
Isc_3ph:		kA

When generators are paralleled, the voltages of the two machines are forced to the exact same magnitude at the point where they are connected to the paralleling bus.
Differences in instantaneous waveforms of electromotive force (emf) generated by the alternators will result in current flow from the machine with higher instantaneous emf to the machine(s) with lower instantaneous emf.
Voltage waveform lines cross each other three times in each half cycle, therefore the current generated appears as a triple of the fundamental frequency current (third-order harmonic).



Circulating Current Calculation

Assumption:
Select an instantaneous voltage difference that is estimated by generator manufacturer:
Instantaneous voltage difference is at 3 x fundamental:

Vg1 -Vg2 =	10	V	**3.6% [%p.u.]**	180 Hz

Circulating phase current at 3 x fundamental:

I_cir =	237	A

Circulating neutral current at 3 x fundamental:

I_cir_N =	710	A

DPNL Calculation

with application of GenLink DPNL

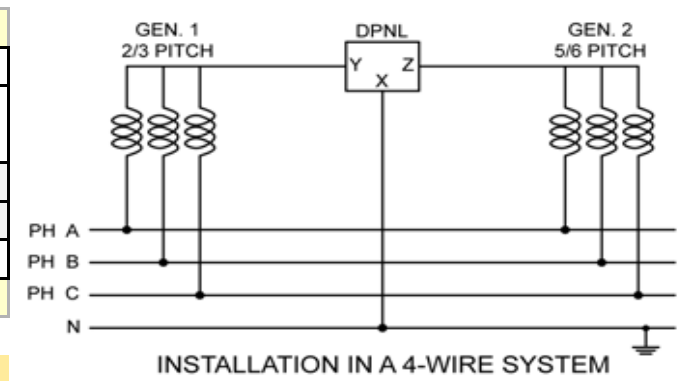
DPNL Ratings				"Shoulder"			"Circ. Path"
Voltage	Current A		Z_base	DPNL Zero-Seq X.yx			X.yz
V	Return	Circ.	ohm	mH	%p.u.	ohm	ohm
480	1500	750	**0.3695**	**0.044**	4.49%	**0.0166**	**0.0662**
					at 3 x fundamental:	**0.0498**	**0.20**
			DPNL saturation factor:	7	DPNL X_sat:	**0.0024**	

Circulating phase current with DPNL at 3 x fundamental:

I_cir = **15.7** A — 15.1 reduction

Circulating neutral current with DPNL at 3 x fundamental:

I_cir_dpnl = **47.0** A — 15.1 reduction



INSTALLATION IN A 4-WIRE SYSTEM

S_base =	3750	kVA	three-phase apparent power base
V_base =	480	V	line-to-line voltage base
I_base =	4510.5	A	current base
Z_base =	0.0614	ohm	impedance base

Fault Current Calculation for each side

No NGI:

	"Y" side				"Z" side				
Z_eq:	0.0179	ohm	0.29	p.u.	0.0159	ohm	0.26	p.u.	Equivalent impedance
X1_eq:	0.0252	ohm	0.41	p.u.	0.0178	ohm	0.29	p.u.	Equivalent positive-sequence reactance
3-ph fault (Isc_3ph):	10.99	kA	2.44	p.u.	15.53	kA	3.44	p.u.	Estimated 3-phase fault current
ground fault (**Isc**):	15.49	kA	3.43	p.u.	17.39	kA	3.86	p.u.	Estimated line-to-ground fault current

Fault Current Calculation of parallel sources

No NGI:

Z_eq:	0.0084	ohm	0.14	p.u. Equivalent impedance of parallel sources
X1_eq:	0.0104	ohm	0.17	p.u. Equivalent positive-sequence reactance of parallel sources

Three-phase fault is balanced, no negative- or zero-sequence current components are present

3-ph fault (Isc_3ph):	26.52	kA	5.88	p.u. Estimated 3-phase fault current at the generators terminals

Single-phase fault: all three positive-, negative-, and zero-sequence current components are present

ground fault (**Isc**):	32.88	kA	7.29	p.u. Estimated line-to-ground fault current at the generators terminals

(a) Solidly

Fault Current Calculation with DPNL

With DPNL:

	"Y" side				"Z" side				
Z_eq:	0.0250	ohm	0.41	p.u.	0.0230	ohm	0.38	p.u.	Equivalent impedance
X1_eq:	0.0252	ohm	0.41	p.u.	0.0178	ohm	0.29	p.u.	Equivalent positive-sequence reactance
3-ph fault (Isc_3ph):	10.99	kA	2.44	p.u.	15.53	kA	3.44	p.u.	Estimated 3-phase fault current
ground fault (**Isc**):	11.08	kA	2.46	p.u.	12.03	kA	2.67	p.u.	Estimated line-to-ground fault current

Fault Current Calculation of parallel sources with DPNL

with NGI

Z_eq:	0.0120	ohm	0.20	p.u. Equivalent impedance of parallel sources
X1_eq:	0.0104	ohm	0.17	p.u. Equivalent positive-sequence reactance of parallel sources

Three-phase fault is balanced, no negative- or zero-sequence current components are present

3-ph fault (Isc_3ph):	26.52	kA	5.88	p.u. Estimated 3-phase fault current at the generators terminals

Single-phase fault: all three positive-, negative-, and zero-sequence current components are present

ground fault (**Isc**):	23.11	kA	5.12	p.u. Estimated line-to-ground fault current at the generators terminals

Note: DPNL and/or NGI application does not affect three-phase fault.

Effective Grounding Calculation

No DPNL:	"Y" side	"Z" side		
X_1:	0.0252	0.0178	ohm	sub-transient reactance of the generator
X_0:	0.0022	0.0119	ohm	zero-sequence reactance of the generator
X_0/X_1 ratio:	0.0868	0.6669	< 3 ? is	effectively grounded

Individual NGI Effective Grounding Calculation

With NGI in each generator neutral:

X_1:	0.0252	0.0178	ohm	sub-transient reactance of the generator
X_0 with NGI:	0.0232	0.0169	ohm	zero-sequence reactance of the generator with DPNL
max. allowable X_0:	0.0756	0.0535	ohm	maximum allowable zero-sequence reactance
X_0/X_1 ratio:	0.9201	0.9491	< 3 ? is	effectively grounded

DPNL Effective Grounding Calculation

With DPNL in the neutral:

X_1:	0.0252	0.0178	ohm	sub-transient reactance of the generator
X_0 with DPNL:	0.0046	0.0143	ohm	zero-sequence reactance of the generator with DPNL
max. allowable X_0:	0.0756	0.0535	ohm	maximum allowable zero-sequence reactance
X_0/X_1 ratio:	0.1808	0.7997	< 3 ? is	effectively grounded

DPNL + NGI Effective Grounding Calculation

With DPNL + NGI in the neutral:

X_1:	0.0252	0.0178	ohm	sub-transient reactance of the generator
X_0 with DPNL+NGI:	0.0022	0.0143	ohm	zero-sequence reactance of the generator with DPNL + NGI
max. allowable X_0:	0.0756	0.0535	ohm	maximum allowable zero-sequence reactance
X_0/X_1 ratio:	0.0868	0.80	< 3 ? is	effectively grounded