Eaton Presentation On Power System Grounding – Generator Grounding - Winding Pitch Factors, Hybrid Grounding

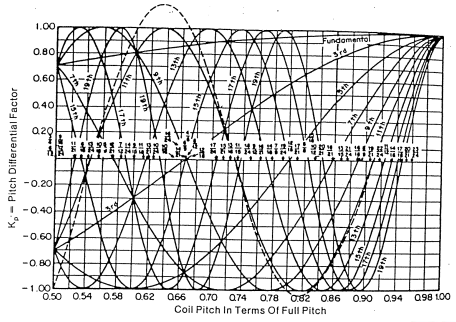
IEEE Nashville

Date: February 3, 2015

Synchronous Generators

- Harmonics – Are generated in the armature windings because flux in the air-gap is non-sinusoidal – especially with Salient Pole machines
- Methods to reduce Harmonics Generated
  - Distribution factor – some of the coils/phase in more than 1 slot
  - Pitch Factor – Each side of coil does not skip a complete pole.

Generator winding Pitch Factor Curve



Preventing Generator Harmonics

$$E_{harm} \cong 0$$

$$When..Winding..Pitch = 1 +/- \frac{1}{h}$$

Symmetrical Components - Harmonics

Harmonic Order Number	Sequence
1	+
2	-
3	0
4	+
5	-
6	0
7	+
8	-
9	0
10	+
11	-
12	0
13	+

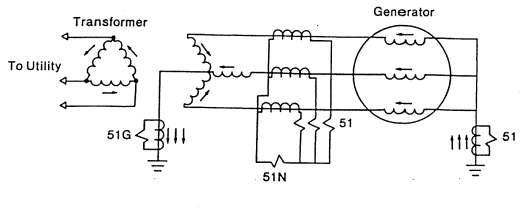
Preventing 3rd Harmonics

$$W.P. = 1 +/- \frac{1}{3} = \frac{2}{3} or \frac{4}{3}$$

$$Use..W.P. = \frac{2}{3}$$

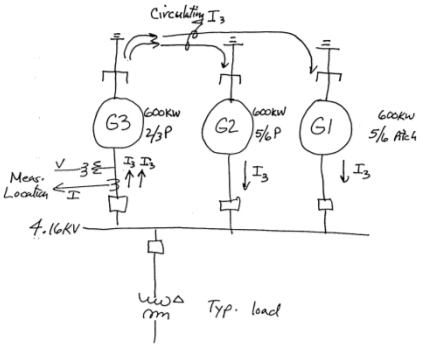
When W.P. = 2/3, X_o < Average

3rd Harmonic Current Flow

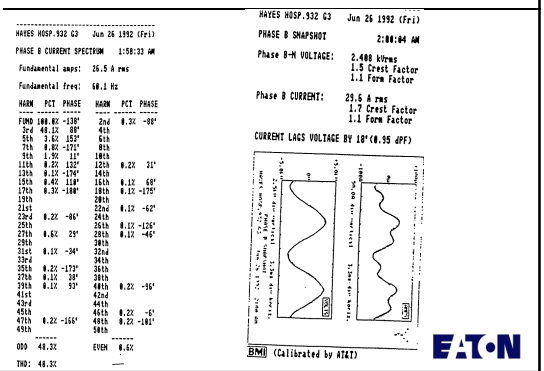


Heating Effect = $f(I_1^2 + I_3^2)$

Generator Circulating 3rd Harmonic Currents

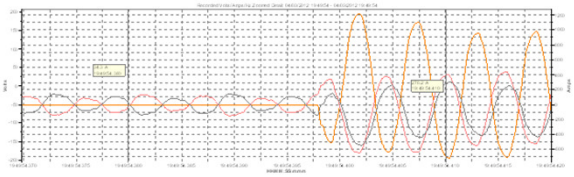


Generator Current Waveform



Pgh Hospital – G1/G2 – 5/6 Pitch G3 – 2/3 Pitch – Icirc Neutral Current

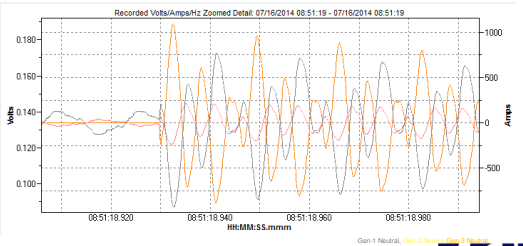
- G1 / G2 Running – then start G3 neutral Note Gen-3 is 180 degrees out of phase with g1 and G2 with twice the amplitude.



Casino – Without Harmonic Blocking Circuitry

Project Specific Power System Studies

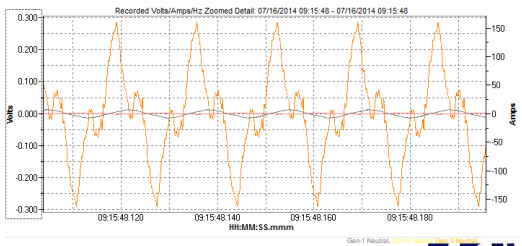
- The waveform below shows neutral current at the point when third generator with different winding pitch, 5/6 comes on line. Two 2/3 Pitch and one 5/6 pitch generators on line.



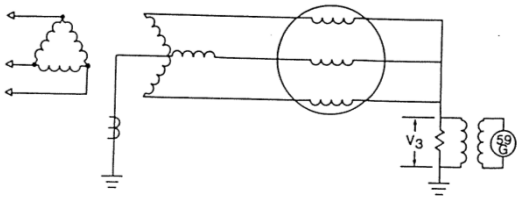
Casino – With Harmonic Blocking Circuitry

Project Specific Power System Studies

- The waveform below shows neutral current with harmonic blocking units engaged on Generators 1 and 2. Generator 3 is solidly grounded to feed single phase loads.



Blocking 3rd Harmonic Current Flow



Generator Ground Fault Currents

$$I_{gf} = 3I_0 = \frac{3E}{Z_1 + Z_2 + Z_0 + 3Z_n}$$

Sample Generator Igf Calculation

- 2500 kVA / 0.8 PF
- 480/277V – Solidly Grounded Neutral
- X"d = X_1=0.1378 p/u
- X_2 = 0.1335 p/u
- X_0 = 0.0098 p/u

Sample Generator Igf Calculation

$$Igf = \frac{3E}{j0.1378 + j0.1335 + j0.0095 + 3*0}$$

$$Igf = \frac{3}{j0.2808} = 10.684\,p/u$$

Sample Generator Calculation

- You Cannot brace Windings Mechanically for Greater than I 3ph S/C
- Compare Igf/I3ph

$$Ratio = \frac{I_{gf}}{I_{3ph}} = \frac{10.684}{7.256} = 1.47x$$

Generator Grounding

- You Should Limit the I_{gf} Magnitude to a Maximum of I_{3ph}
- Answer = Add External Grounding Reactor
- You Must Meet Transient Overvoltage Criterion X_o/X_1 less than or equal to 3.0 to Supply VLN Loads

Generator Grounding
Which Winding Pitch Factor Should You Specify?

- L.V. - - Must Approach Solid Grounded to Serve VLN Loads
- 1 Emergency Generator – Can Specify "Optimum Pitch = 5/6, 6/7, etc". No Chance for Circulating 3rds – Stand Alone
- Multiple Generators / Operate in Parallel with Utility = 2/3 Pitch with Grounding Reactor
- HRG - Your Choice

Generator Grounding
Which Winding Pitch Factor Should You Specify?

- M.V. – Should be LRG, HRG or HHRG Grounded
- Your Choice - 2/3 Pitch to Control Circulating 3rds not Required

Additional Complications

- Frequently, Igf is Greater than I3ph Short Circuit
- Generation Swgr Easily Can be overdutied for Ground Fault Conditions but not 3 Phase Short Circuits
- Have to Convert to Reactance Grounding, HRG or Increase Swgr S/C Ratings

LV Generator Grounding Questions

- Do you have circulating Ground Currents?
- Do your emergency Generators share load equally?
- Do you have to Curtail Load or Add Extra Generators on line to Supply Load?
- Do Your Generator Grd Flt Protection / Alarms Nuisance Operate?
- Have You Evaluated Your Emergency Swgr for SLG Interrupting Capacity?

FIG. 2 - Grounding Example - Typical Generator Ground Fault [Author = Powell]

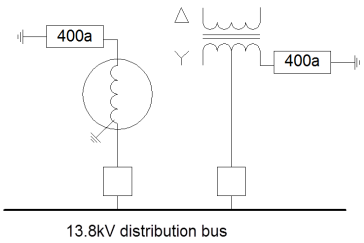
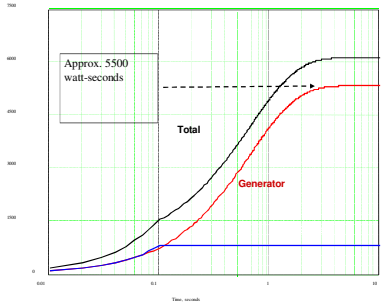
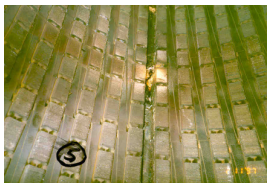


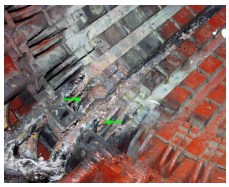
Figure 3: Watt-Second Fault Energy vs Time



Introduction – M.V. Generator Failures

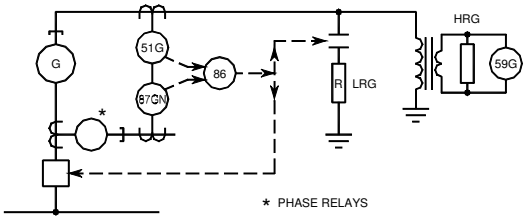
- LRG with Grd Flt.
- Ungrded + Arcing GF





MV GENERATOR SOLUTIONS – Hybrid High Resistance Grounded

- GEN. H. R. GROUNDED AND SYSTEM L. R. GROUNDED
  [Author=Shipp]



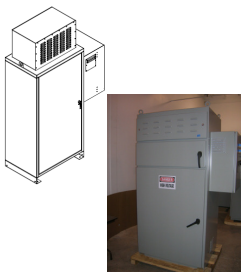
HHRG: Breaker Version

Mini – HHRG – Resistors at L.V.-Modular

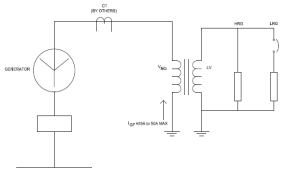
- HHRG Control Cab'nt
- HHRG Resistors

Mini – HHRG – Resistors at L.V. – Data Centers

Cabinet



Schematic



Typical Mini HHRG Applications

- Data Centers
- Large Embassies
- Hospitals
- Any Emergency System with Multiple Generators on 1 System at Medium Voltage
- LRG Typically 25A to 50A
- All Resistors and switching at LV
- HRG Component Under 10A's
- A Fix for Solidly Grded MV Emerg Gen Systems