Repair the Hydro Generator by Cutting Out Stator Winding Bars/Coils

IRMC-Iris Rotating Machine Conference

New Orleans, Louisiana, USA

May 06-09, 2019

Presented by:

Igor Chichkin, P.Eng

BC Hydro, Canada

BC Hydro
Power smart

Why generator stator winding fails?

- **Poor coil/bar manufacturing quality**
- **Poor coil/bar installation quality**
- **Winding stresses during generator operation**

Sources of stress in the machine that lead to stator winding deterioration :

- **Thermal** – heat generated by the working generator (thermal cycling)
- **Mechanical** – caused by machine vibration
- **Electrical** – caused by voltage stress
- **Chemical stresses** – caused by the breakdown of materials, insulation “glue” (epoxy resin) and other components over time.
- **Environmental factors**

Rarely does one factor work alone to cause a problem.

Temperature affect on Stator Coil/Bar

Found some similarities ?

BC Hydro
Power smart

Stator winding faults

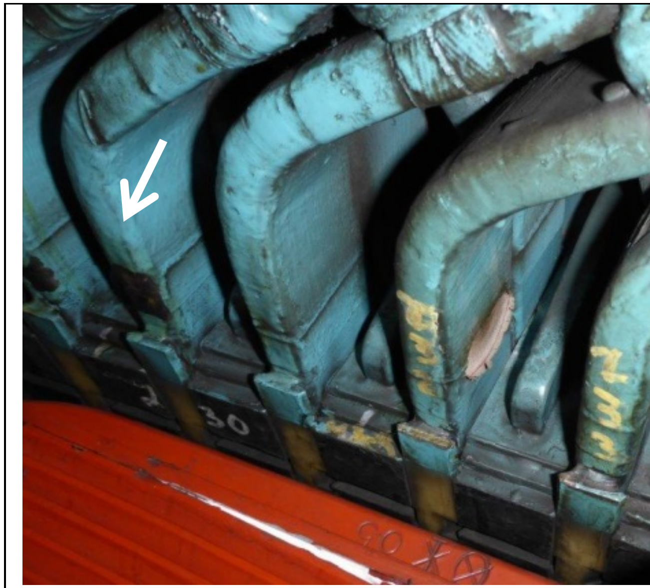
- ✓ **In service fault**
- ✓ **During off-line testing fault**

- **A section of groundwall insulation breaks down and conducts electrically under the operating voltage stress.**

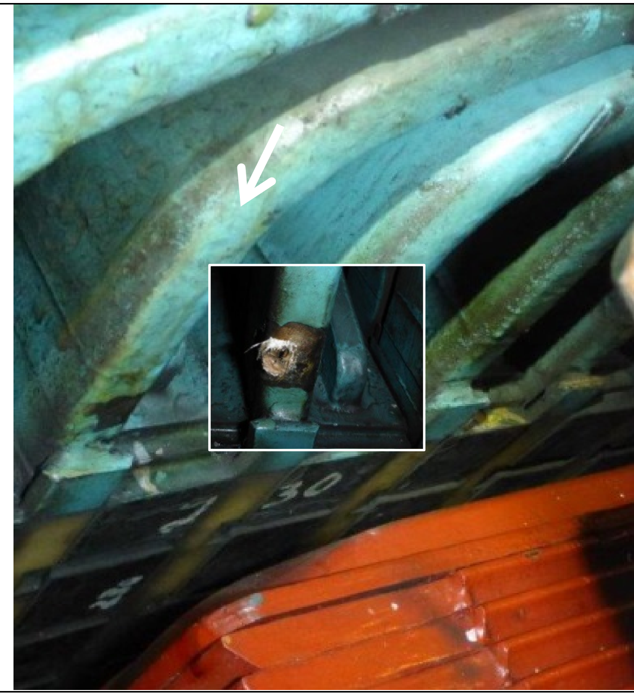
- **Insulation is usually permanently damaged due to electrical burning and tracking at the fault location.**

- **One of two (Conventional “ Smoke test” or “Non-destructive”) methods can be used to locate the faulty bar/coil depending on testing equipment availability and expertise.**

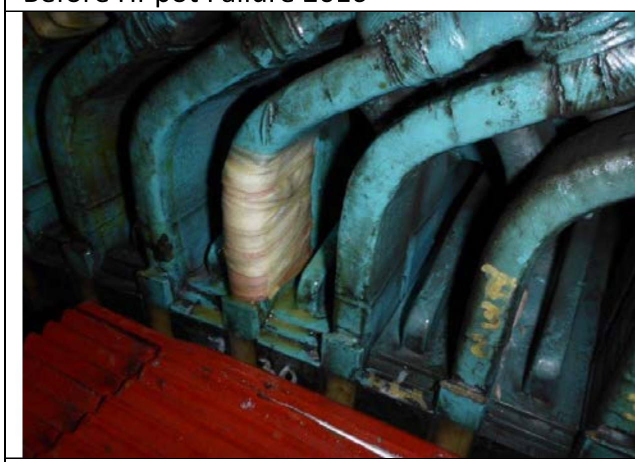
Stator winding faults (example)



Before Hi-pot Failure 2016



After Hi-pot Failure 2016

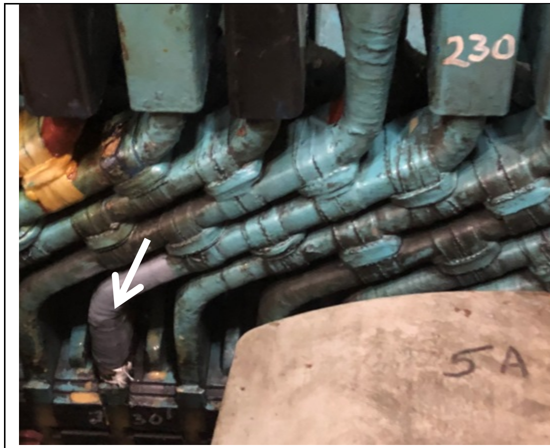


Tape re-insulated 2016

Semicon Gradient Paint 2016

BC Hydro
Power smart

Stator winding faults (example)



2018- As Found inspection (after Hi-pot failure)

Thumper

Thump Test - Flash over starting at bar 230F

Flashes over at bar 230F

Stator winding faults (example)

Removed end cap and brazed connection (Top & Bottom)

Isolated 230F to test for additional faulty bars. No additional faulty bars found.

Locating the Stator winding faults

- **Conventional " Smoke test" method may use high-voltage, high power AC/DC source equipment.**
  - **This may cause insulation or stator core damage adjacent to the fault site.**
- **"Non-destructive" methods may use low-power DC source to charge the winding and trace discharging transient currents as arc-down occurs at the fault site.**
  - **This may help to avoid burning the adjacent bars/coils or stator core iron at the fault site.**

For this test details you may refer to the following publication:

"A Non- Destructive Test Method Utilizing Transient Discharge Current For Locating Stator Winding Ground Faults in Large Synchronous Hydro-Generators and Motors ", by Philip L. Atwater and Eric P. Eastment ,IRMC, New Orleans, June 2004.

Locating the Stator winding faults

Ground faults in stator winding may be found by several methods

- Confirm that the ground fault relay operation was correct .
- Megger the stator winding 3 Ø and Single Ø (at 5,000 Vdc for 13.8-16 kV machines).
  - Before meggering, make sure all paths to ground are removed

    (such as PTs, neutral TRF, surge arresters, etc.)
  - Don’t rush to apply Hipot, Welder or <u>Thumper for bar winding</u> ,yet.
- If the fault is identified during the Megger ,perform stator winding visual inspection for obvious signs of “ground”.

Locating the Stator winding faults

- When problem phase is identified a **Variac** can be used to supply 5 amps to the fault by connecting it between the faulted phase group terminal and ground.
  - Energize only that part of the winding required.
  - Using a clamp-on AC ammeter (with large aperture) follow the current from the terminal through the ring bus ,through the winding (use winding diagram) until it disappears down one slot and does not leave the slot at the other end.
  - The slot into witch the current disappears is the slot with the faulty bar/coil.

BC Hydro
Power smart

Locating the Stator winding faults

Ground faults in stator winding may be found by several methods

- The tester has some other choices on which fault allocation method to follow.
  - If sufficient manpower is available to “watch and listen” the winding during the Welder or Thumper tests.
  - The Welder or cable Thumper for bar winding(*) may be applied when the fault location is generally known and attention can be focused to one area of the machine (in the stator slot, and quick application of Thumper can be made.
  - The danger of using this method is that high welder currents can cause stator core iron damage and increase repair time and cost.

(*) A cable Thumper test may be used in single turn winding ,i.e. "bars” vs multi-turn coils. Turn-to-turn induced voltages may damage turn insulation in coils.

CAUTION: High currents will induce voltages in other winding,e.g.in field when testing stators, so other windings should be shorted and grounded.

Cutting Out a Bar/Coil

- Now we must decide whether to cut the bar/coil out of the circuit :
  - Completely ?
  - or make a half coil repair ?
  - or make a complete bar/coil repair ?

- The simplest repair : cut the coil out of the circuit
  - This is perfectly safe if machine has many poles and coils connected single circuit and the unbalance in phase voltage would be small.

Cutting Out a Bar/Coil

- The next best repair, if it is a top coil side, is to cut out the top coil side and replace it with the new top coil side.

  - This could be done by removing two or three rotor poles , and splicing in a new top half ,carefully connecting strand to strand, insulating between strands, taping each group of strands forming a turn with a proper turn insulation and finally applying the ground insulation.

  - Sometime the rotor to be removed if the fault is in the bottom coil side. Lift the coil lap long enough to get the faulty coil, replace, drop the lap and reassemble.

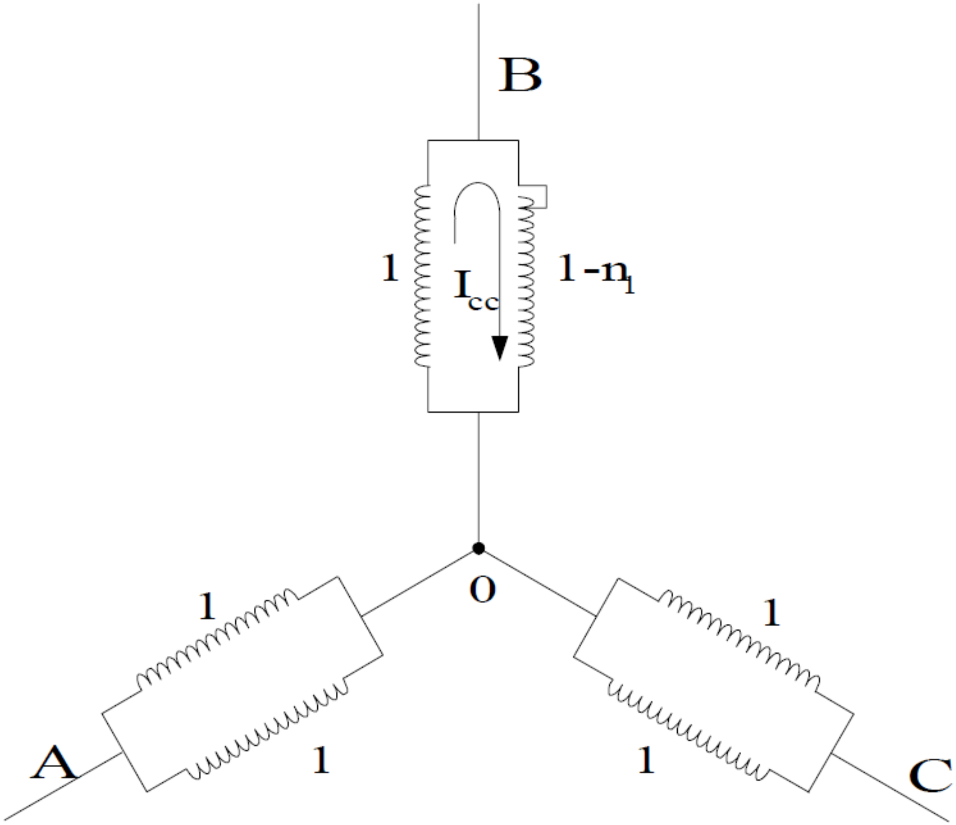
Cutting Out a Bar/Coil

- **Machine with many poles and parallel circuits** would have slight unbalance between parallel circuits ,causing circulating currents to flow between parallels and some extra heating.
  - The actual values would have to be calculated to determine the magnitude of unbalance before a decision could be properly made.

- If during the repair, the failed coil is cutout from one circuit, while the corresponding healthy coil <u>is not removed</u> from the second parallel circuit an unbalanced current is **circulating** between the two parallel circuits.

  - This current does not contribute to power generation; on the contrary, this current creates a probability of overheating, vibrations, etc.

Cutting Out a Bar/Coil



The effects of the cutout coil are dependent:

- on the type of machine and winding connection.

- In some cases, there is very little impact on operation, while in other cases, serious overheating has resulted.

Cutting Out a Bar/Coil

- The purpose of the unbalanced current calculation is to provide information for the Split Phase (SP) protection operating setting and to determine the permissible load of the generator, while under cutout coil conditions.

The calculation method is based on the EPRI Report "Synchronous Machine Operation with Cutout Coils" (EL-4983,1987).

BC Hydro
Power smart

Hydro Generator cut-out coils calculations EXAMPLE (*)

Hydro Generator	MVA	Voltage (kV)	Current (A)	Power Factor	RPM	Frequency (Hz)
Westinghouse Canada **(1958)**	**28**	**13.8**	**1171**	**0.9**	**514**	**60**
Phase	**Stator Winding Insulation Class**	**Total number of slots**	**Number of Poles**	**Parallels per phase**	**Coils per Parallel**	**Turn per Coil**
3	**B**	**162**	**14**	**2**	**27**	**3**

The generator tripped off line while in service by 64G neutral ground protection. Front coil in slot #7 (ph. A) had failed and was cut-out along with front coil # 87 (ph. A) to balance the winding.

(*) : *This is just an example to show the concept of calculations . Author of this presentation **is not responsible** for any errors or omissions, or for the results obtained from the use of this information".*

BC Hydro
Power smart

Hydro Generator cut-out coils calculations

Calculate the **coils removed per circuit (n_1), <u>per unit</u> :**

Total number of slots (S) : 162

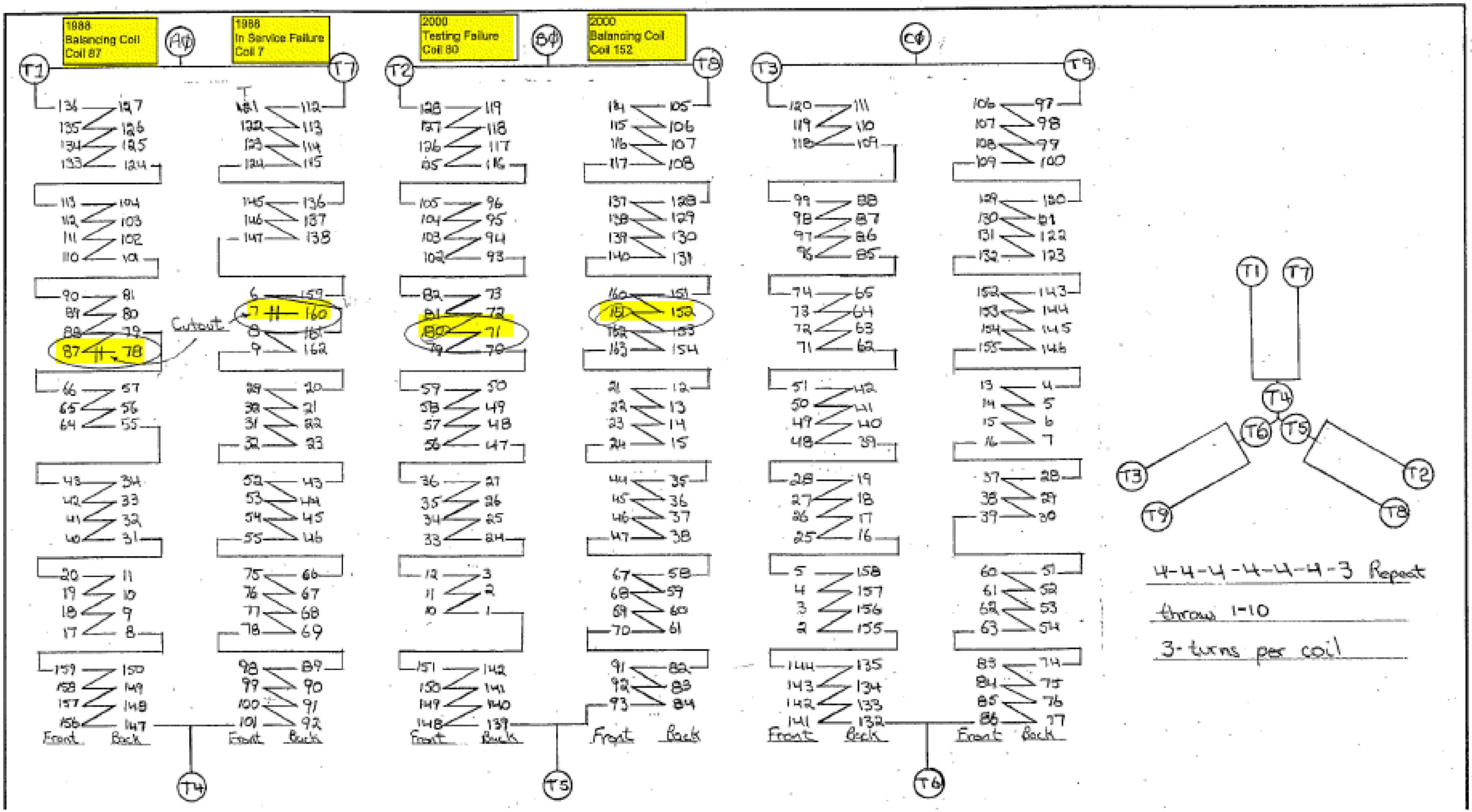
Number of parallels per phase (m) : 2

Number of coils to cut-out (N) : 1

$\mathbf{n_1}$ = (3 x N x m) / S = (3 x 1 x 2) / 162 = 1/27 = 0.0370

Hydro Generator cut-out coils calculations

Important : this generator has already two coils cut-out in phase B from the past.



BC Hydro
Power smart

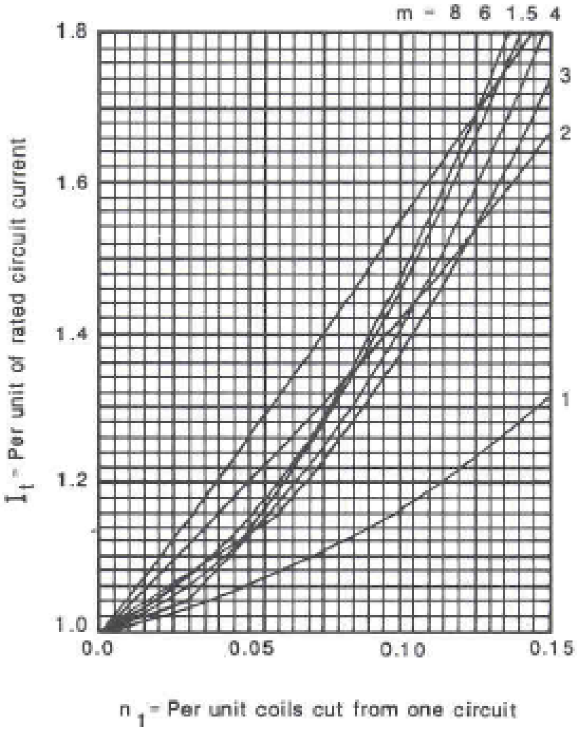
Hydro Generator cut-out coils calculations

Hence, due to an equal number of coils are damaged in each of two circuits in each of two phases ,m = ½ of the actual number of parallel circuits in each phase to be used.

m = ½ x 2 parallel circuits = 1

i.e. since one coil was cutout from each of the two circuits, so that *m* = 1.

Hydro Generator cut-out coils calculations



From Fig.3-5 (for 0.9 PF machine) with n_1= 0.037 and m = 1 , find **per unit highest value of circuit current in the machine (I_t)** that is = 1.04

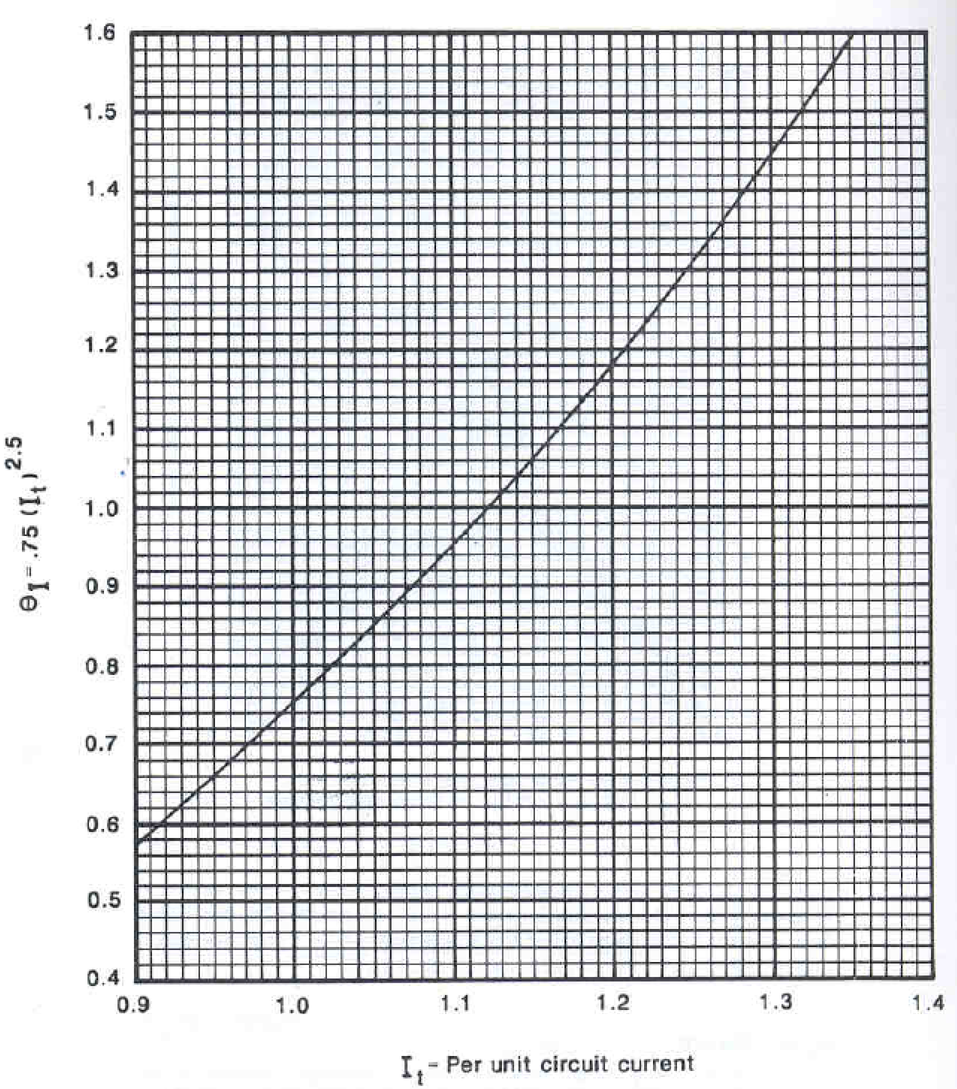
Machine rating is 1 / 1.04 = 0.962

Assume use of overload 115% :

28 MVA x 115% x 0.962= 31.0 MVA
(i.e. generator output was de-rated to 31 MVA)

Figure 3-5: It at Full Load vs. n1, for coils cut from one circuit in each of two phases of a Y-connected Ungrounded 0.9 PF Synchronous Machine

Hydro Generator cut-out coils calculations

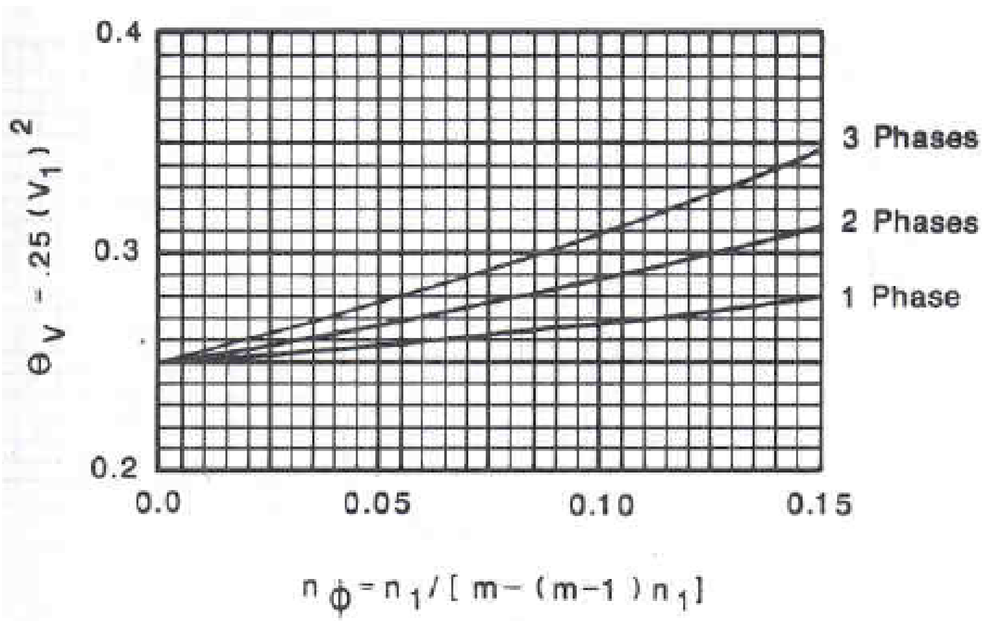


Corrected $(I_t) = 1.04 + 0.15 = 1.19$ (see Note 1).

Note 1: if a 1.15 Service Factor generator is to operated at 1.15 S.F load ,it will be necessary to increase the full load value of (I_t) by an increment of 0.15 to allow for the service factor, before looking up for (Qi) for Eq.3-3 when determining Qs, the per unit winding temperature rise.

From Fig.3-10 , with $(I_t) = 1.19$ find (Qi)=1.16 that is a heating factor in per unit due to current.

Hydro Generator cut-out coils calculations



Calculate the winding unbalance ($n\phi$) due to cut-out coils :

$n\phi = n_1 / [\, m – (\, m- 1)\ x\ n_1\,] =$
$0.0370 / [\, 1- (\, 1-1)\ x\ 0.0370\,]$
$= 0.0370$

From Fig.3-11
with $n\phi = 0.0370$,using the 2 phases , find Qv= 0.26

Figure 3-11: Heating factor in per unit due to internal voltage change with coils from one, two, or three phases.

Calculate the per unit temperature rise (**Qs**) and the total expected operating stator winding temperature rise in the affected circuit at full load after repair (T):

Qs = Qi + Qv = 1.16 + 0.26 = 1.42

Hydro Generator cut-out coils calculations

$T = Qs\ (Qsr + Qh)\ K_{SF} + Ta = 1.42\ (80°C+10°C)\ 0.75 + 40°C = 136°C$

Hence the total expected operating stator winding temperature in the affected circuit at full load after repair (T) is 136°C and would be in a low risk category (i.e. <170°C) for short time emergency service for Class B winding from Table 3-3.

Ta = 40°C rated ambient temperature.
Qsr = 80°C stator winding observed temperature rise for Class B winding at rated voltage and load prior to the fault from Table 3-2
Qh = 10°C temperature allowance from Table 3-2
K_{SF} = 0.75 when using Qsr, the rated SF temperature rise taken from the nameplate for 1.15 SF synchronous generator.

BC Hydro
Power smart

Hydro Generator cut-out coils calculations

Table 3-2: Stator winding limiting observable temperature and allowances for synchronous motors* at rated load with 1.0 service factor

Machine Rating	Method of Temp. Determination	Temp. Rise, °C Insul. Class A	B	C	Temperature Allowance, °C
All horsepower* ratings	Resistance	60	80	105	10
1500 horsepower* and less	Embedded detector	70	90	115	0
Over 1500 horsepower*					
(1) 7000 V and less	Embedded detector	65	85	110	5
(2) Over 7000 V	Embedded detector	60	80	105	10

BC Hydro
Power smart

Hydro Generator cut-out coils calculations

Table 3-3

RISK OF FAILURE VS TOTAL WINDING TEMPERATURE
FOR SHORT-TERM EMERGENCY OPERATION

INSULATION CLASS	LOW RISK	MODERATE RISK	HIGH RISK
B	<170°C	170-190°C	190-210°C
F	<195°C	195-215°C	215-235°C

BC Hydro
Power smart