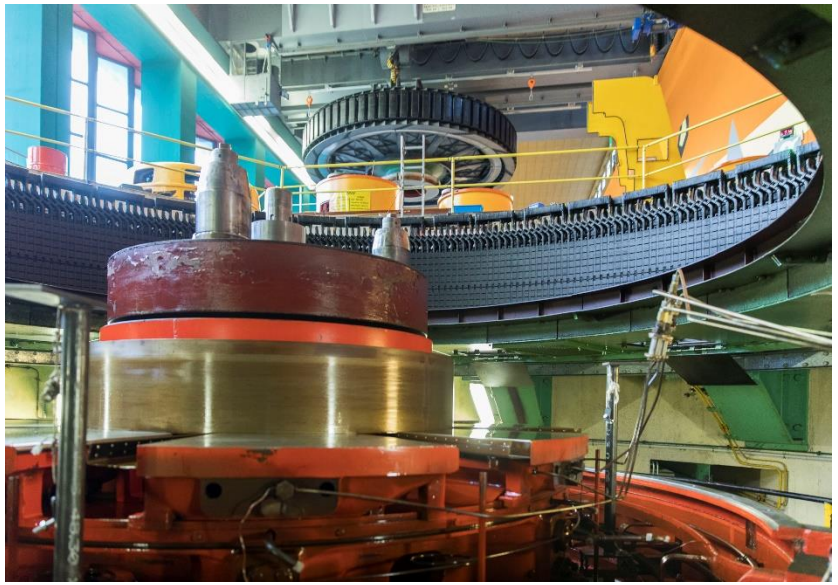
Centre d’Ingénierie Hydraulique

BALANCING OF HYDRO STATOR WINDING IN CASE OF MULTIPLE COIL BY-PASSING



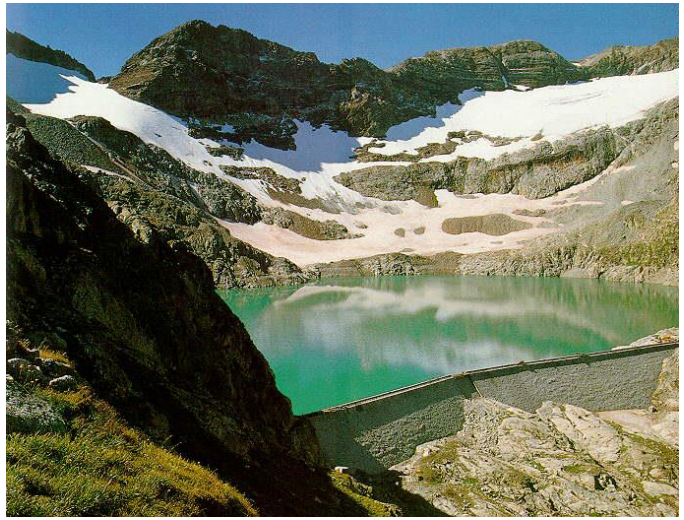
EDF DATA FOR THE HYDRO FLEET

EDF is the largest hydroelectricity producer in European Union (after Norway, not part of EEC)

21% of EDF installed power; <10% of the energy production

1134 hydro units in 439 power plants

5000MW of PSP



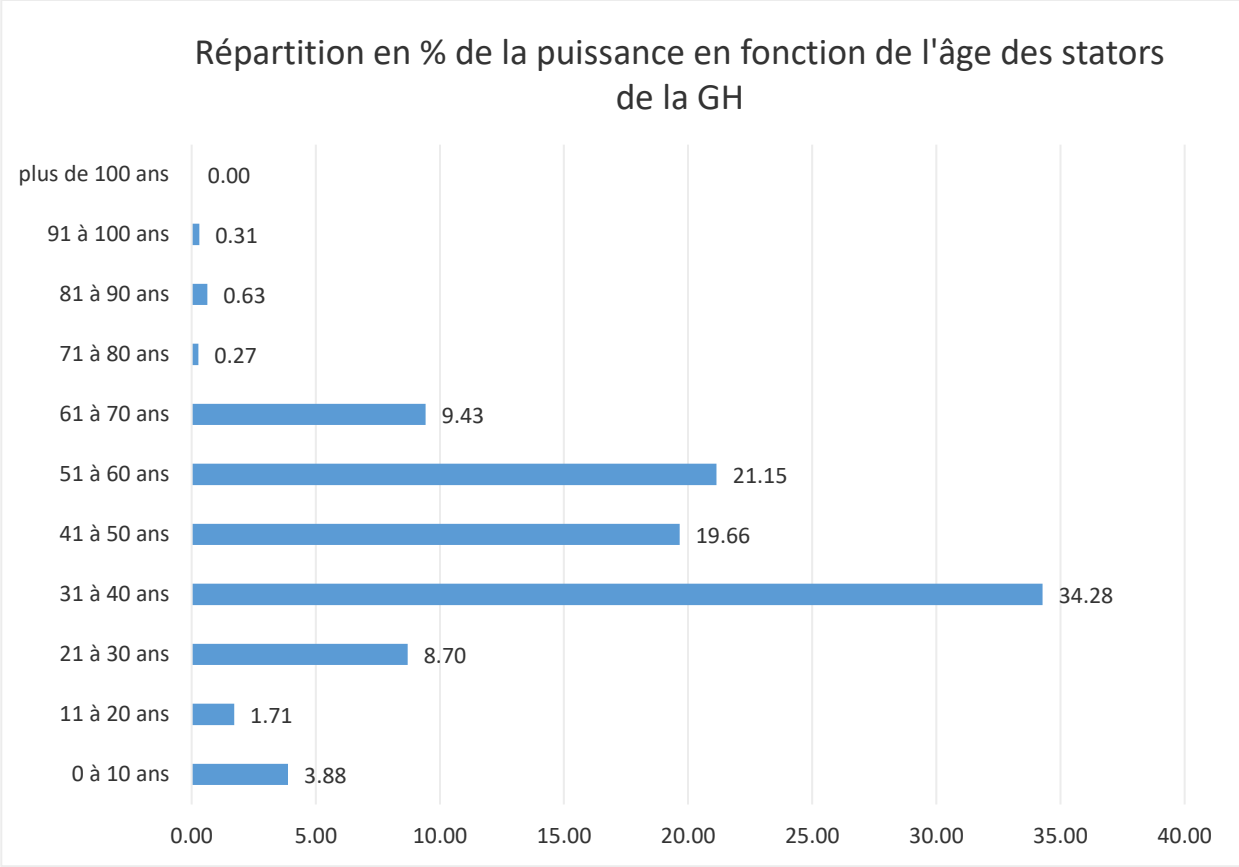
Highest head (Portillon) = 1418 m

EDF HYDRO STATOR FLEET

Most Units date back second half of 20th century

Average age 50 years +

Stator Fault tend to occur and service must resume fast

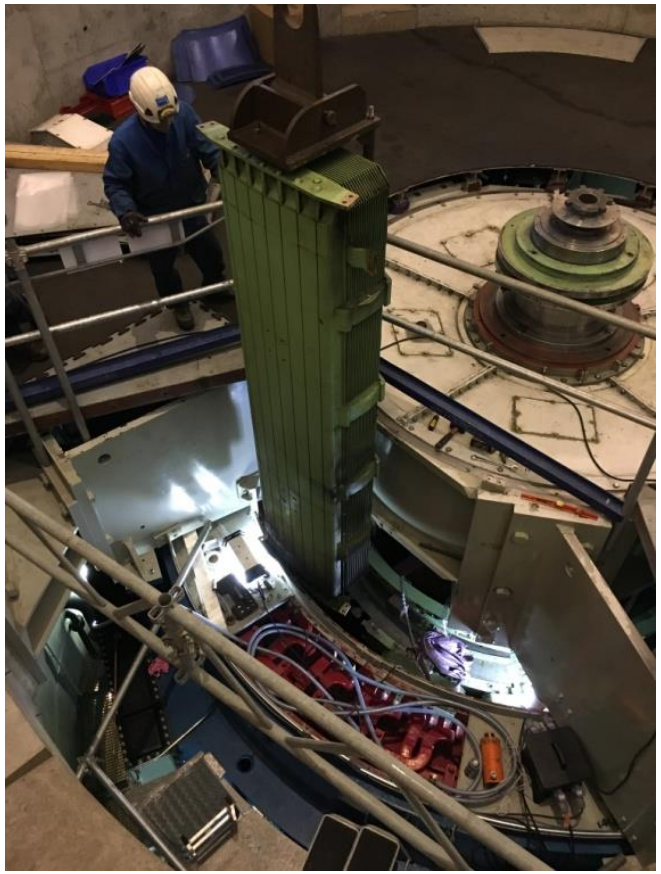


STRATEGY FACING AN EARTH FAULT

- **Rewind**
  - Effective
  - But long lead time
  - Cost
  - Sometimes compulsory if winding badly damaged
    - Case of multi phase fault

STRATEGY FACING AN EARTH FAULT

- **Replace faulty coil or stator bar**
  - Effective
  - But access to fault zone sometimes complicated
    - Case of fault at a bottom bar
  - Need to have spare coils or bars in good state
    - Spare coils are as old as original winding
    - Storage condition may be questioned
    - Spare coils need to be tested prior to usage
  - May require rotor removal or at least pole removal
  - Rather cost effective
  - Takes several weeks to undertake



STRATEGY FACING AN EARTH FAULT

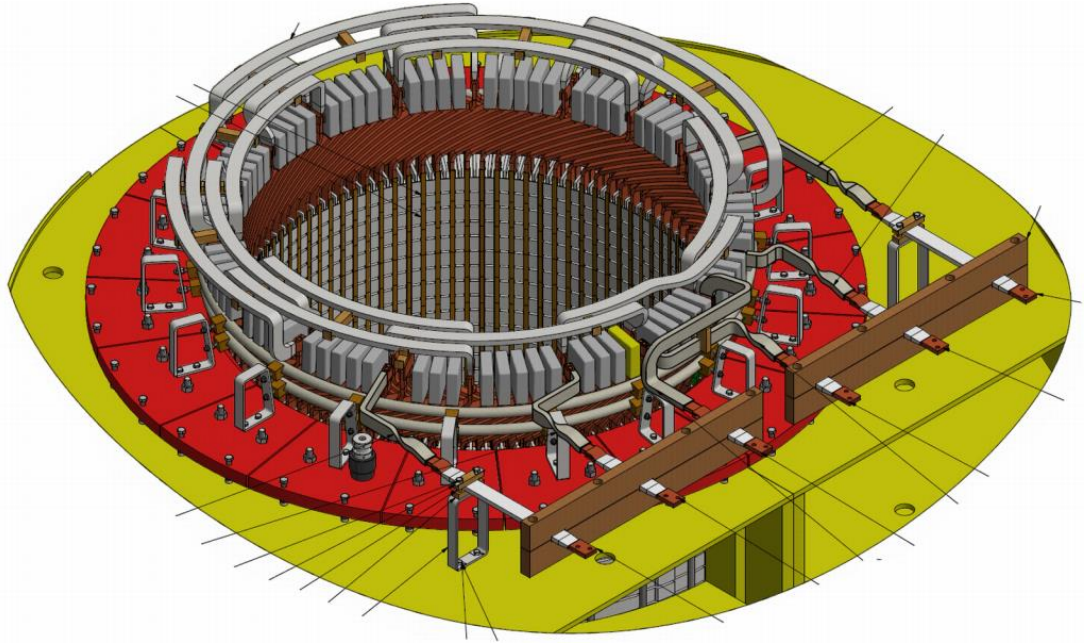
- **By pass the faulty coil**
  - And Keep operating with by passed coil
  - Sometimes several coils are by passed on same machine
  - Applicable to any machine
    - Though beyond 100MVA, operators are reluctant
  - Cost effective
  - Repair takes a few days (10 +/-)

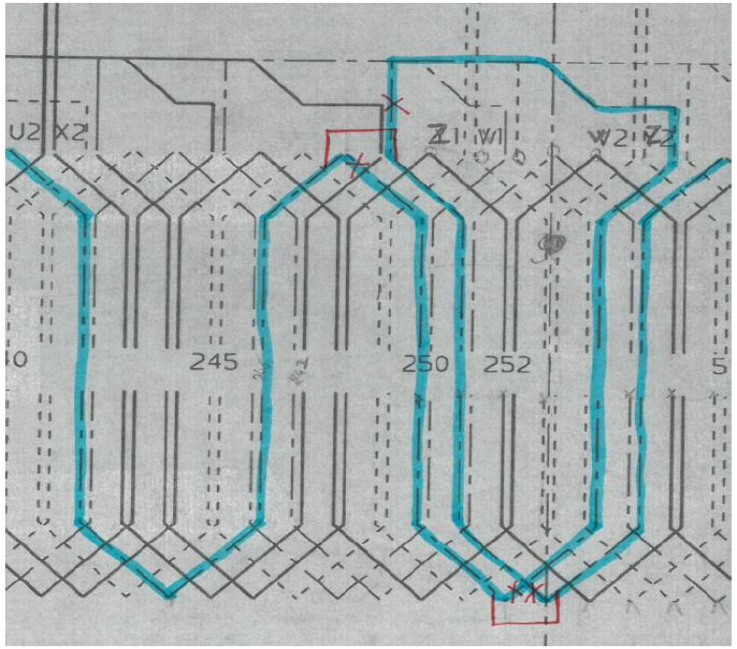
COIL BY PASSING

- Is a quick way to resume service

BUT a few issues to manage

- Locate fault
- Use proper winding diagram
- Identify faulty coil to be by passed
- Hire skilled winder
- Identify balancing coils should vibration or over heating or voltage be out of bearable condition



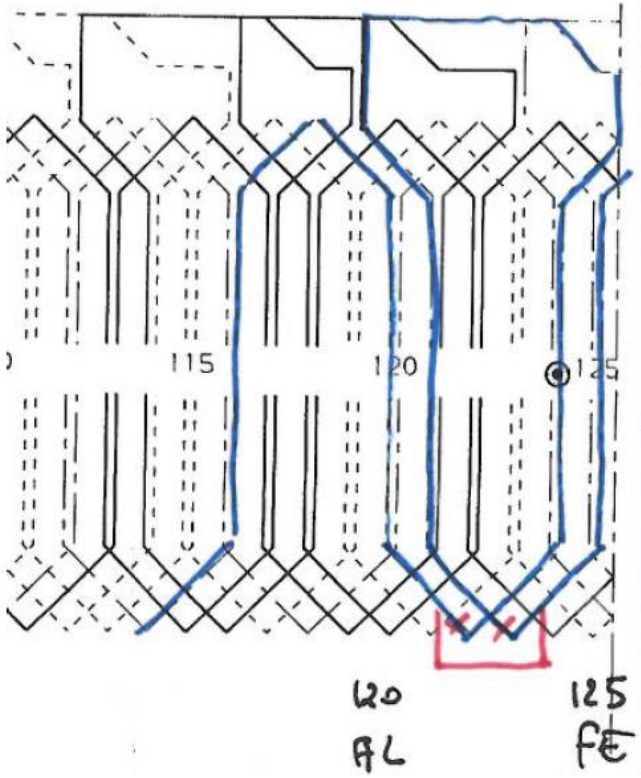


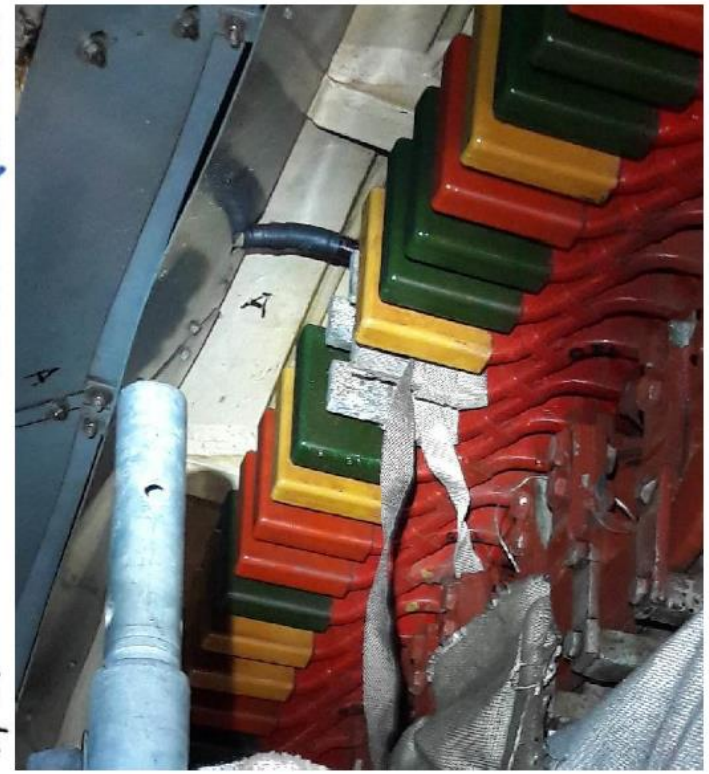
COIL BY PASSING PROCESS

- **Locate fault bar or coil**
  - Burn and smoke
  - Dichotomy with Meggering
- **Use winding diagram to draw by pass circuit**
- **Check on site potential by pass area**
- **Manufacture by pass copper segment**
- **Weld by pass and insulate**
- **Run machine**
- **Measure vibration off load and on load**
- **Measure voltage**
- **Measure phase and neutral current**
- **Monitor winding temperature**

COIL BY PASS BALANCING

- **By passing a coil modifies stator flux**
- **Hence has an impact on**
  - Phase Voltage
    - Balance of phase voltage is no longer true (amplitude and angle)
    - Criteria 5% max
    - Current in between parallel paths at no load
    - Current in Neutral point
  - Air gap forces
    - Balance of airgap forces
    - Vibration load dependant
    - Might lead to staor or rotor attachment fatigue
- **Impact is more sensitive if**
  - Winding has several parallel paths





MITIGATION MEASURES WHEN BY PASSING COILS

- First model the electric diagram
- Calculate Voltage difference
- If greater than 5% between phases or parallel, then balancing is recommended
- Balance voltage in other parallel paths
- And in other phases
- May lead to several other by pass chosen to balance both voltage amplitude and angle
- It is an iterative process to find best option
- Using an automated tool makes the job much easier

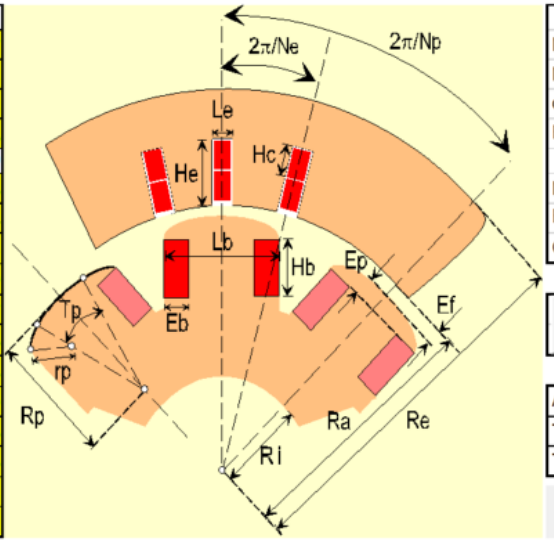
- Calculate magnetic pull
- To Balance magnetic a coil must be by passed on same phase at ~180° (mech)
- It increases the voltage unbalance
- to be done if vibration or bearing condition is not at all suitable

- To limit by passed coils, compromise between voltage and magnetic pull balancing is key

BALANCING BY PASSED WINDING

- Automated tool
- Makes calculation faster
- Can be computed with excel
- Example of pull after one by pass
- Work table to find balancing by pass

Paramètre	Symbole	Valeur
rayon externe stator (m)	Re	1,367
rayon interne rotor (m)	Ri	0,35
rayon d'alésage stator (m)	Ra	1,05
nombre de pôles	Np	8
nombre d'encoches	Ne	120
entrefer (m)	Ef	0,026
grand rayon du pôle (m)	Rp	1,024
ouverture du pôle (rad)	Tp	0,35
largeur du pôle (m)	Lb	0,499
épaisseur du pôle (m)	Ep	0,07
hauteur des bobines rotor (m)	Hb	0,176
épaisseur des bobines rotor (m)	Eb	0,08
petit rayon du pôle (m)	rp	0,9
largeur d'encoche (m)	Le	0,026
profondeur d'encoche (m)	He	0,136
hauteur conducteur (m)	Hc	0,05485
fer nette (m)	L	2,1

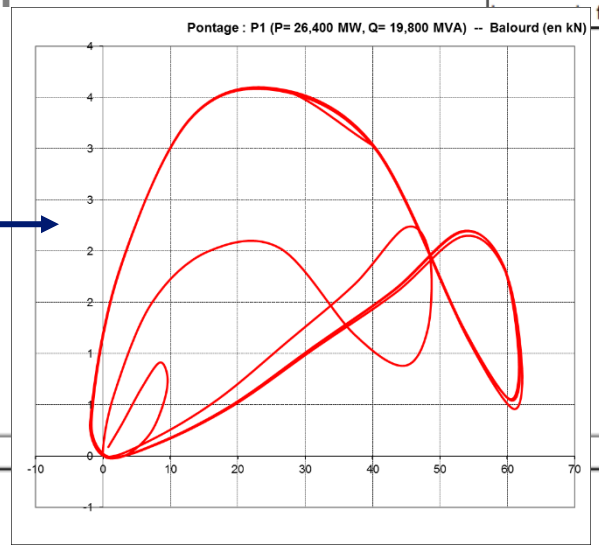


Stator :	
Nombre de circuits en // stator :	1
Nombre de spires par bobine :	1
demi-résistance d'une section (Ω) :	0,000144
Résistance de neutre (Ω)	500
Rotor :	
Nombre de spires par pôle :	49
Résistance circuit inducteur (Ω):	100
Courant rotor nominal (A)	600

Modifier le nombre d'encoches	120
Modifier le nombre de circuits	1

Angle en degré par encoche	12
Tension Composée (kV)	10,3
Tension Simple (kV)	5,94670777

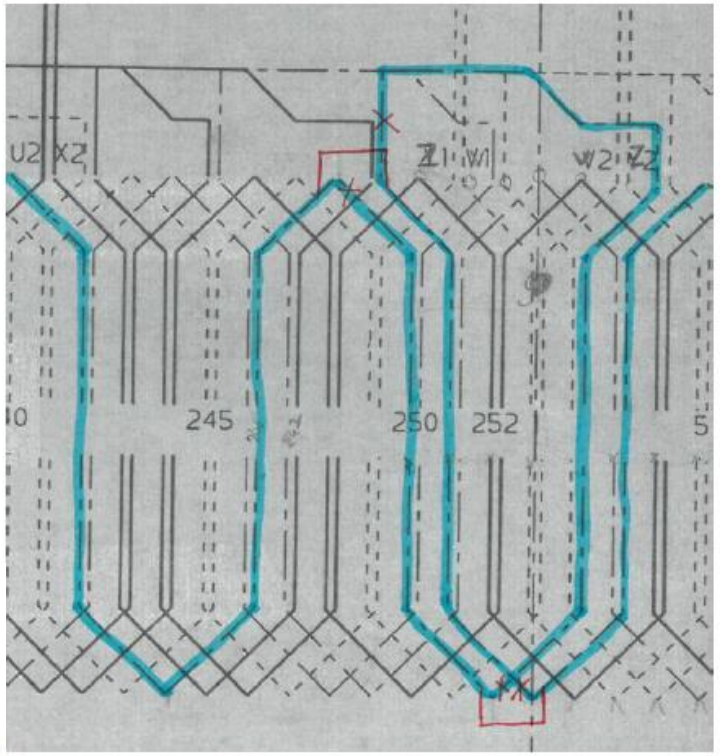
Créer la Machine

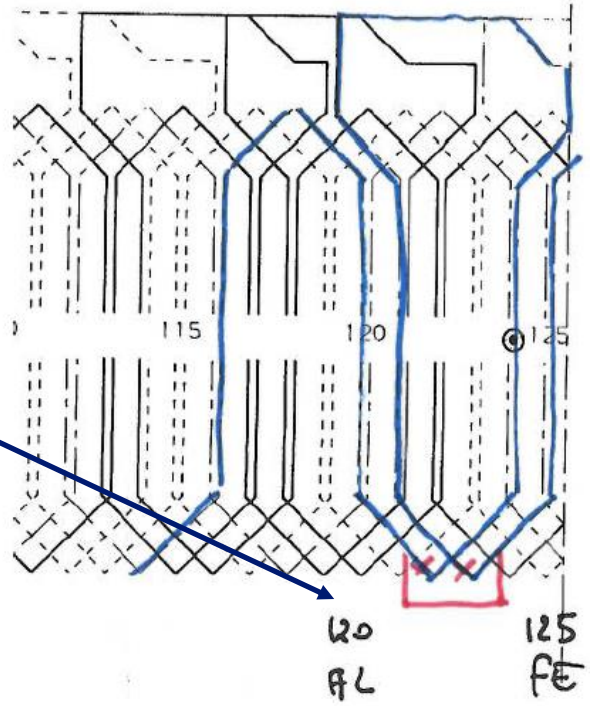


	Paramètres Réseau		Phases						Neutre	Courant crête dans les circuits (A)			Résultats mécaniques				
Cas n°	P (MW)	Q(MVAR)	courant (A_{eff})			tension (V_{eff})			A_{eff}	Phase 1	Phase 2	Phase 3	P (MW)	balourd moyen (N)		balourd variable (N)	
			I_1	I_2	I_3	U_1	U_2	U_3	I_n	C1	C1	C1		horizontal	vertical	horizontal	vertical
	26,400	19,800	1857	1857	1857	5947	5947	5947	1	2620	2620	2620	27	0	0	0	0
1	26,400	19,800	1845	1857	1857	5907	5945	5947	1	2595	2623	2622	26	62699	2943	63593	3589
1 bis	26,400	19,800	1833	1856	1857	5868	5942	5947	1	2572	2626	2624	26	0	0	0	0

EXAMPLE OF BY PASSED WINDING

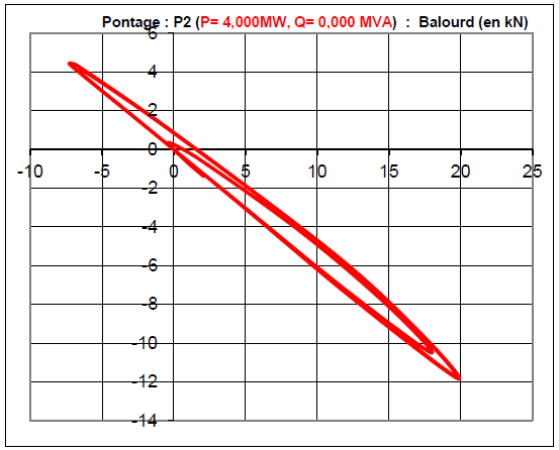
- **Case of a unit with 2 parallel per phase**
- **100rpm; 252 slots; 3.6kV; 36MVA**
- **Stator earth fault on ciruit 1**
  - By pass of faulty coil in slots 2 and 251
- **Balancing of circuit 2**
  - To balance voltage between circuit
  - And try to balance magnetic pull
  - By pass of coil 124 /121

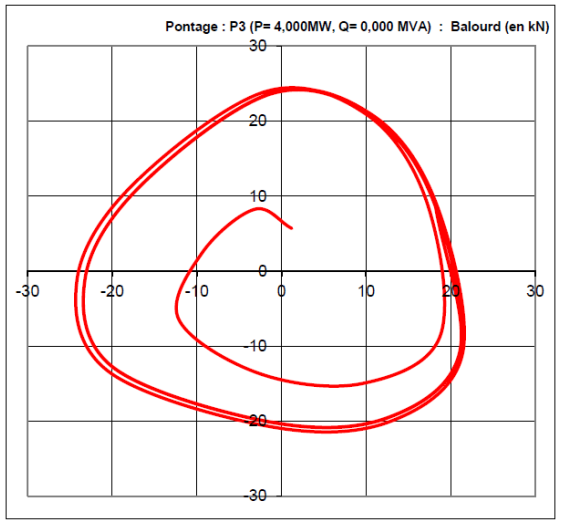


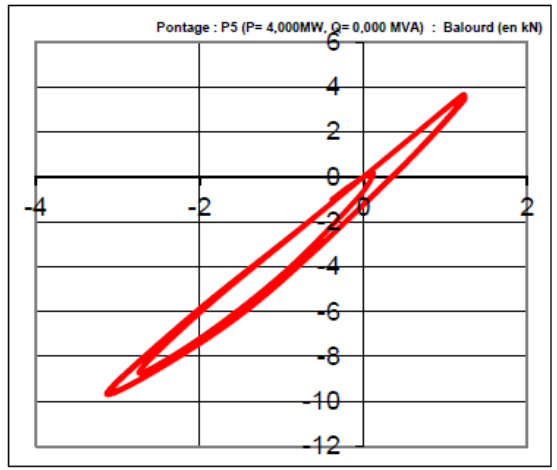


EXAMPLE OF COUNTER INTUITIVE IDEA

- **Balancing magnetic pull**
  - Original pull vector with one by pass
- **One common idea is to by pass coils in other phases 120° (mech) apart from faulty coil.**
- **It tends to center the pull force but not to cancel it**
- **Because stator current in each phase are shifted 120° elec so the force vector are also shifted in time and never cancel out at any given moment**
- **Balaning pull with a by pass on same phase 180°mach apart from original fault**

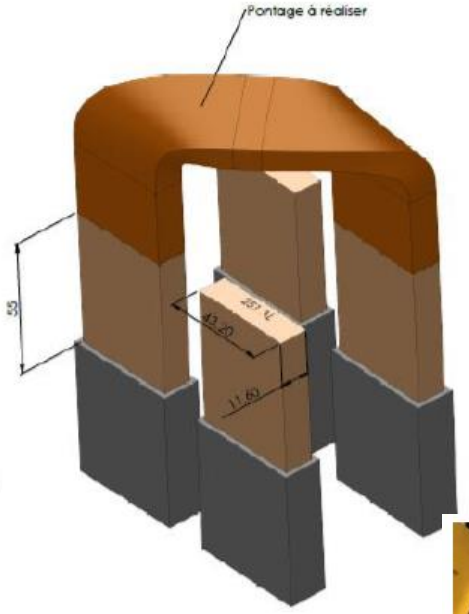


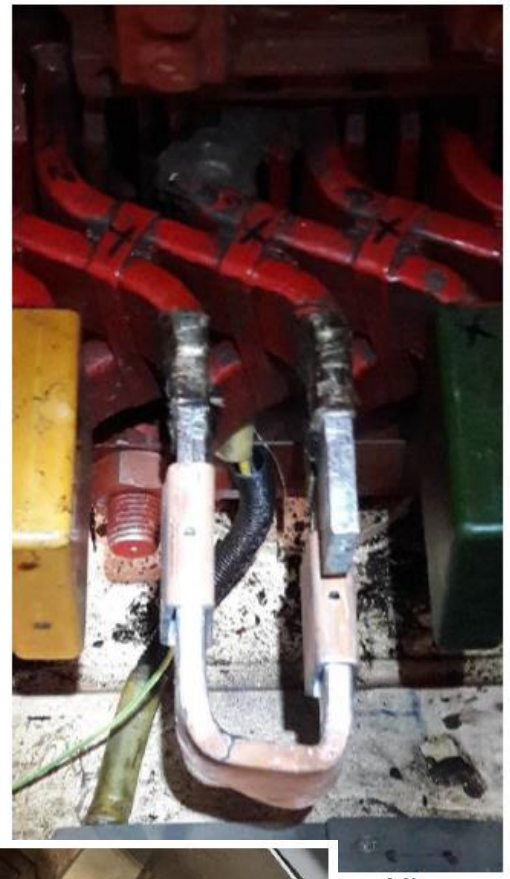


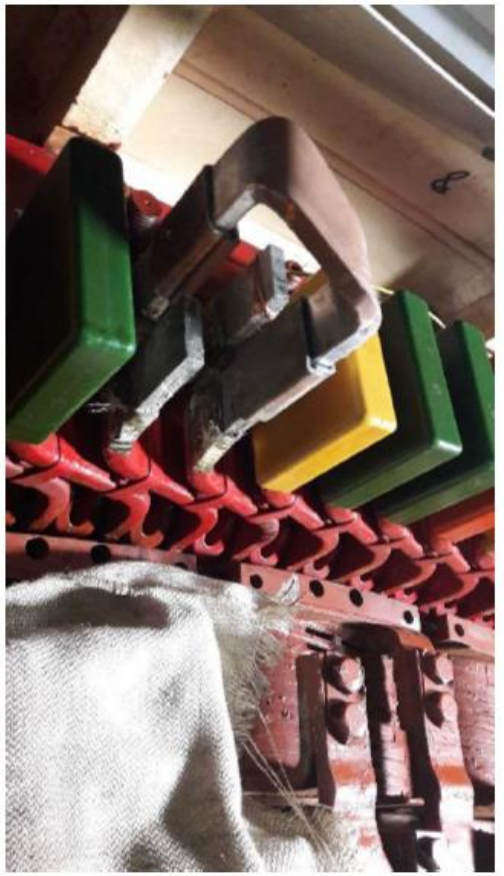


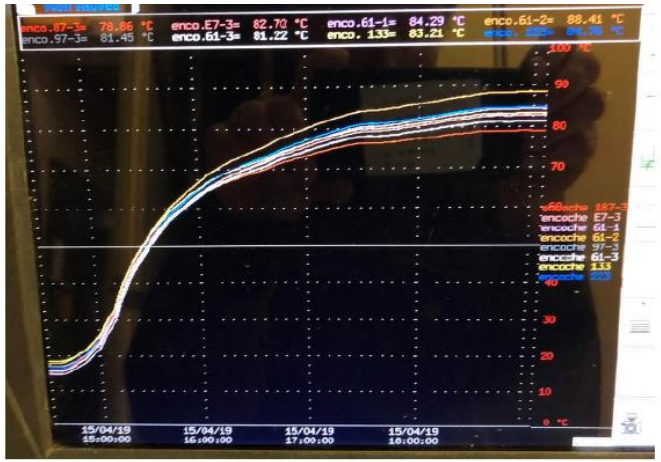
REPAIR PROCESS

- **Actual by pass must be implemented on the stator winding**
- **Phase circuit must be open**
- **By pass shunt must be desig manufactured and soldered**
- **Insulation must be applied**
- **Hi Pot**
- **Commissioning test**
  - Vibration check
  - Temperature measurement of stator winding









CONCLUSION

- **Coil by passing can save the day after a stator earth fault**
- **It can be applied to many generators**
- **Considering phase voltage, circulating current and vibration mitigation measure can be applied using balancing technique**
  - Balancing thanks to relevant by passed coils requires some calculation
  - Some ideas are misleading/counter intuitive
  - A spreadsheet calculation helps the job