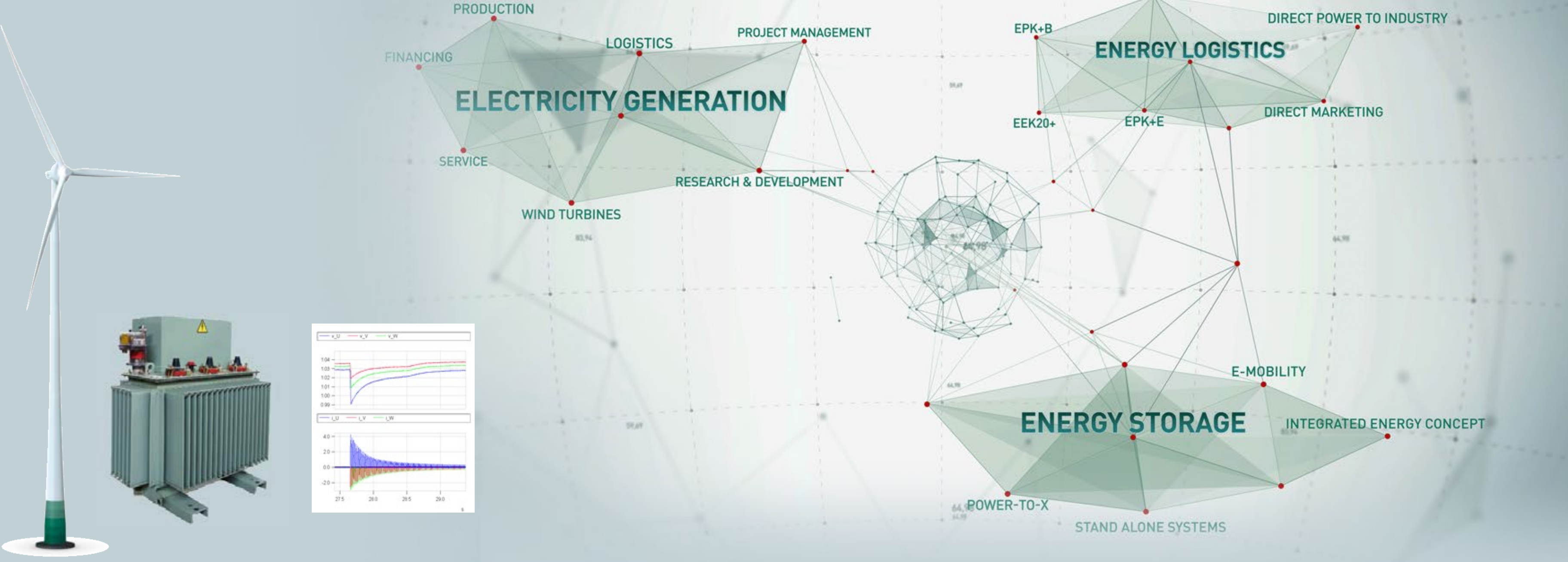

Inrush current : one less thing to worry about !

4th International Hybrid Power Systems Workshop

Crete, Greece – May 22nd 2019

Victor GOMES –Sales Grid Integration – Enercon Gmbh France

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Agenda

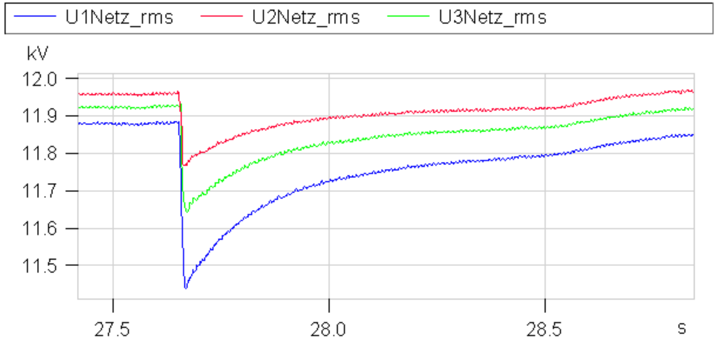
1. Introduction : a bit of context
2. Inrush current physics
3. Existing mitigation methods
4. The Enercon solution : “Smart Energise”
5. Conclusion

1. Introduction : a bit of context

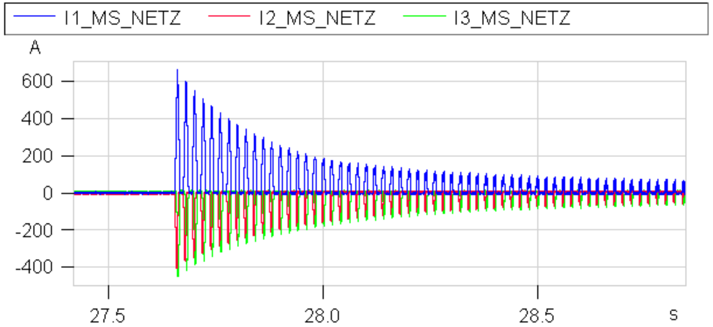
Main issue : a voltage dip
- Depth reaching a few %U_{rated}
- Asymmetrical dip

Reason : high current drawn from the grid
- Typically 5 to 10 times I_{rated}
- Can be much higher depending Z_{grid}
- Asymmetrical current
- DC component

Consequences : grid quality / protection issues
- Flicker
- Tripping of protection relays



Voltage dip @PoC following the energisation of a WEC



Inrush @PoC following the energisation of a WEC

1. Introduction : a bit of context

System Operators (DSOs & TSOs) impose some requirements trough their Grid Codes

- usually by imposing a maximum voltage dip
- or eventually by imposing a maximum inrush current

Ex: ENEDIS (main French DSO)

« Les à-coups de tension au Point de Livraison dus à l'Installation de Production, consécutivement par exemple aux opérations de couplage et de découplage ou à la mise sous tension de l'Installation, ne doivent pas dépasser 5% »

➔ **voltage dip must be limited to 5%Ur.**

Ex: SYNERGRID (Federation of Belgium SOs)

« Pour les transformateurs raccordés au réseau MT, le courant d'appel doit être limité à 100%Inom) partir des valeurs ci-dessous : »

Niveau de tension	Valeur limite
10kV	2600 kVA
11kV	2800 kVA
12kV	3200 kVA
15kV	3900 kVA
29,9kV	5100 kVA

➔ **Inrush current must be limited to 100%Ir…**

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1. Introduction : a bit of context


BERKELEY LAB
Bringing Science Solutions to the World
ELECTRICITY MARKETS & POLICY GROUP
SUMMARY BRIEF
emp.lbl.gov

November 2016

Reducing Wind Energy Costs through Increased Turbine Size: Is the Sky the Limit?

Berkeley Lab study shows significant potential for further turbine scaling

Ryan Wiser, Maureen Hand, Joachim Seel, Bentham Paulos

The inrush current issue is gaining on importance, and it deserves a greater awareness !


E-44
E-48
E-53

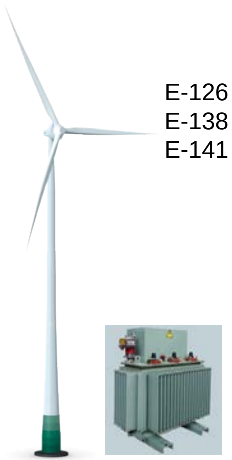
~1995
1MW


E-70
E-82
E-92
E-103

~2005
2MW


E-101
E-115

~2012
3MW

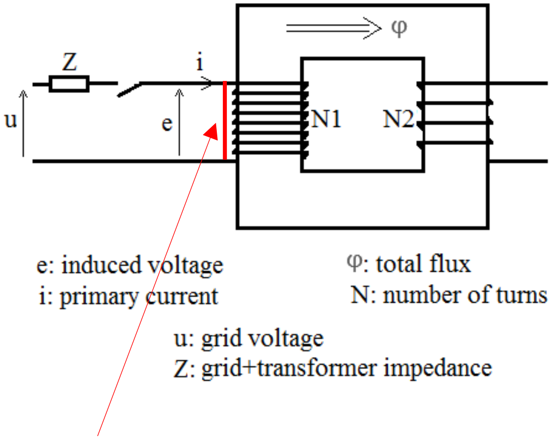

E-126
E-138
E-141

~2018
4MW


E-136
E-147
E-160

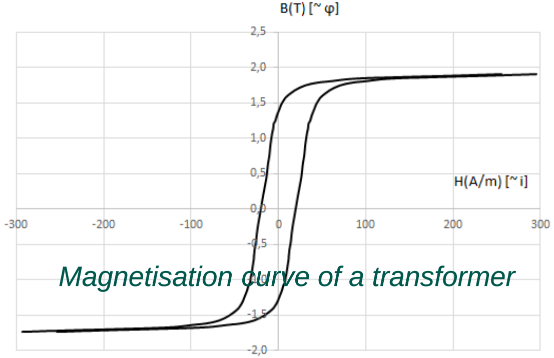
~2022
5MW

2. Inrush current physics



1/ if for any reason, ‘e’ cannot develop (ie ‘e’~0V), it is very like a short circuit !

2/ if the flux cannot vary, then ‘e’ cannot develop!
$e(t) = N1 * d\varphi/dt$ (Faraday law)



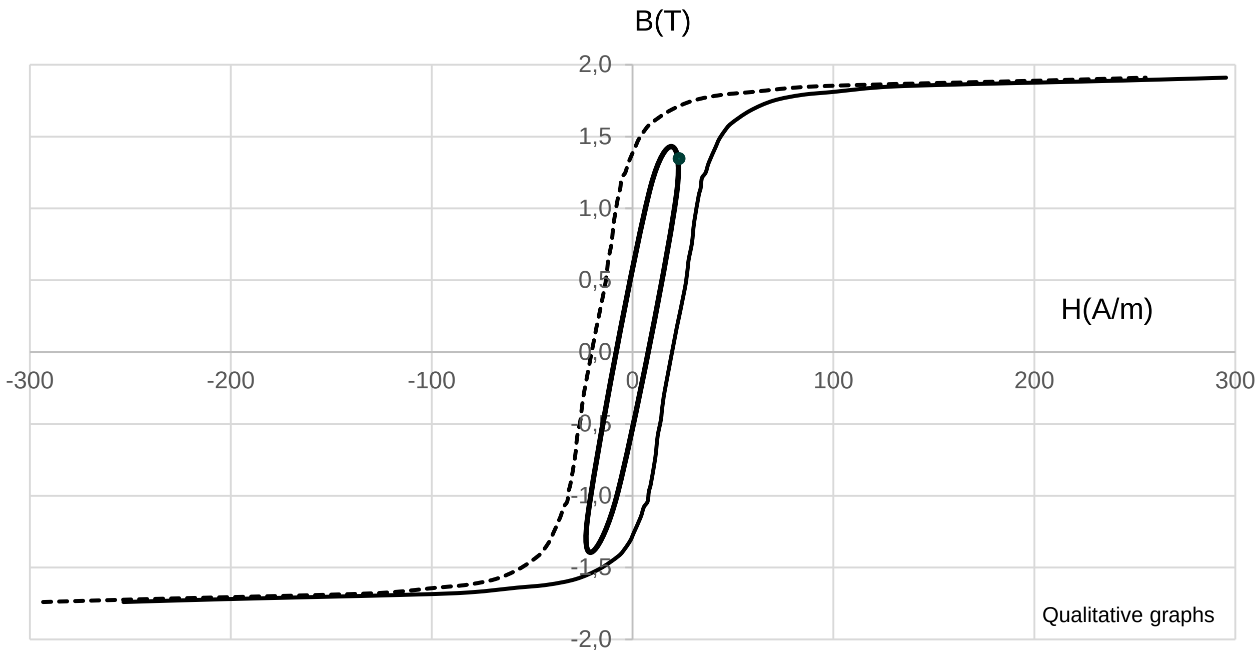
Magnetisation curve of a transformer

3/ if the flux is too important, then we reach the saturation of the core.

➔ An inrush current occurs, when the transformer core reaches the saturation limit !

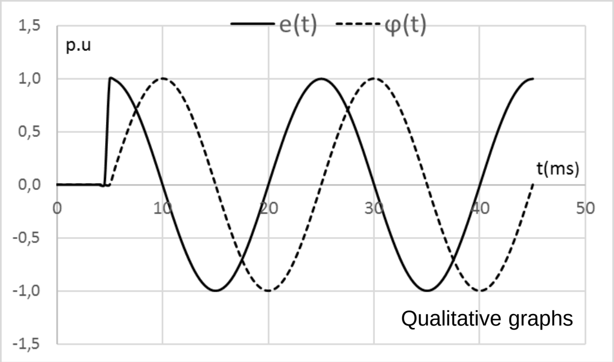
2. Inrush current physics

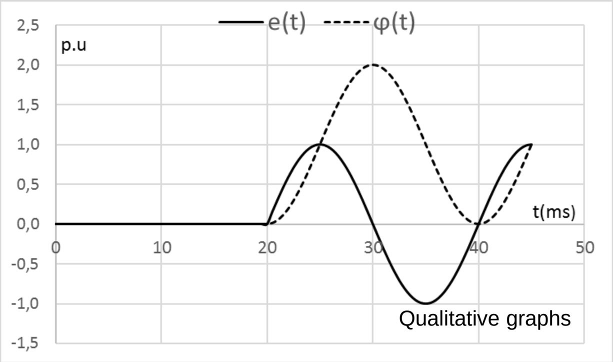
A transformer is so made that in steady state, the saturation is not reached

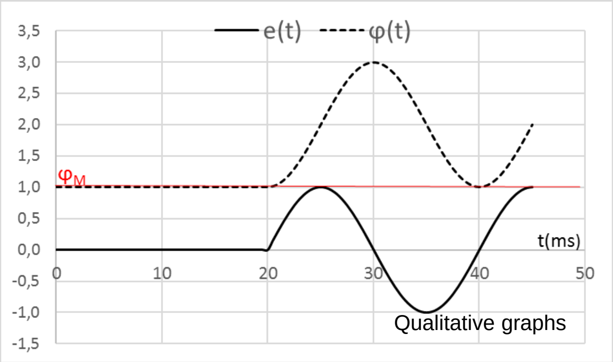


Steady steate operation of a transformer

2. Inrush current physics







Energisation config 1
- *@max voltage*
- *No residual flux*

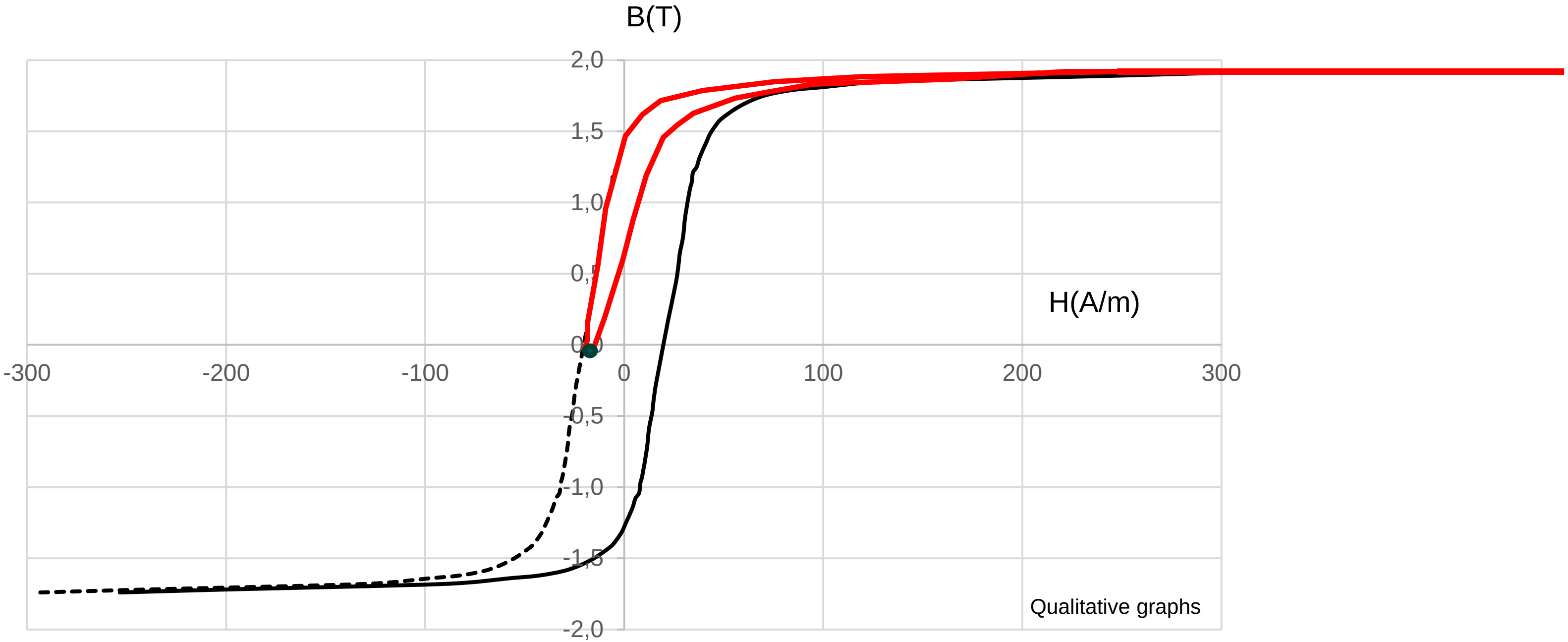
Energisation config 2
- *@zero voltage*
- *No residual flux*

Energisation config 3
- *@zero voltage*
- *Some residual flux*

At every instant, 2 rules must be fulfilled (and according to Faraday law) :
1/ The flux is lagging the voltage of 90°
2/ The flux cannot be discontinued

➔If energised at the wrong instant, and offset of flux is generated.

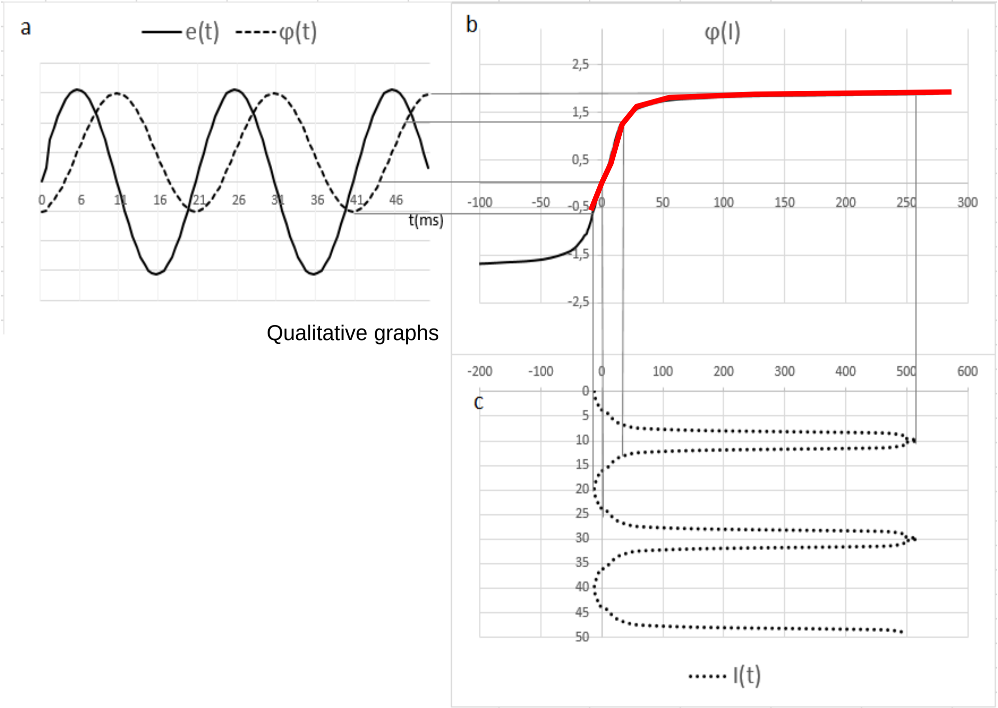
2. Inrush current physics



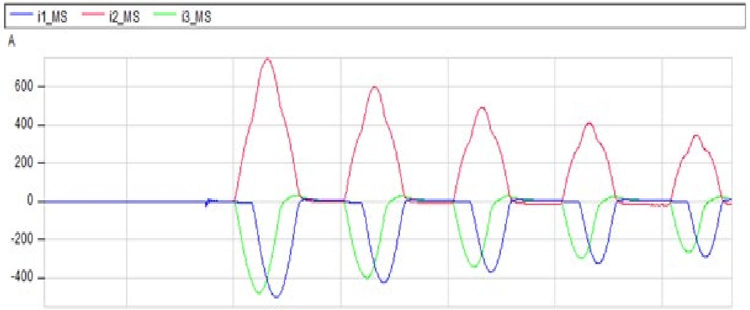
Operation while in saturation

2. Inrush current physics

Qualitative evaluation of the inrush current by projection of the Flux into the saturation curve



Qualitative graphs



Real measurement of the inrush in a 3,5MVA transformer

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3. Existing mitigation methods

The « cascade control »

- This method is not addressing the individual inrush current of a unit
- It addresses the resulting « aggregated inrush » if several units are connected simultaneously
- The energisation of the individual units is delayed by the mean of a single relay on each transformer

The « low inrush transformer »

- One way to avoid the saturation of the core is to oversize it
- This method has been used in « mild cases » where simulated voltage dips were just above the limits

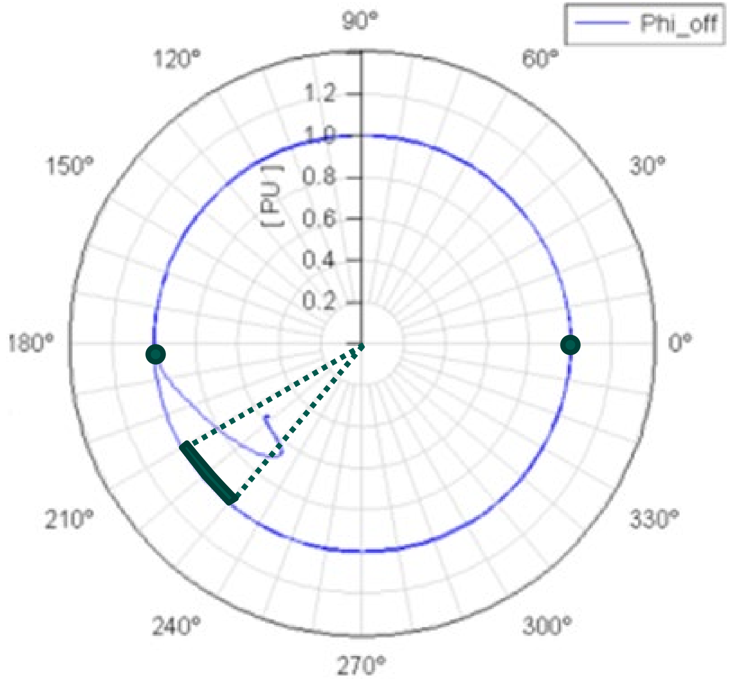
The « Pre-insertion resistor »

- The inrush current can be effectively limited with a pre-insertion resistor
- Efficient but not really practicable due to costs and space requirements
  (as it has to be installed usually in a MV switchgear).

3. Existing mitigation methods

The more advanced methods : point-on-wave switching

- Steady state : rotating field
- Disconnection : flux decreases until reaching a residual value
- A micro-controller monitors the instant of disconnection
- Based on the instant of disconnection, the residual flux is estimated (green area) and the proper instant of reconnection is calculated.
- When necessary, the transformer is reconnected at the calculated instant.



Flux in a dq representation

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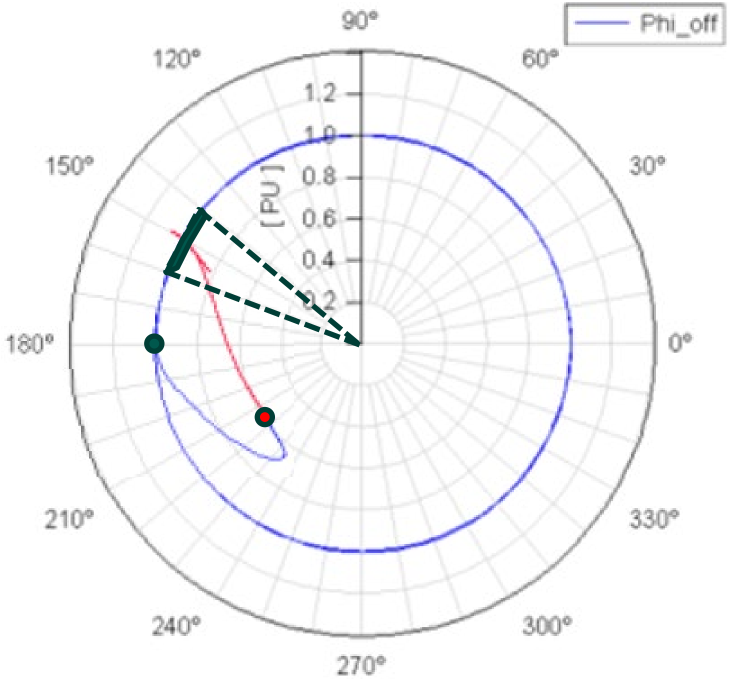
4. The Enercon solution : “Smart Energise”

- The instant of disconnection is <u>not monitored</u>
- But wherever is the residual flux, the Smart Energise imposes a new known and required residual flux
- The proper instant of reconnection is then always the same

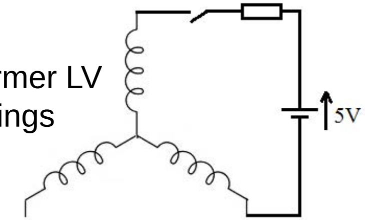


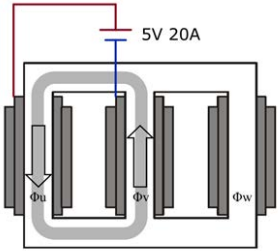
Flux in a dq representation

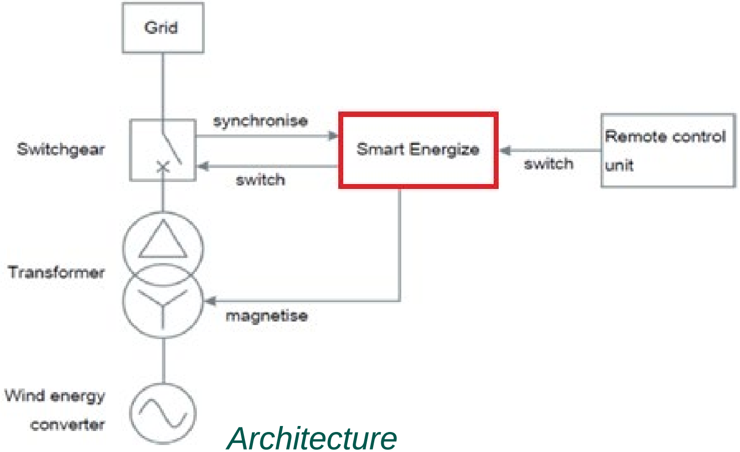
4. The Enercon solution : “Smart Energise”

- A single DC source is used to impose the new residual flux by feeding 2 of the LV windings!
- After a few couple of seconds, the DC source is disconnected

Transformer LV windings



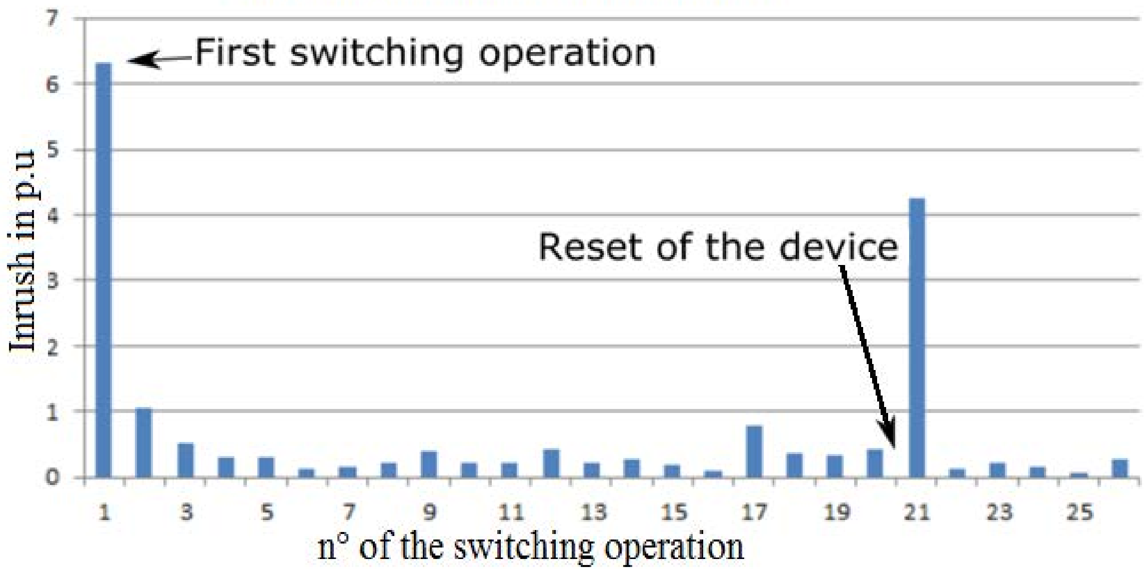




Architecture

Smart energise box

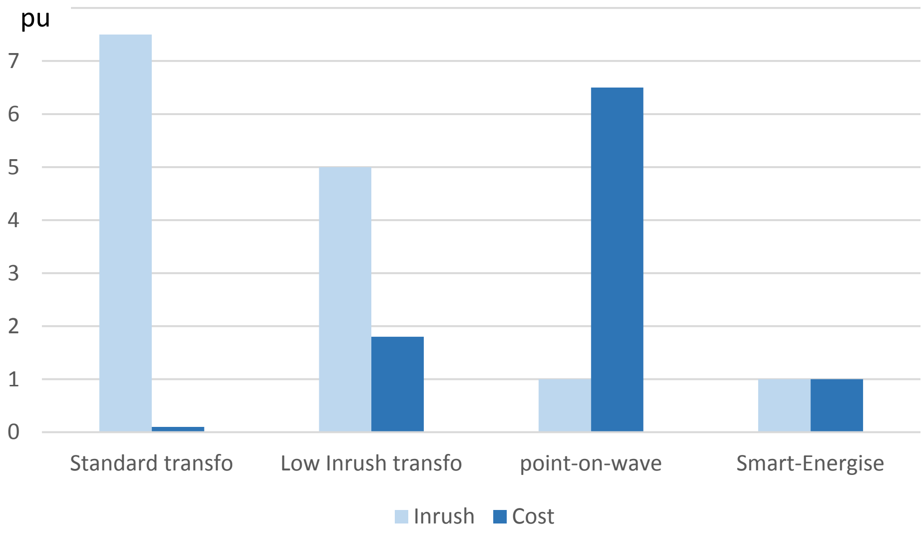
4. The Enercon solution : “Smart Energise”



On field testing of a 3MW wind turbine

After a 1st energisation (during which an auto-setting is performed), the following energisations show a very low inrush

4. The Enercon solution : "Smart Energise"



Performance & cost of different methods

Smart energise is very efficient and for a low cost

5. Conclusion

- ✓ Transformers used in wind power plants (but not only) are becoming more and more powerful
- ✓ The resulting inrush current deserves a greater awareness
- ✓ Existing mitigation methods are efficient but at a significant investment cost
- ✓ The ‘Smart Energise’ is an innovative method : simple, inexpensive and very efficient

THANK YOU