The Highly Efficient And Reliable smart Transformer (HEART)

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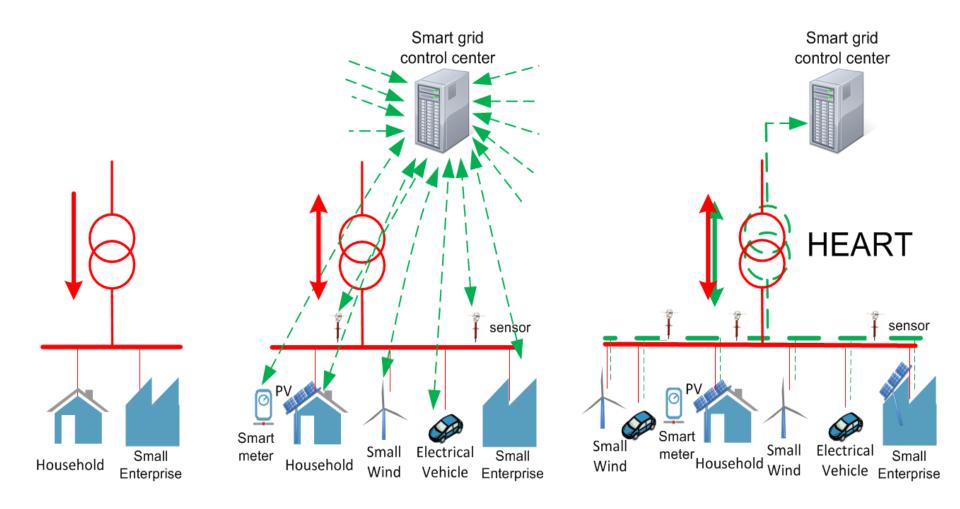
Outline

- 1. HEART Project
- 2. The Smart Transformer and the other intelligent solutions
- 3. Examples of ST functionalities in power system
- 4. ST architecture choice
- 5. Active thermal control
- 6. Implementation of HEART Project

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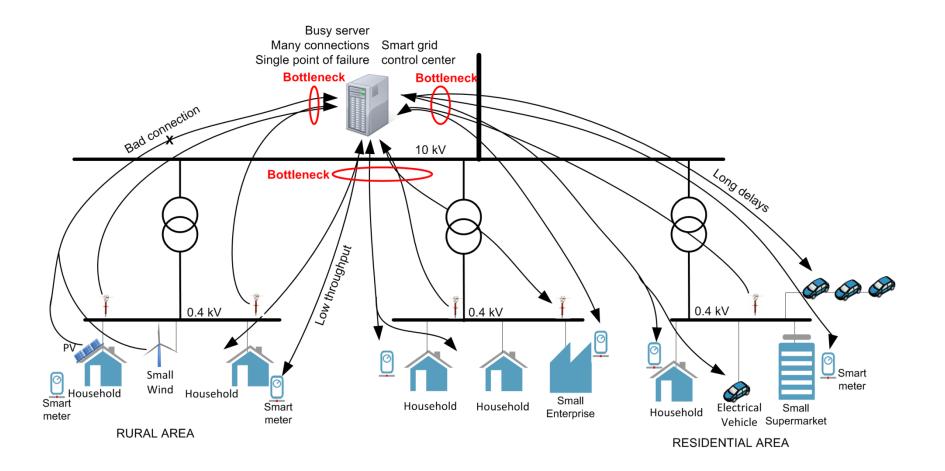
A new Heart for the Electric Distribution System



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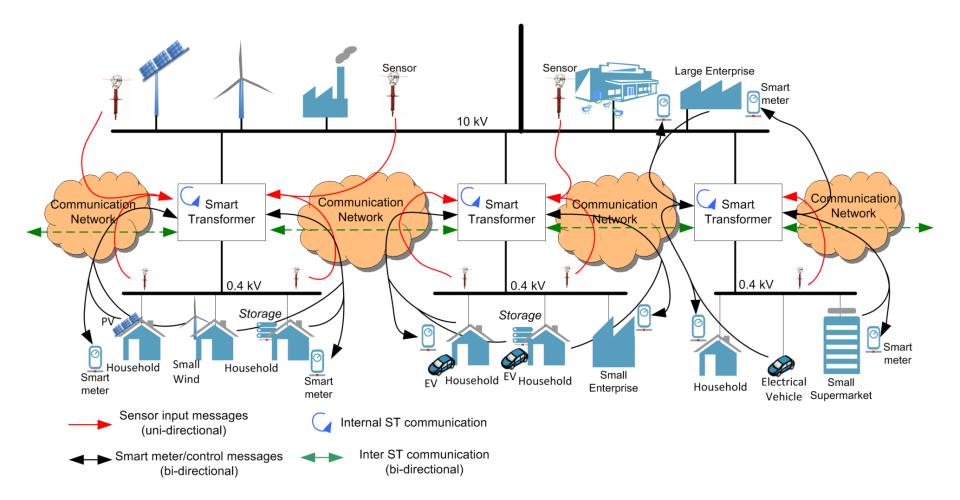
Critical issues of the future electric grid



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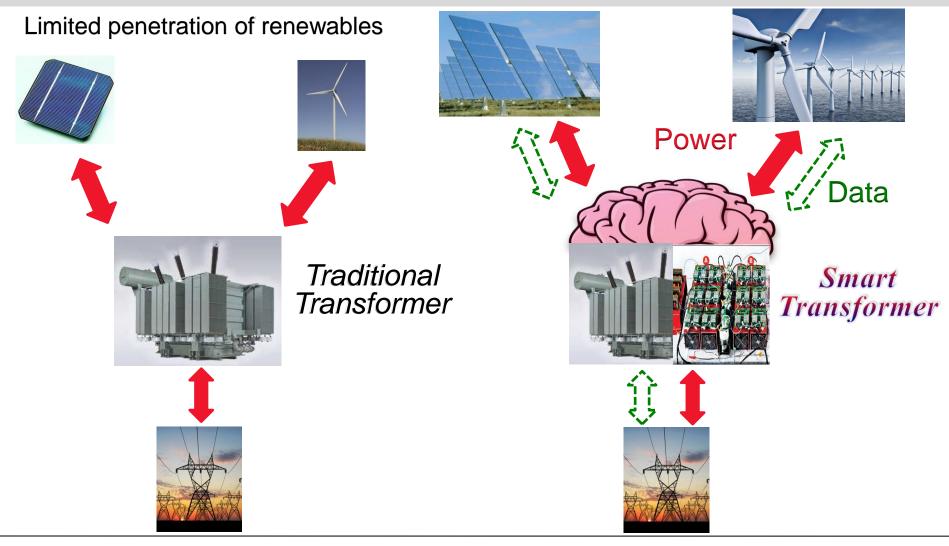
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A possible solution: the Smart Transformer



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A new Heart for the Electric Distribution System

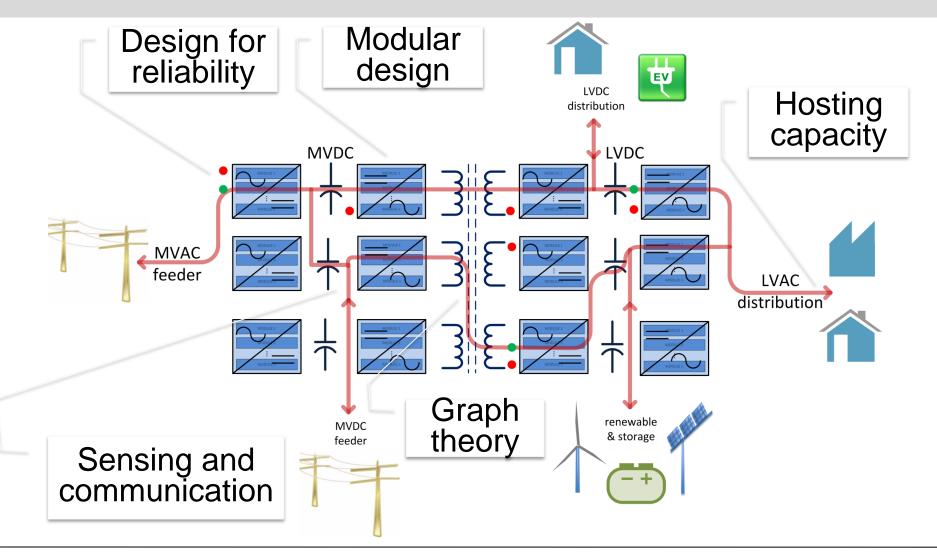


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Innovative idea and adopted methodologies



Approaches and methodologies

Hosting capability and reliability of the electric grid

- Benchmark the results respect to the smart grid
- If needed set a contigency plan

Design for reliability of the smart transformer

- ST lifetime estimation
- set a basis for on-line control of ST reliability

Modular design

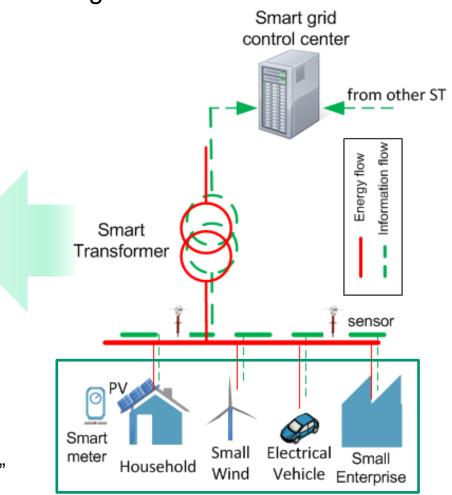
designing a modular ST architecture to allow routing the "packets of energy"

Active thermal control

find optimal paths (min losses and max reliability) for the "packets of energy"

Sensing and comunication

Junction temperature knowledge and real-time communication for routing the "packets of energy"



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Expected results and potential contribution to the field

Smart grid	Too decentralized Re-use of old concepts	New semi- decentralized managment	HEART is the solution !
Smart transformer	Many solutions taken from other applications	New energy router controlling on-line efficiency and reliability	HEART is competitive !
sensors, actuators and communication	No holistic solution	Actuate the energy routing	HEART is feasible !

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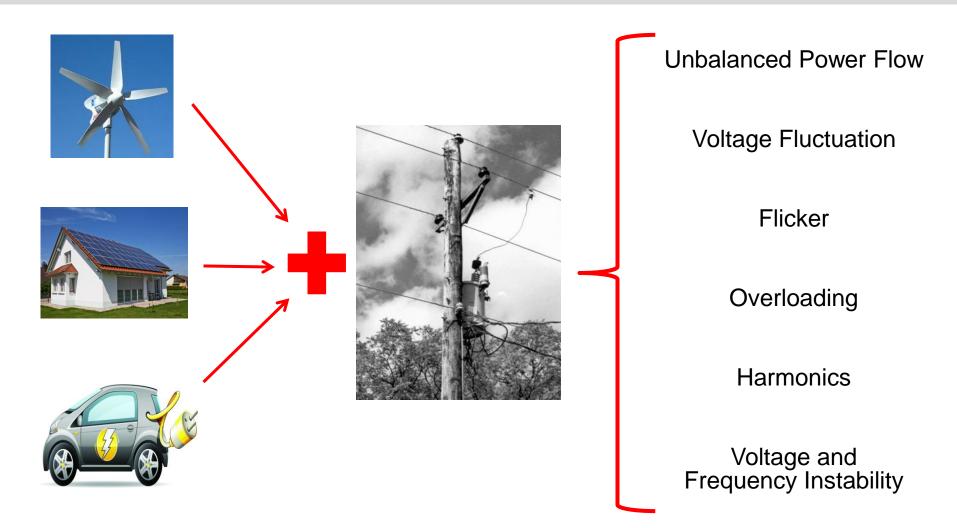
The Highly Efficient And Reliable smart Transformer (HEART)

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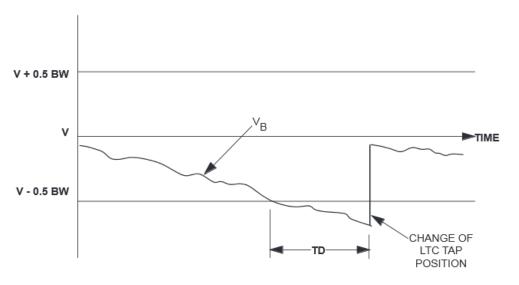
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Low Voltage Grid Issues



On-Load Tap Changer (OLTC) Transformer



V=Voltage Setpoint of tapchanger control

Figure 1 Illustration of the Interaction of Three Basic Control Settings

The OLTC modifies its voltage set point when the voltage profile goes down a predefined threshold. A time delay **TD** has set, avoiding the temporary voltage violations, operating only when the voltage violation is permanent.

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In the Low Voltage grids the tolerance Bandwidth (BW) is commonly set within a range [1.5-3] V.

The working logic is the Line Drop Compensation, that controls the voltage in specific points of the grid. This represents a difficult task, due to the complexity of the grid, and the length of the lines.

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Hybrid solution*

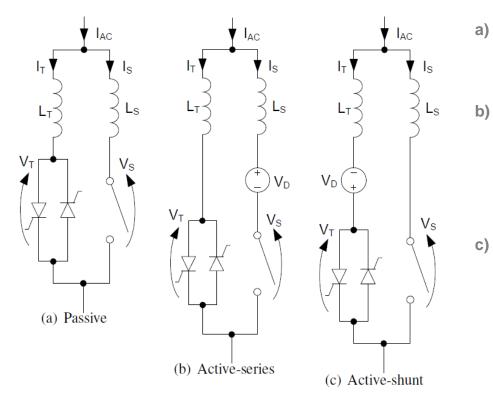


Fig. 1. Classification of hybrid OLTC schemes

- **Passive type**: relies on the process of mechanical contact separation to drive current into an alternate path.
- Active-series type: opposing a voltage source in series with the mechanical switch, the power is transferred to the semiconductor path. It avoid the switch under load.
- c) Active-shunt type: the voltage source is placed in the semiconductor leg It cancels the thyristor forward voltage and drives a current equal to the load current into the semiconductor path. The switching current is zero and the arc-less operation is ensured.

^{*} Rogers, D.J.; Green, T.C., "An Active-Shunt Diverter for On-load Tap Changers," Power Delivery, IEEE Transactions on , vol.28, no.2, pp.649,657, April 2013

Siemens solution*

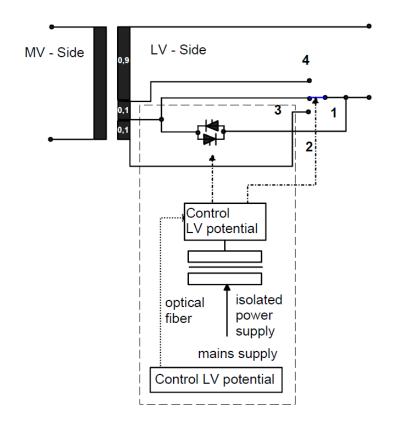


Figure 3: Principle of on-load tap changer

New concept: the solid-state relay acts to ensure continuous current flow by conducting the current during the mechanical switching operations.

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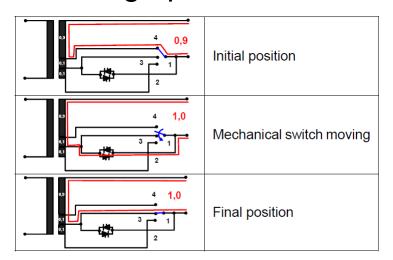


Figure 4: Commutation process

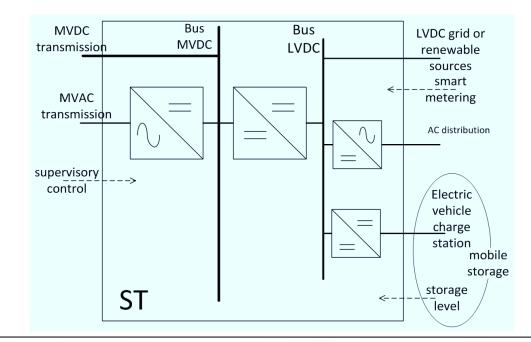
*G. Hipski, R. Schmid, R. Maier, K. Handt, G. Buchgraber, "Distribution Transformers – ready for the smart grid", 21st International Conference on Electricity Distribution, CIRED, Frankfurt, 6-9 June 2011.

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Capabilities of the Smart Transformer

- Power quality enhancement: disturbance isolation, harmonics and transients
- DC-connectivity: future MVDC, low voltage DC grids and renewable energy
- Fault reclosing coordination
- Energy storage: Electric vehicle batteries (challenges and opportunities)



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Comparison among transformers*

TABLE I.OVERVIEW OF THE SUPPORT FUNCTIONS FROM
TRANSFORMERS

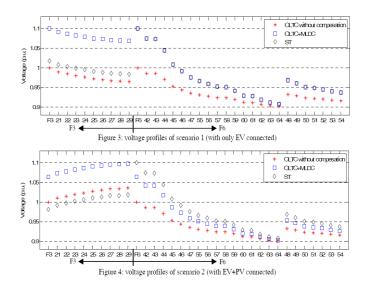
	Traditional transformer with off load tap changer	Traditional transformer with on load tap changer	ST
Reducing grid losses	partly	yes	yes
Improving EV/PV hosting capacity	partly	partly	yes
Eliminating voltage harmonic	no	no	yes
Reducing voltage unbalance	partly	partly	yes
Relieving flicker	no	no	yes
Relieving voltage fluctuation (duration > 1minute)	no	partly	yes
Fault isolation	no	no	yes
Supply reliability	no	no	yes

*Shaojun Huang; Pillai, Jayakrishnan R.; Liserre, Marco; Bak-Jensen, Birgitte, "Improving photovoltaic and electric vehicle penetration in distribution grids with smart transformer," Innovative Smart Grid Technologies Europe (ISGT EUROPE), 2013 4th IEEE/PES, vol., no., pp.1,5, 6-9 Oct. 2013

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Improving EVs and PVs Hosting Capacity*

The smart transformer perform better voltage regulation and support higher EV and PV penetration levels in the local distribution grids, when compared to the conventional transformer with OLTC.



$$U_n(V_{se}) = (V_{nom} - V_{n,\max})^2 + (V_{nom} - V_{n,\min})^2$$

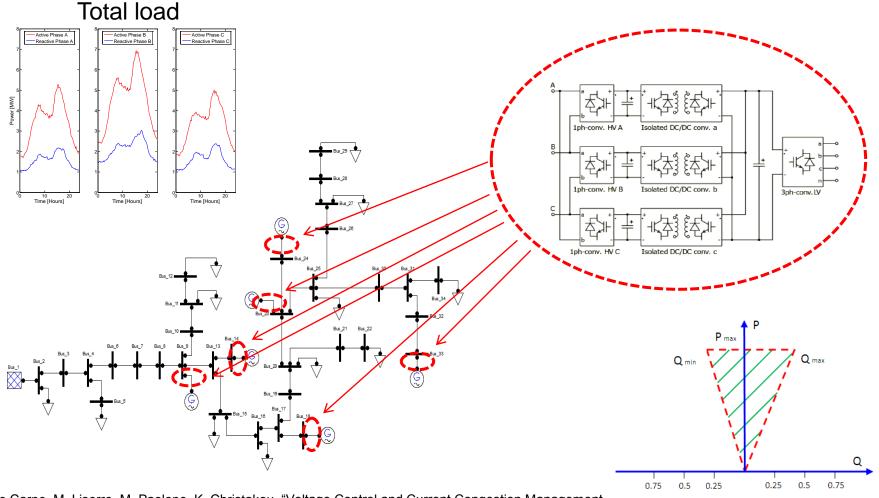
	Feeder 3(PV penetration level of 27HH)	Feeder 6(EV penetration level of 39HH)
Traditional transformer+ OLTC (no compensation)	64.8%	10.7%
Traditional transformer + OLTC (MLDC method)	64.8%	20.6%
ST	64.8%	25.5%

*Shaojun Huang; Pillai, Jayakrishnan R.; Liserre, Marco; Bak-Jensen, Birgitte, "Improving photovoltaic and electric vehicle penetration in distribution grids with smart transformer," Innovative Smart Grid Technologies Europe (ISGT EUROPE), 2013 4th IEEE/PES, vol., no., pp.1,5, 6-9 Oct. 2013

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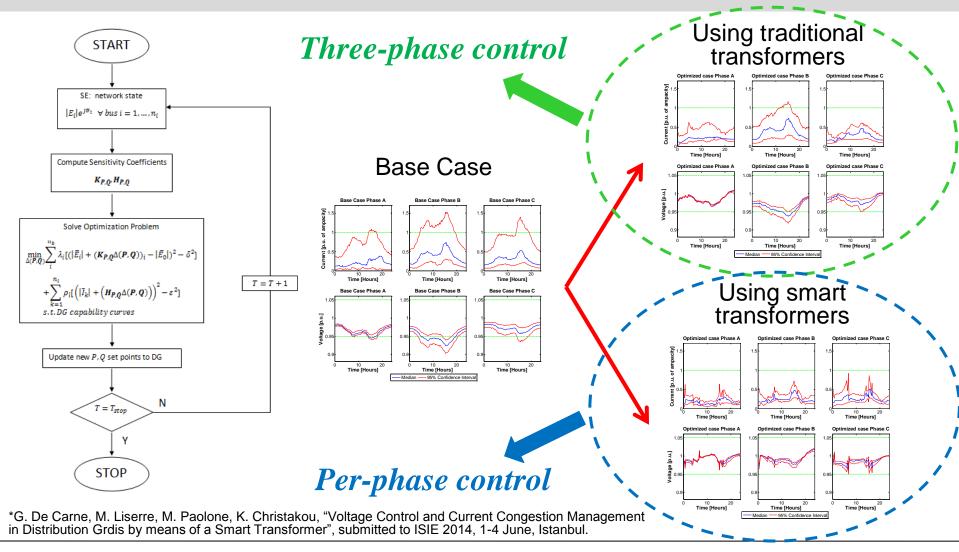
Voltage Control and Current Congestion Management*



*G. De Carne, M. Liserre, M. Paolone, K. Christakou, "Voltage Control and Current Congestion Management in Distribution Grdis by means of a Smart Transformer", submitted to ISIE 2014, 1-4 June, Istanbul.

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Voltage Control and Current Congestion Management*



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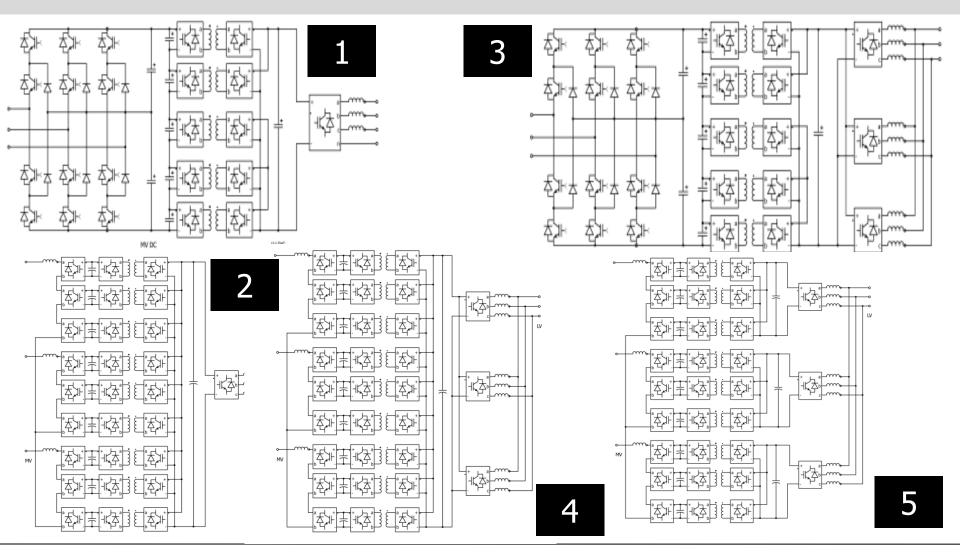
ST Architecture

- ✓ One stage (AC-MV/AC-LV)/ Two stage (AC-MV/DC-MV /AC-LV)
 - ✓ Reduced component counts
 - ✓ Does not allow integration of either MV/LV DC network
 - $\checkmark\,$ disturbances on one side may also affect the other side
- ✓ Three Stage (AC-MV/DC-MV/DC-LV/AC-LV)
 - ✓ DC-links on both sides and performing three stages of conversion
 - $\checkmark\,$ Allows direct integration of renewable DC sources
 - ✓ Modularity

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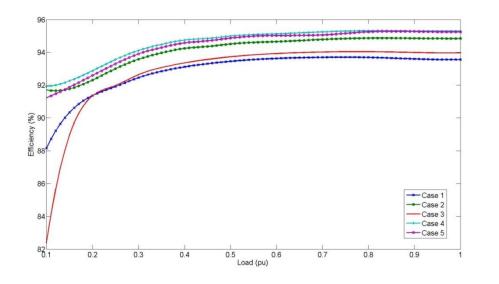
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Several architectures



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Comparison



- Cascaded H-bridge seems to be the best solution but it does not allow MVDC connectivity
- MVDC connectivity is at the expense of efficiency

Case	Modularity	Efficiency	Reliability	Cost	DC connectivity
1	-	-	++	++	MV and LV
2	+	+	+	+	LV
3	+	-	++	++	MV and LV
4	++	++	+	+	LV
5	++	++	+	+	LV

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Topology Impact on the Distribution System Enhancement

			NPC		СНВ											
	LV (Common DC I	link	LV Separate	e DC links	LV	Common DC	LV Separate DC links								
	One Inverter	Multi-In	verter	Multi-Ir	Multi-Inverter In		Multi-In	verter	Multi-In	verter						
	One Feeder	Each Phase	Each Feeder	Each Phase	Each Feeder	One Feeder	Each Phase	Each Feeder	Each Phase	Each Feeder						
Unbalanced Voltages Control	+	++	++	++	++	+	++	++	++	++						
Voltage Variations & Flicker Compensation	-	+	++	++	++	+	+	++	++	++						
Harmonics Pollution Reduction	++	++	+	+	+	++	++	+	+	+						
Unbalanced Power Flow Control	-	+	++	+	+	-	+	+	-	-						
Limit EVs Impact and Improve Hosting Capacity	-	+	++	+	++	-	+	++	-	-						
Losses Reduction	+	++	++	++	++	+	++	++	++	++						
MV DC link accessibility	+	+	+	+	+	-	-	-	-	-						
LV DC link accessibility	+	+	+	++	++	+	+	+	++	++						

Converter

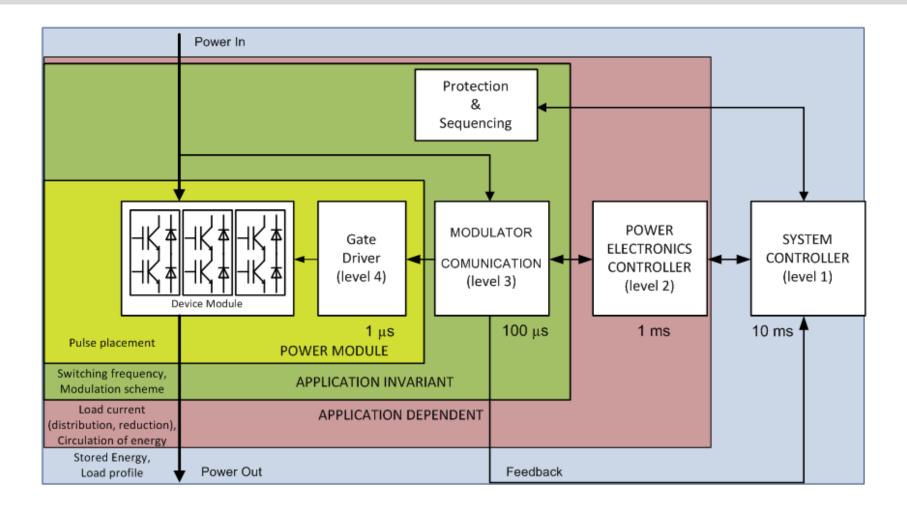
Active Thermal Control

Sa Control • High temperatures, Set-point Control S_b & humidity, shocks and Modulation S_c T_i^* Regulator vibration reduce the lifetime T_j of a power module as well as thermal cycling Direct measurement of the Observer/ junction temperature is Lookup table/ voltages and currents Thermal equivalent model problematic, which calls for observers, models or lookup Normalized temperature tables Reference Temperature Wear out changes thermal Reference band for minimum and behavior over time maximum temperature Measured Temperature

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time

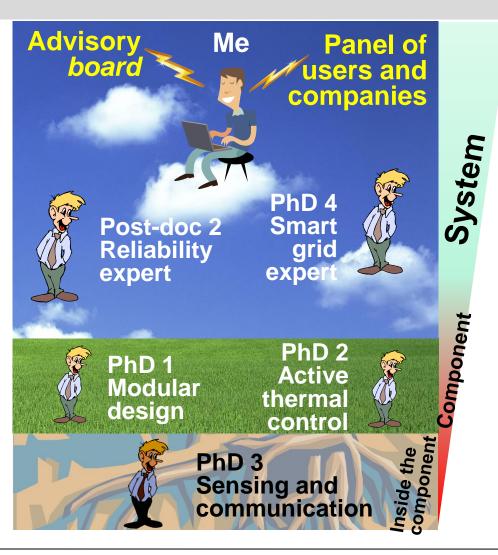
Active Thermal Control



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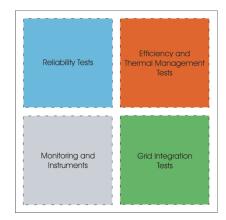
The research team



The project will be carried out in cooperation with



A Laboratory will be developed to carry out the project



Plan of activities

		The Project HEART		
	Research p	blan	Research approaches	
System	Task 1: Reliability analysis of the ST for Overall objective: To bridge reliability of the ST with relia different working conditions, especially those most critical that	Analysis of the hosting capacity and reliability of electric grid Design for reliability (DFR)		
	the components of the S		of the Smart Transformer	
Component	Task 2: Architectural design of the ST (PhD 1 project) Overall objective: To define design guidelines for the architecture (static or reconfigurable) of the ST that could make possible the best trade-off between electrical system requirements and component limits.	Task 3: Active thermal control of the ST (PhD 2 project) Overall objective: To define the optimal control of the ST that could minimize component stress in relation to the power system needs.	Modular design of the Smart Transformer Graph theory to find optimal energy paths	
Inside the Component	Task 4: Implementation solutions (Ph Overall objective: To desig solutions of the ST, throug sensors, control and con	n few optimal energy flow h semiconductors, drivers,	Sensing and communication technologies	

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Timetable

1.1 Analysis of ST features for electric distribution (PD1) X <th>Tasks</th> <th></th> <th>Y</th> <th colspan="2">Year 1</th> <th></th> <th>Yea</th> <th>r 2</th> <th></th> <th>Ye</th> <th>ar 3</th> <th></th> <th>Year</th> <th>r 4</th> <th></th> <th>Year</th> <th>5</th> <th>1</th>	Tasks		Y	Year 1			Yea	r 2		Ye	ar 3		Year	r 4		Year	5	1
PhD courses (1-week international) X	0	Project coordination																1
Public seminars and open-source software N <td></td> <td>Project homepage</td> <td></td> <td colspan="2"></td> <td></td> <td>1</td>		Project homepage																1
2.1 Study of the ST's architectures (1st year PhD1) Image: Star Star Star Star Star Star Star Star		PhD courses (1-week international)		X					2	K						X		S
2.1 Study of the ST's architectures (1st year PhD1) Image: Star Star Star Star Star Star Star Star		Public seminars and open-source software			X					X							X	
2.1 Study of the ST's architectures (1st year PhD1) Image: Star Star Star Star Star Star Star Star		External review (IAB and PUC)								X							X	1 🛱
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2.1 Study of the ST's architectures (1st year PhD1) Image: Star Star Star Star Star Star Star Star	1.	Reliability analysis of the ST from system point of view																1 P
2.1 Study of the ST's architectures (1st year PhD1) Image: Star Star Star Star Star Star Star Star	1.1	Analysis of ST features for electric distribution (PD1)			X					X								ar
2.1 Study of the ST's architectures (1st year PhD1) Image: Star Star Star Star Star Star Star Star	1.2	Assessment of the hosting capacity and reliability of the electric distribution (PD2)								X							X	ers
2.1 Study of the ST's architectures (1st year PhD1) Image: Star Star Star Star Star Star Star Star	N	Report			*					#							#	ő
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