Ageing of Power Electronics in NPP safety systems

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Introduction to the mission

Background

More and more power electronic components (PE) are introduced in NPP´s.

The robustness of a PE component is impacted by ageing and transients.

Developed degradation in a device may be a reason of future failures e.g. during severe transients.

Information and data on ageing and reliability of PE components are available in literature mainly from applications of renewable energy systems and can be relevant also for PE components in NPP´s.

Scope and aim

- Increase the knowledge about ageing of NPP safety system containing PE.
- Conclude on aging mechanisms relevant for NPP´s, specifically power converter safety systems.
- Provide recommendations for health monitoring and exchange strategies for PE in whole or part.

Methods

- Literature study
- Interviews with NPP owners
- Analysis combining information about aging mechanisms with information about NPP specific conditions

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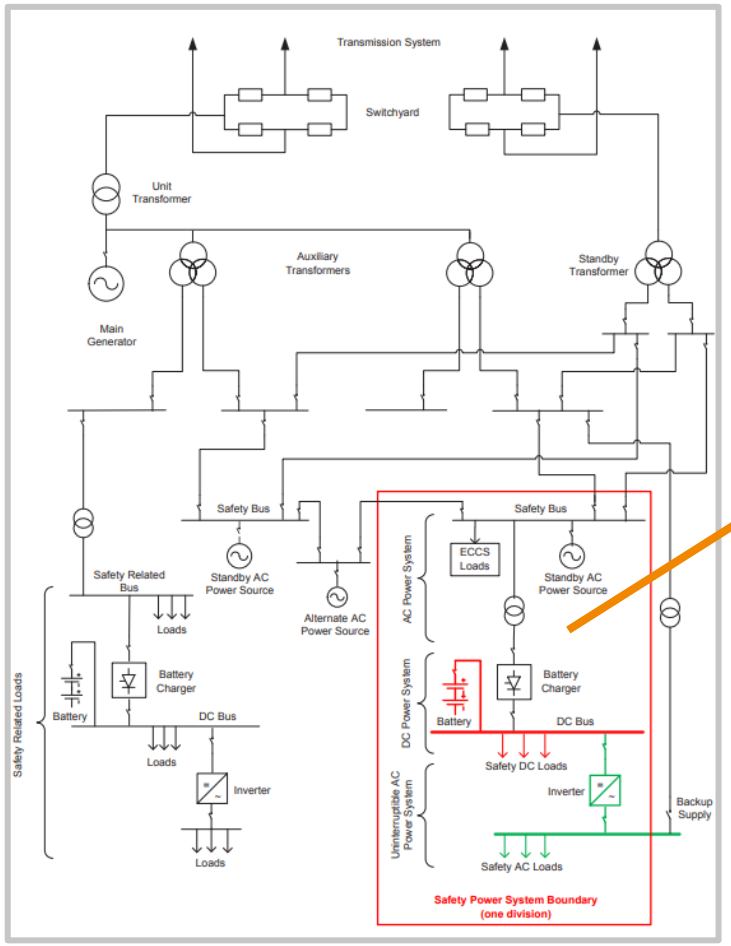
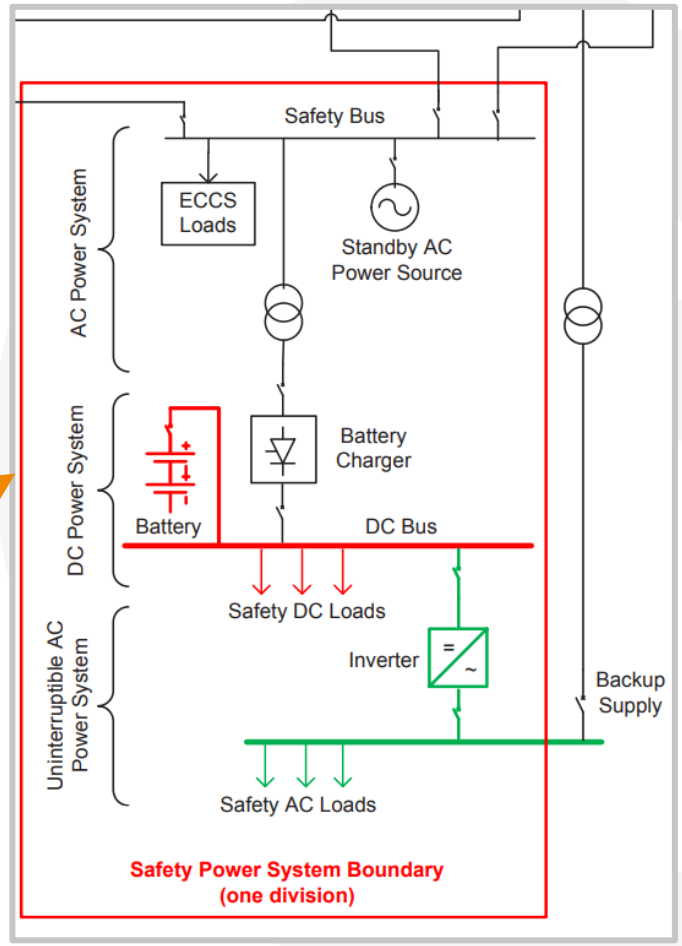
System i focus of the study





Redundant parallel rectifiers feeding each DC bus.

Transient protection often implemented.

Input : 690/500/400V
output : 220/110/48/24V

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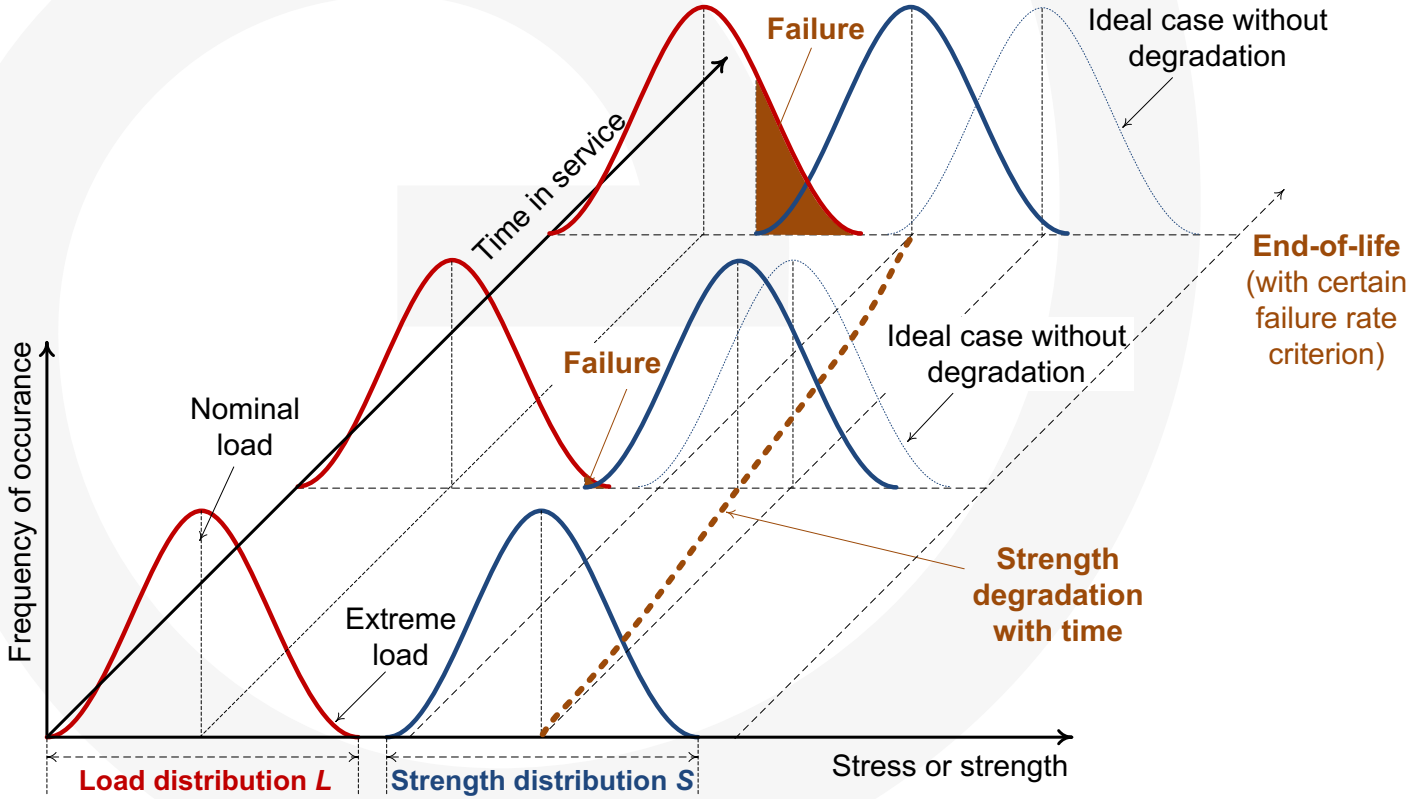
Ageing of power electronics, general introduction

Failure sources and key life cycle phases affect reliability performance

Why a hardware item fails?



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Critical stressors for different components in PE systems

Load			**Focus points**									
Climate + Design => Stressor			Active power components			Passive power components		Control circuitry, IC, PCB, connectors…				
Ambient	Product design	Stressors	Die	LASJ	Wire-bond	Cap.	Ind.	Solder Joint	MLCC	IC	PCB	Connectors
Relative humidity-RH(t) Temperature -T(t)	-thermal system -operation point -ON/OFF -power P(t)	Temperature swing ΔT	**X**	**X**	**X**			**X**				
		Average Temperature T	X	X	X	**X**		X	X	x	x	x
		dT/dt	x	x	x	x						
		Water								**X**	**X**	x
		Relative Humidity	x	x	x	X	x	x	x	**X**	**X**	x
Pollution	Tightness	Pollution						x			x	
Mains	Circuit	Voltage	x	x	x	**X**	X		x	x	x	x
Cosmic	Circuit	Voltage	x									
Mounting	Mechanical	Chock /vibration	x			x	x	x	x			x

*Die – chip of power semiconductor, LASJ - Large Area Solder Joint, MLCC - Multi-Layer Ceramic Capacitor, IC- Integrated Circuit, PCB – Printed Circuit Board, Cap. - Capacitor, Ind. - Inductor, Level of importance (from high to low): **X**-**X**-X-x*

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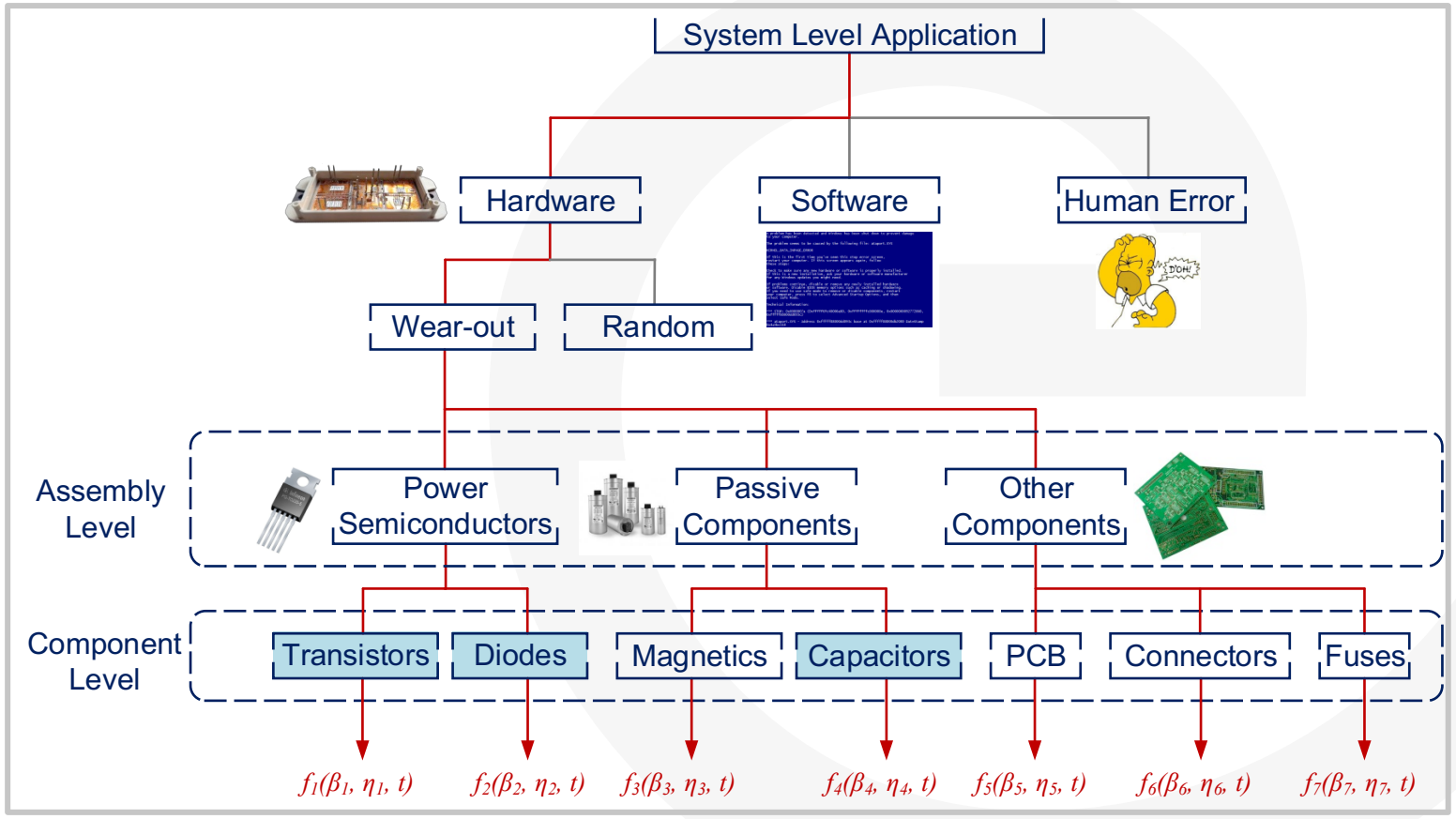
Multi-Components/Multi-Failure Sources in Power Electronic Converters



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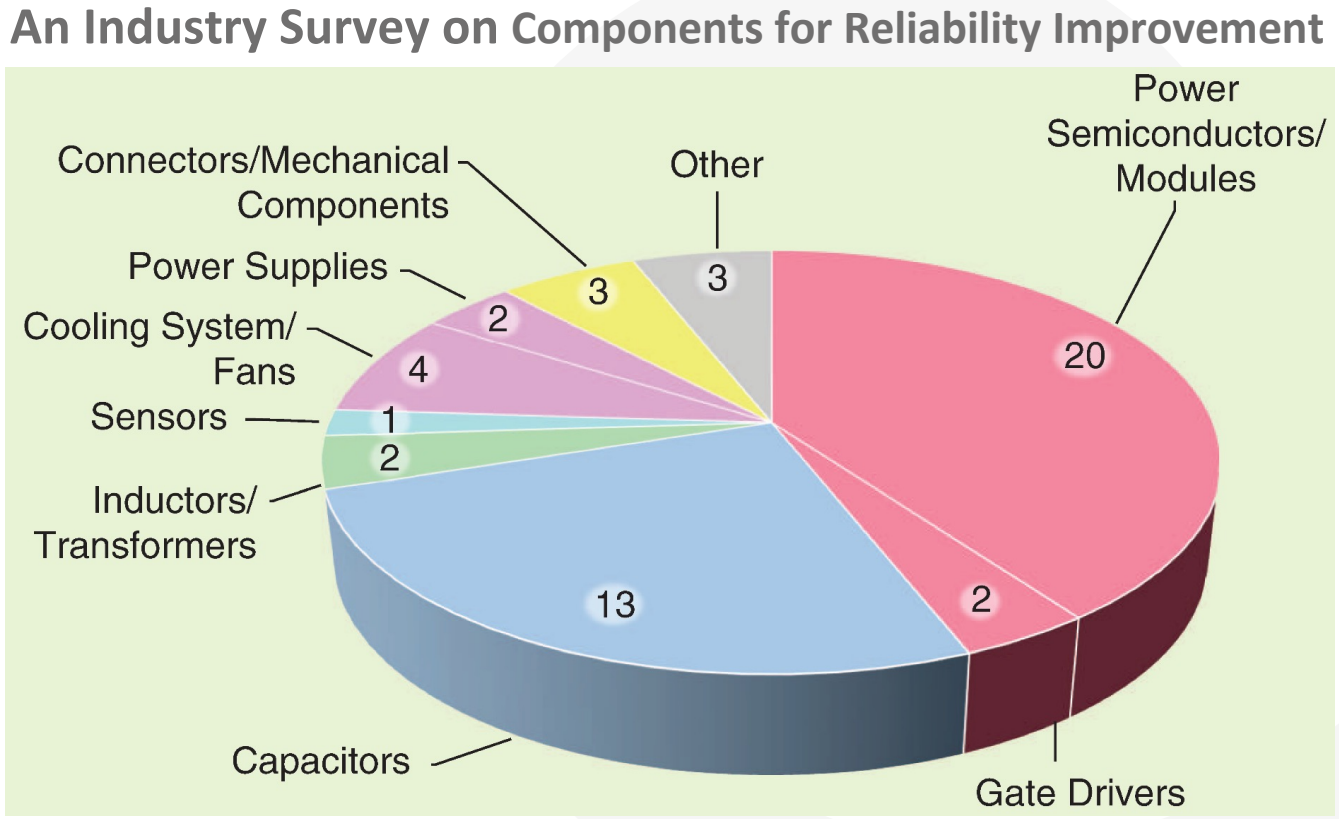

Source: J. Falck, C. Felgemacher, A. Rojko, M. Liserre and P. Zacharias, "Reliability of Power Electronic Systems: An Industry Perspective ," IEEE Industrial Electronics Magazine, vol. 12, no. 2, pp. 24-35, Jun. 2018.

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Interview results

- Components installed are thyristor or switched mode rectifier or a mix of both.
- Operating conditions are dry with stable temperature, controlled electrical conditions and 25-50% normal load.
- Few experiences of transients.
- Few experiences of errors leading to interrupted function.

- Exchanges are performed according to supplier's recommendations. Regular visual inspection.
- Some NPP's have performed exchanges of rectifiers systems, other plan for exchanges in near time.
- Main reason for exchanging equipment is obsolescence of spare parts. Simplified maintenance with module-based design is one advantage often mentioned with new equipment.

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Ageing aspects relevant for NPP conditions

Load			Focus points									
Climate + Design => Stressor			Active power components			Passive power components		Control circuitry, IC, PCB, connectors…				
Ambient	Product design	Stressors	Die	LASJ	Wire-bond	Cap.	Ind.	Solder Joint	MLCC	IC	PCB	Connectors
Relative humidity-RH(t) Temperature -T(t)	-thermal system -operation point -ON/OFF -power P(t)	Temperature swing ΔT	**X**	**X**	**X**			**X**				
		Average Temperature T	X	X	X	**X**		X	X	x	x	x
		dT/dt	x	x	x	x						
		Water								**X**	**X**	x
		Relative Humidity	x	x	x	X	x	x	x	**X**	**X**	x
Pollution	Tightness	Pollution						x			x	
Mains	Circuit	Voltage	x	x	x	**X**	X		x	x	x	x
Cosmic	Circuit	Voltage	x									
Mounting	Mechanical	Chock /vibration	x			x	x	x	x			x

*Die – chip of power semiconductor, LASJ - Large Area Solder Joint, MLCC - Multi-Layer Ceramic Capacitor, IC- Integrated Circuit, PCB – Printed Circuit Board, Cap. - Capacitor, Ind. - Inductor, Level of importance (from high to low): **X**-**X**-X-x*

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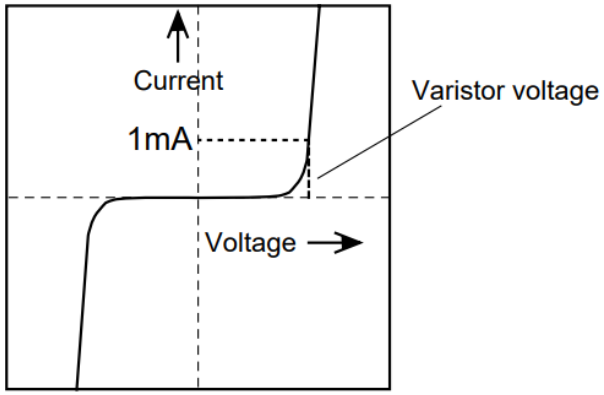
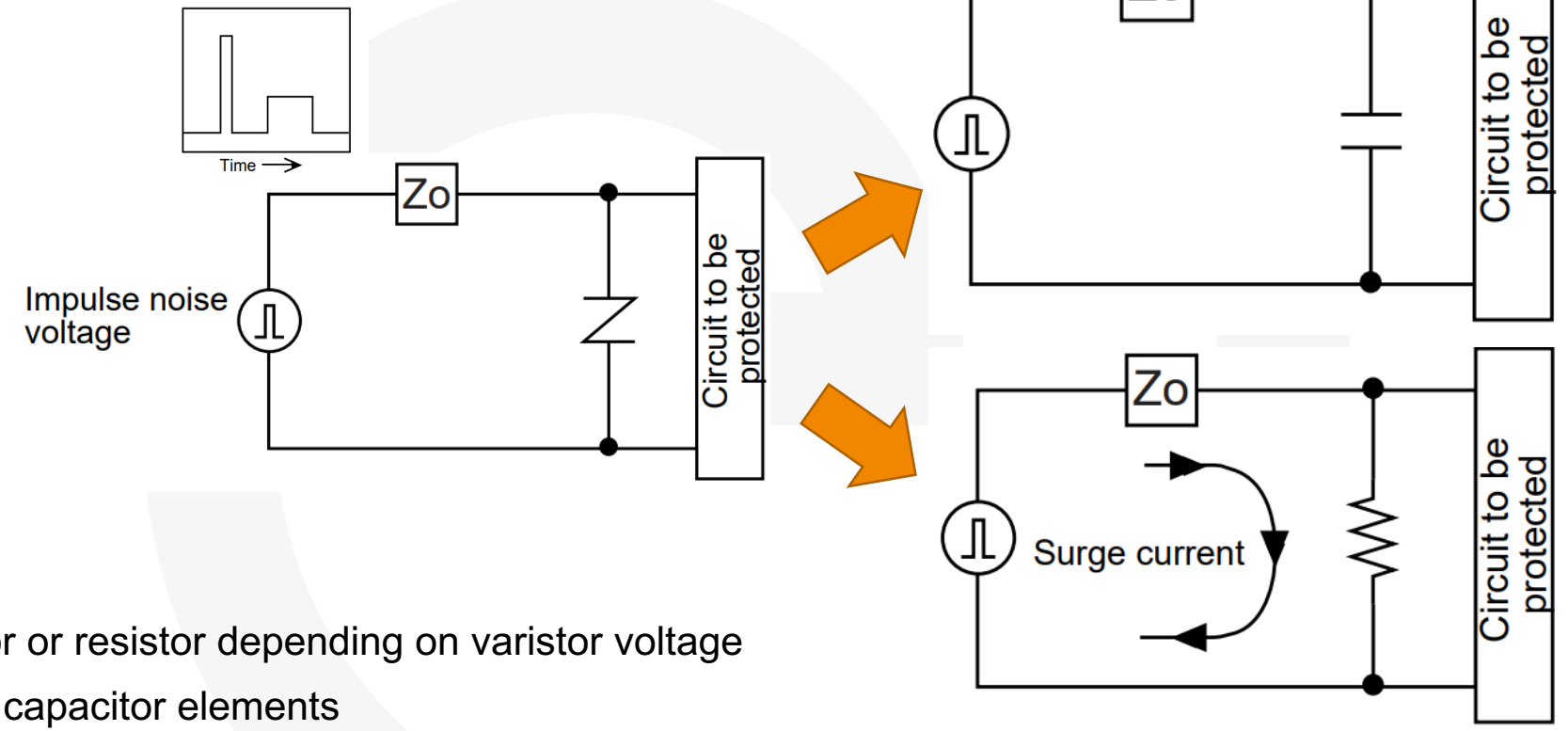
Rectifier technologies - Surge voltage





- Over-voltage capability:
  - Varistor: Function as capacitor or resistor depending on varistor voltage
  - Snubber circuit: Resistor and capacitor elements
- Over-current capability:
  - Thyristor has a much higher over-current capability compared to the transistor

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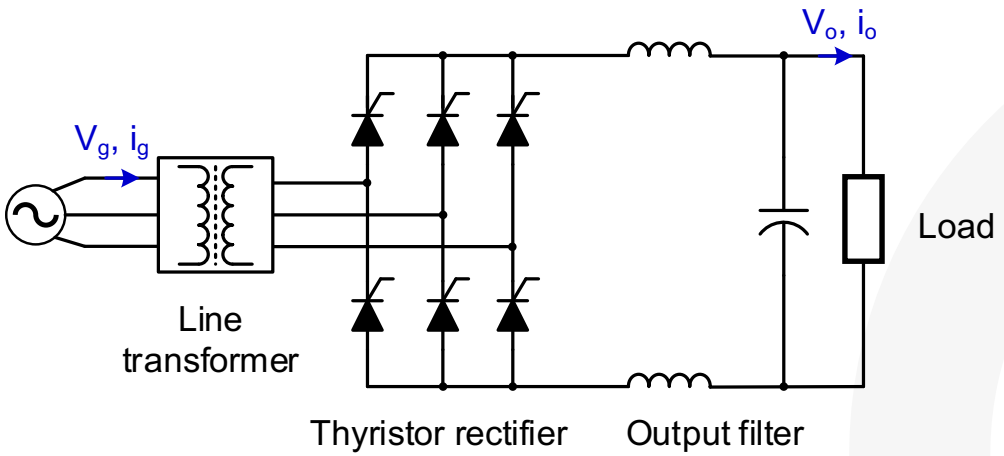
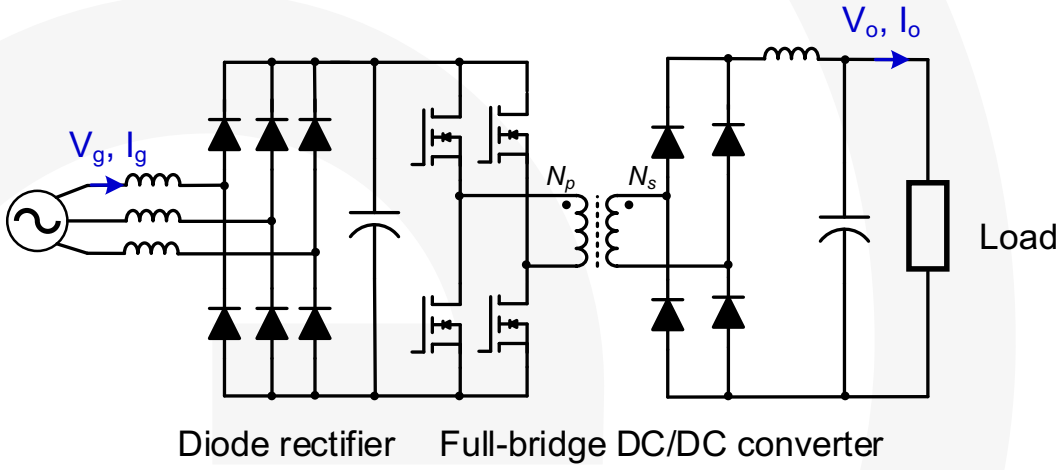
Rectifier technologies - Topologies



Thyristor-based rectifier



Transistor-based rectifier

Rectifier topology	Thyristor-based	Transistor-based
Input voltage	3 * 400 Vac ±10%	3 * 400 Vac ±10%
Output voltage	110 V	110 V
Output current	60 A	60 A
Voltage ripple	5%	1%
Power factor	0.78	0.92
Efficiency	0.93	0.91
Type of cooling	Air natural cooling	Forced-air cooling
Controllability	No SW or programmable device	Pulse width modulation

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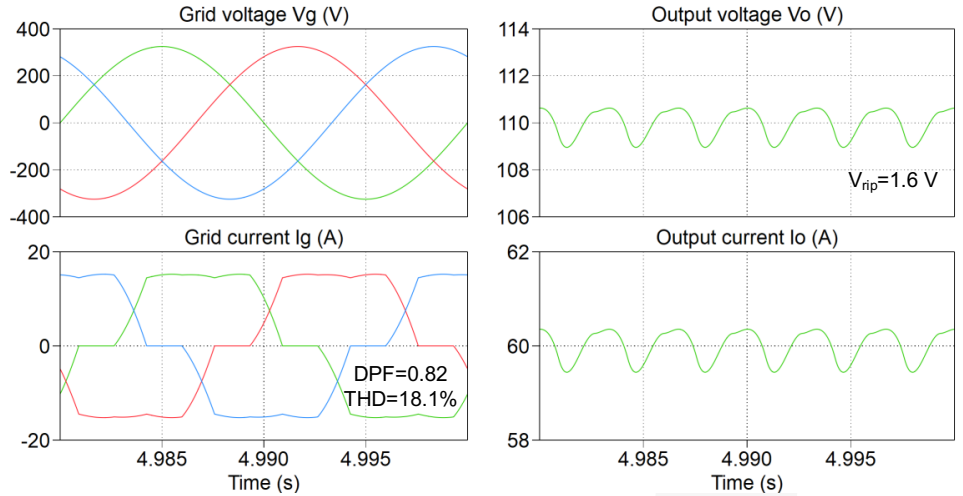
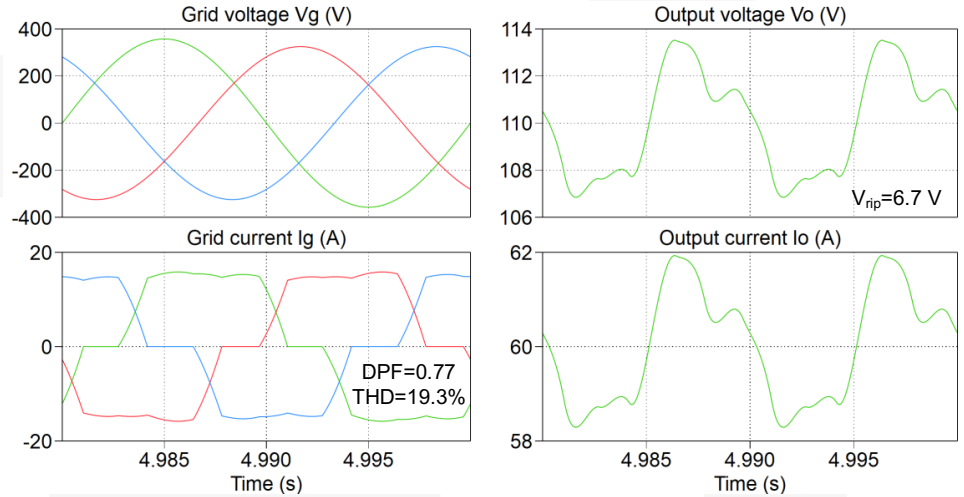
Voltage amplitude variation – Simulation results

Normal grid

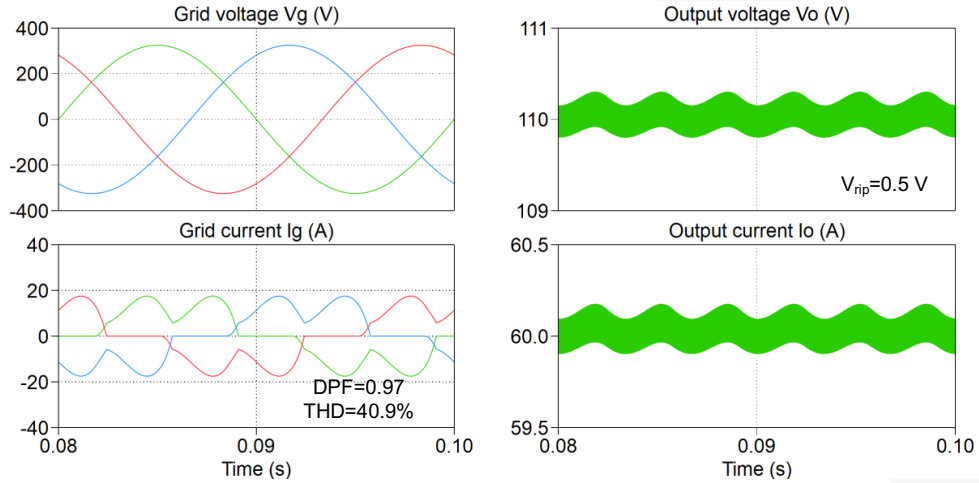
Asymmetrical grid

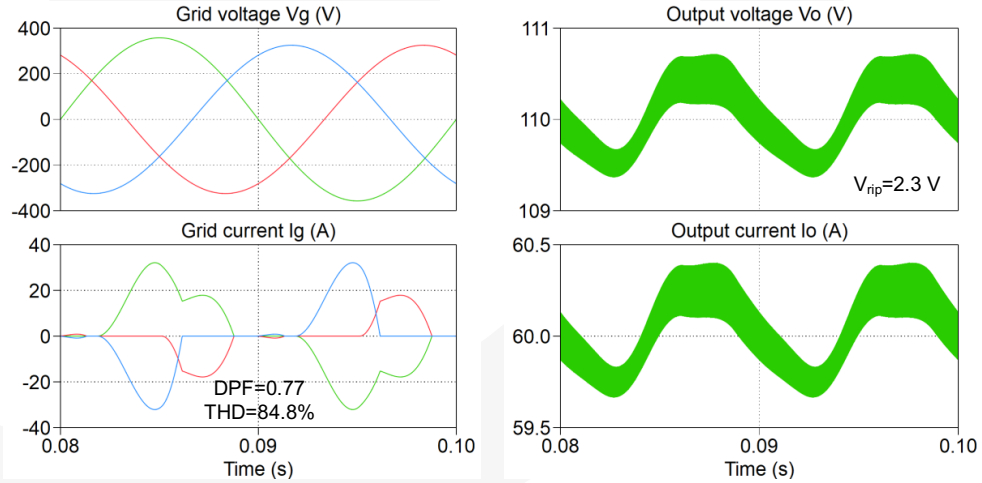
Thyristor -based





Transistor -based





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Conclusions

- Risk of failure due to aging of PE in NPP is much lower as compared to wind- and solar power plants. This is concluded as load as well as environmental stress is much lower in NPP applications.
- Wear-out failure of PE components in the rectifier systems is unlikely as operational load is relatively light.
- Single-event effect, over-stress, misuse, or design defect can cause sudden failure of PE components in NPP, which can be independent of the power level.

- Thyristor-based rectifiers have higher over-current capability from the power semiconductor device perspective. Transistor-based rectifiers achieve better operational performance, leading to lower ripple currents and less impact on the degradation of the batteries to be charged.
- Routine-based maintenance of PE converters is the practice in NPP and it needs to be investigated further whether condition-based methods creates value in NPP application.

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Recommendations

- Collect representative voltage and current data of mains to be able to do further failure cause analysis.
- Investigate further the performance of the front-end protection of the rectifiers in the presence of peaks and transients from the mains.
- Investigate the shelf-life of electrolytic capacitors.
- Study the feasibility and the level of demands for alternative maintenance strategies (e.g., condition-based) as compared to routine-based methods as applied currently.
- Study the feasibility of a new redundancy strategy by increasing the number of rectifiers with lower power ratings.


Thank you!
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