

(E-)HAZOP:

New application domain for the most
known risk analysis technique



Agenda (1)

- ▢ Short introduction Prohead Engineering
- ▢ HAZOP – **HAZ**ard & **OP**erability studies
 - History
 - Typical use cases
 - Method
 - Example
- ▢ E-HAZOP: **E**lectrical **HAZ**ard & **OP**erability studies
 - History & link with HAZOP



Agenda (2)

▢ E-HAZOP: **E**lectrical **HAZ**ard & **OP**erability studies

- Necessity
- Method: 3 sub studies
 - Safety Analysis (SAFAN)
 - System security & Operability (SYSOP) – HAZOP analogue
 - Operator Task Analysis (OPTAN)
- Examples of the 3 sub studies – Battery energy storage system
- Summary

▢ Questions



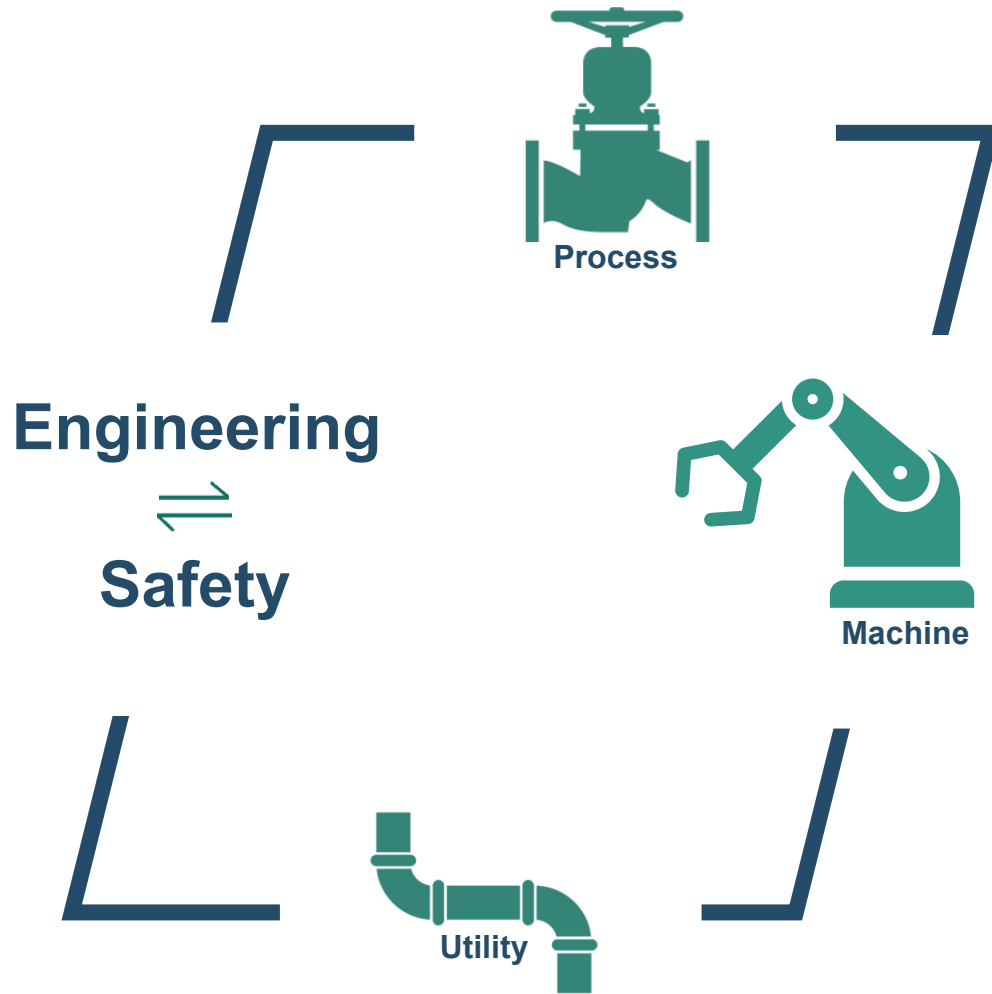
OUR VISION: Performant and safe industry



OUR MISSION: Excellent interdiscipl. engineering



Our expertise:



- 1/ **Process safety** (HAZOP/LOPA/SWIFT, EU/Seveso compliance, PED, ...)
- 2/ **Explosion safety** (EPD, IHA, ATEX, Haz. zone classification, CFD,...)
- 3/ **Process design** (conceptual, basic, design office, calculations, ...)
- 4/ **Functional safety** (SRS/SIL/SIS, PL, V&V, FSA, NIS2, ...)
- 5/ **Machinery compliance** (CE, Machinery directive/regulation, RA, ...)
- 6/ **Safety solution engineering** (conceptual, basic, detailed, ...)
- 7/ **Utility compliance** (RA safety & critical installations, AREI, ...)
- 8/ **Utility Engineering** (Hazardous fluids $H_2/NH_3/...$, loading docks, HVAC, wastewater, steam, power, ...)



end-to-end safety engineering partner for your plant



HAZOP

History

Typical use cases

Method



HAZOP: History



Developed in 1960's by chemical companies

Formalised, fine-tuned and labelled (~1983) by Trevor Kletz

→ EN-IEC 61882

Structured and systematic technique:

- Done by multidisciplinary team of experts
- Identification of hazards & risks

After identification of hazards & risks

→ Determining current safeguards and required additional safeguards

→ (Inherent) safer design



HAZOP: Typical use case

Usually performed during 3 stages:

- | | |
|----------------------|------------------|
| 1. During design: | “Design” HAZOP |
| 2. During operation: | “As built” HAZOP |
| 3. MoC: | “Design” HAZOP |

➔ Safer design and operation

HAZOP: Method



Dividing process / installation into smaller parts (nodes)

Systematic discussion of possible deviations (guide word + parameter)

- Cause(s)?
- Consequence(s)?
- Current safeguards?
- **Risk assessment**
- Recommendations required?

Guide word	Parameter	Deviation
No	Flow	No flow
More	Pressure	Higher pressure
Less	Temperature	Lower temperature
...	...	...

HAZOP: Method



Risk assessment according to risk matrix

- Calibrated
- (Usually) corporate matrix
- Example shown below

For this HAZOP study, a risk matrix is used that balances the severity of the hazard against the likelihood of the hazard in order to obtain a risk ranking. The following risk rankings are distinguished in the matrix to evaluate the hazard scenario:

- 1 Stop the work immediately
- 2 Measures required
- 3 Measures recommended
- 4 Attention required
- 5 No measure necessary

Severity	Likelihood				
	LL1	LL2	LL3	LL4	LL5
E5	3	2	1	1	1
E4	3	2	2	1	1
E3	4	3	2	2	1
E2	5	4	3	2	1
E1	5	5	4	3	2

Example of HAZOP worksheet



Deviation	Causes	Consequences	CAT	Inherent Risk			Safeguard	Eff ?	Current Risk			Recommendations	Residual Risk			Notes
				S	LL	RR			S	LL	RR		S	LL	RR	
7. Higher pressure	1. blocked in water line	1. pressure surpassing design pressure of heat exchangers / piping	CN T	E3	LL4	2	1. Design pressure of piping is PN 10. Pump discharge pressure 3 barg, static pressure 7 barg	N	E3	LL4	2	26. Consider implement safety valves per drying zone. Preference for a closed system solution with a PSV not effected by back-pressure	E3	LL2	3	1. Pmax: 16 barg for HE
												27. Attention to be paid: leakage to be avoided on the kiln. Water leakage containment on top of kiln and evacuation away from kiln must be implemented.				2. practical installation: avoid water entry in kiln at all costs (steam explosion)
												48. Consider implementing possibility to bypass and decouple a HE on top of kiln, to ensure process continuity.				3. leakage containment on top of kiln: excavation of water away from kiln (metal connection/drain)
												77. Consider utilizing a higher pressure rating for the water circuit piping to ensure sufficient margin between the maximum occurring operating pressure (pump discharge pressure and static pressure), the set pressure of the pressure safety valves and the pressure rating of the water circuit piping.				4. 'start up' 1/y expected --> thermal cycling low.
																5. bolts: thermal galanised bolts required

E-HAZOP

Application of HAZOP method to Electrical
installations
(High Voltage)



E-HAZOP/SAFOP: History

- Method less showcased compared to HAZOP
- First documented use in 1993 (L.D. Forster, W.H. Brown):
Instrumentation and control HAZOP: A new application of technology for the Auger tension leg platform (<https://doi.org/10.4043/7119-MS>)

Performed complementary to regular HAZOP

Focussed on instrumentation & control systems (ballast & bilge control, F&G detection, compressors, ...)

Also “somewhat time and resource intensive”

- Further development in-house → No visibility in literature

E-HAZOP: Necessity



Electrical installation: Shift in focus from black box to full-fledged process installation

E.g.

- Battery park for temporary electricity storage
- Green H₂ production (electrolysis)
- Shore power supply
- Wind turbine
- Water dam

HAZOP inadequate in its current form for electrical (process) hazards

E-HAZOP: Necessity



Belgium: Strictly regulated

Low voltage: GREI Book 1

High voltage: GREI Book 2

Transmission & distribution: GREI Book 3

GREI: focus on verification

No validation of inherent safer design

Cfr. Book 1/2/3 §5.1.1.1:

*“ The electrical material must be chosen and installed ...
... to ensure that people and goods will not be at risk”*

New technologies preceding standards: demonstrating safety

➔ E-HAZOP as risk analysis & verification of basis of design



E-HAZOP: Method (1)

E-HAZOP adapts HAZOP method for

▢ **Systematic design evaluation**

▢ **Safety**

- People (personnel, contractors, public)
- Installation
- Environment

For electrical installation

▢ **Objectives:**

- Evaluate & minimise hazards to people (in vicinity of) installation
- Evaluate installation design on operability and safety overall system
- Task risk analysis for field and remote operator



E-HAZOP: Method (2)

Broad objectives E-HAZOP → split in 3 sub studies

1. SAFAN: Risk Analysis hazards present during construction, commissioning & operation on personnel
2. SYSOP: Risk Analysis of the installation design (HAZOP analogue)
3. OPTAN: Risk Analysis operator tasks (Field & control room): Y/N questions

Timing:

- Initial study – after completion conceptual design
- Final study – after (90%) completion of design

E-HAZOP: Method (3)



Systematic evaluation:

- Dividing installation into '**Elements**' (~ HAZOP nodes)
- Use of typical **hazards, guide words & key words** to stimulate creative thinking
Note, **different lists per sub study**
- **Team of experts** (multidisciplinary)
- Risk assessment
- Safeguards
- (Additional) **Recommendations**
- Structured reporting of results (cfr. HAZOP worksheets)

E-HAZOP

E-HAZOP Sub study flow charts

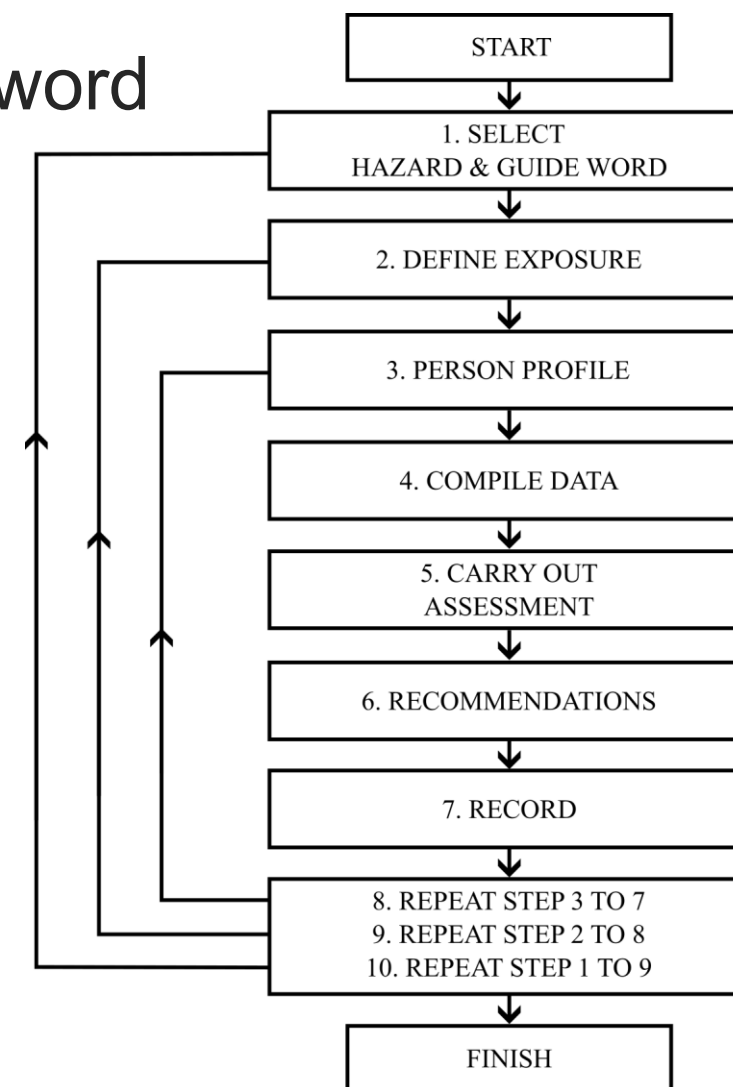
Safety Analysis	(SAFAN)
System security & Operability	(SYSOP)
Operator task analysis	(OPTAN)

E-HAZOP: SAFAN



SAFAN: Flowchart, example of hazard & guide word

Hazard	Guide word
Electrocution	Direct contact
	Indirect contact
	Vicinity
	Induction
	Step potential
	...
Fire	Poles
	Batteries
	(diesel)generator
	AC arc
	DC arc
	...

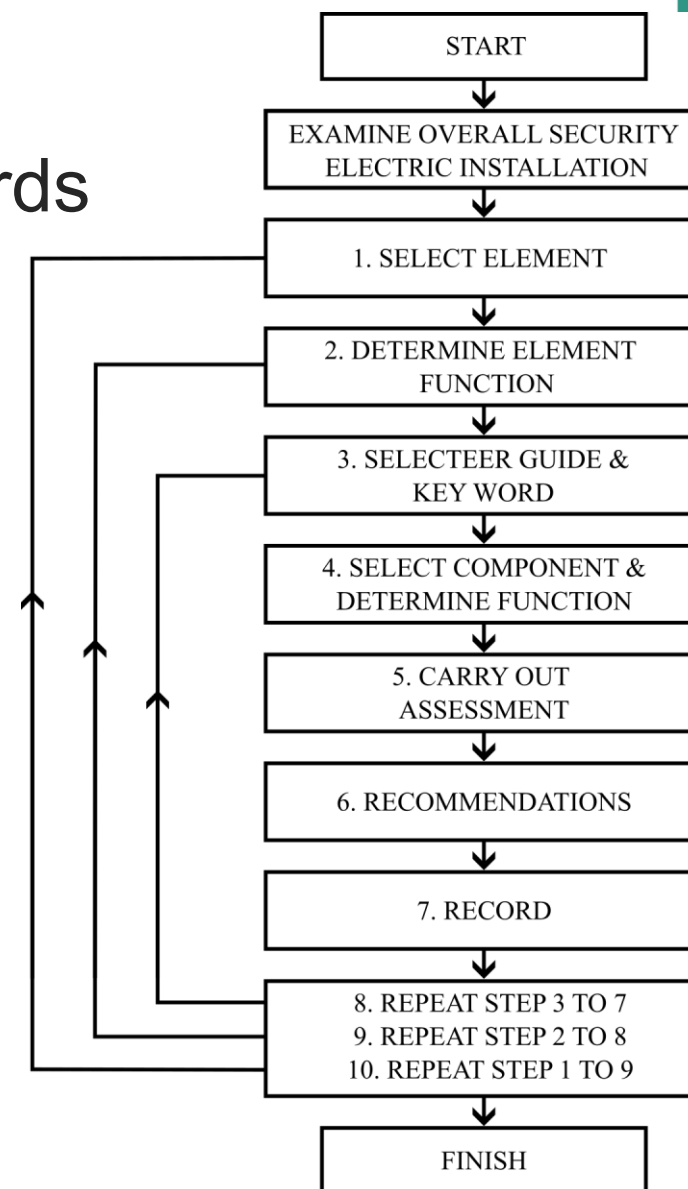


E-HAZOP: SYSOP



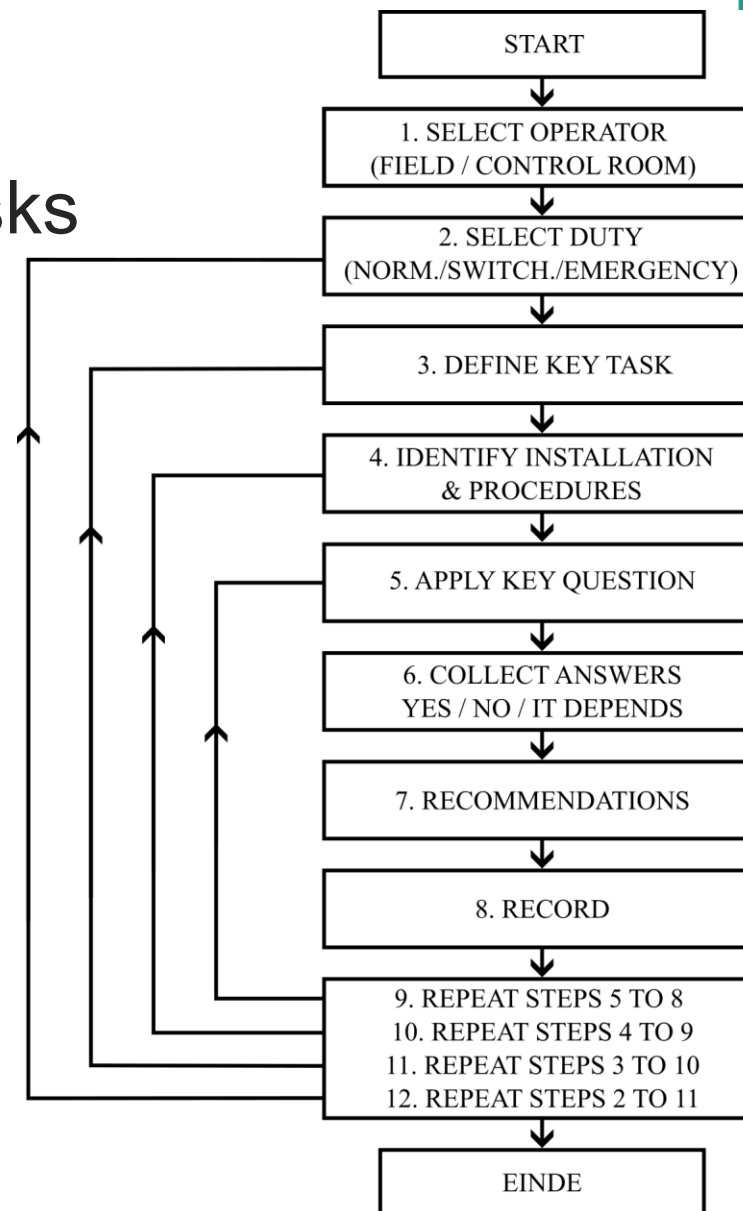
SYSOP: Flowchart, example of guide & key words

Guide word	Key word
Identify	Unable to identify Misleading identification Misidentify
Operate	Will not operate Will not open Will not close Will not trip Will not tap ...
Control	Cannot control Incorrect control ...



OPTAN: Flowchart, example of duty & key tasks

Duty	Key Task
Normal duties	Monitor / check Make decisions Actions
System switching	Monitor / check Make decisions Actions
Abnormal/emergency conditions	Monitor / check Make decisions Actions



E-HAZOP: Method



Similarities with HAZOP:

- Systematic and detailed
- Team of experts (multidisciplinary)

Unique characteristics (compared to HAZOP):

- Risk Analysis for **construction, commissioning** and **operation**
 - Safety Analysis (personnel safety)
 - SYSOP (installation safety)
- **Task Risk Analysis** operator duties (OPTAN)

➔ Safer design & operation of installation

E-HAZOP

Elucidation of E-HAZOP execution

Anonymised case study example



E-HAZOP: Anonymised case study

Starting conditions

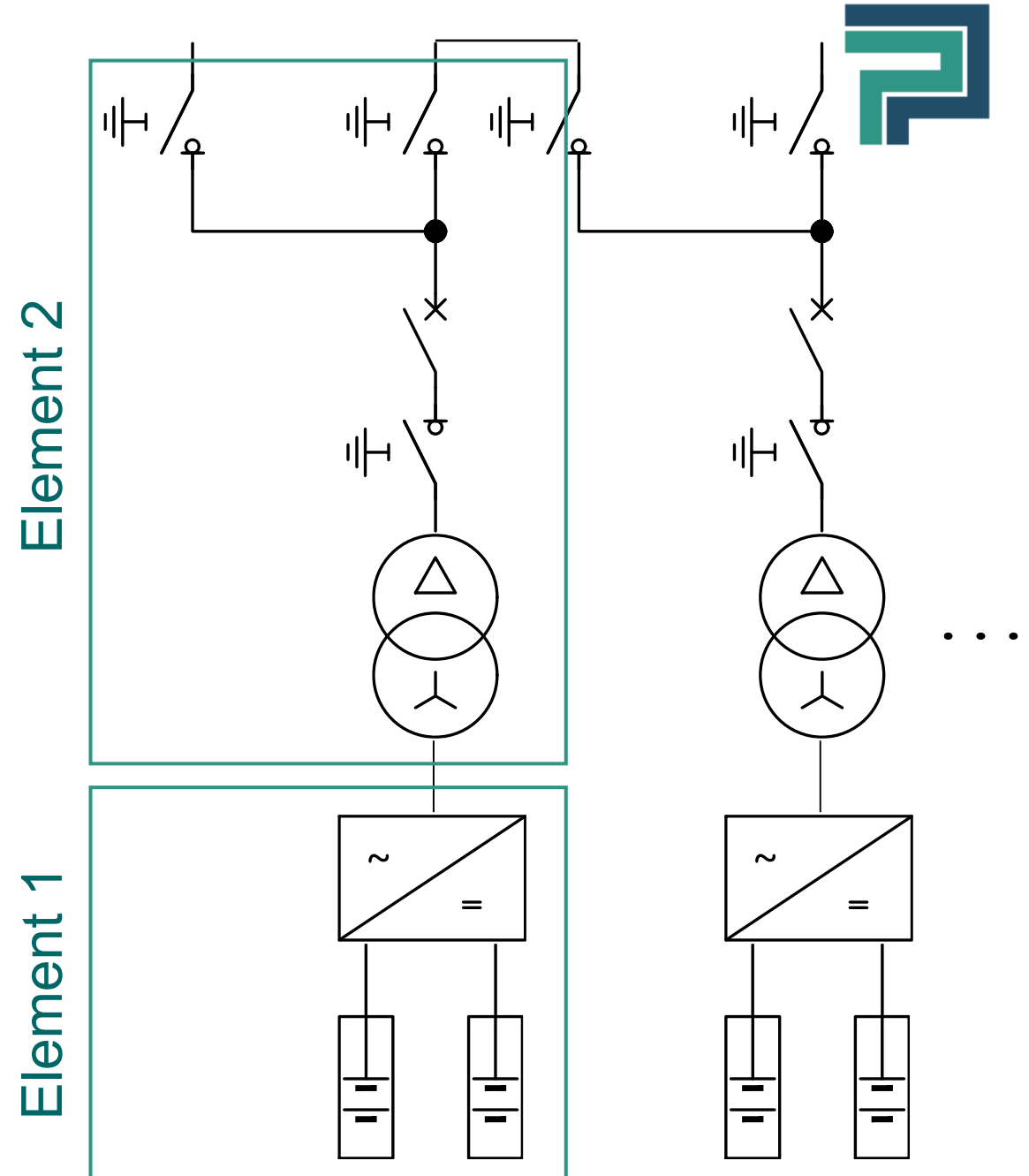
- Availability of required information:
Layout, **single line diagram**, design basis, power, earthing, lightning protection
- Availability team of experts
- Dividing installation in “logical” parts (**Element**)
- Choice and execution of sub study
 - SAFAN
 - SYSOP
 - OPTAN

BESS typical (1)

Design & single line diagram

- Batteries
- Power conversion DC → AC
- Transformer
- Coupling (with Ring Main Unit)
 - To next transformer / battery unit

Designation of “**Elements**”

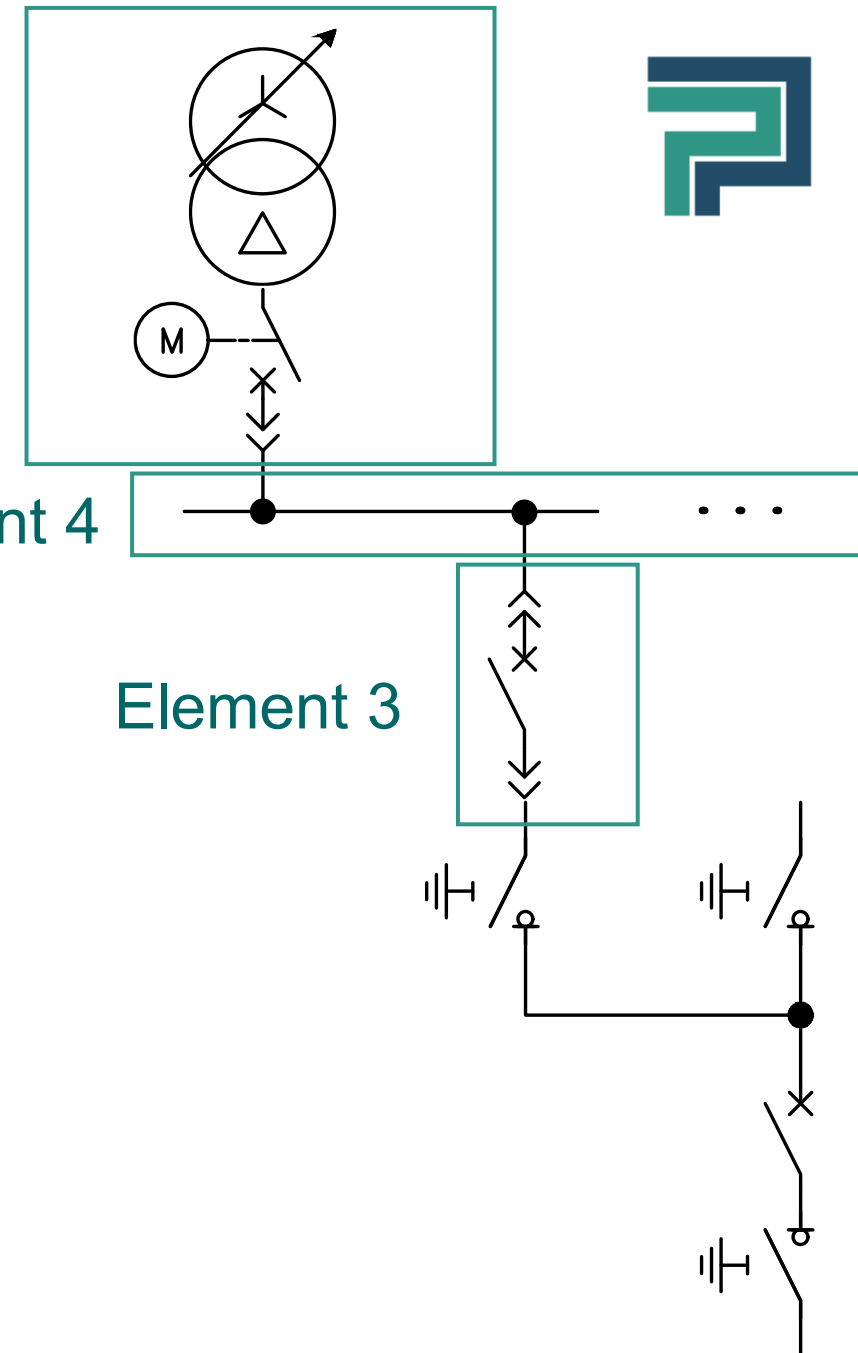


BESS typical (2)

Design & single line diagram

- Combination into string of batteries
- Distribution cabinet
- Step up transformer
- High voltage grid

Designation of “Elements”



Risk matrix



Utilised risk matrix (received)

Severity	Likelihood			
	LL4	LL3	LL2	LL1
S4	A	A	B	C
S3	A	B	C	D
S2	B	C	D	D
S1	C	D	D	D

Risk	Description
A	Unacceptable risk. Reduction to C/D with technical measures and/or different technology
B	Unacceptable/unwanted. Reduction to C/D with technical and/or organisational measures
C	ALARP – risk reduction to D is advised unless excessive cost compared to achieved reduction
D	Acceptable



Safety Analysis (SAFAN)

Applied to case study:

Battery park energy storage system



BATTER
EXHAUST

Safety Analysis (SAFAN)



During construction – Elektrocution

Guide Word	Scenario	Profile	Conseq.	Inherent risk			Safeguard	Eff	Current risk			Recommendation	Residual risk		
				S	LL	RR			S	LL	RR		S	LL	RR
direct contact	Damaging live underground HV cable	contractor	Damage to machinery and 1 casualty	4	4		1. Use of KLIP/KLIM plans 2. Test trenches 3. Mechanical protection of HV cable 4. HV as a ring	Y Y N	4	1		1. Implement digging procedure, e.g. flat bucket, manual excavation 2. Evaluate possibility to de-energise HV cable	4	1	

Safety Analysis (SAFAN)



During construction – Elektrocution

Guide Word	Scenario	Profile	Conseq.	Inherent risk			Safeguard	Eff	Current risk			Recommendation	Residual risk		
				S	LL	RR			S	LL	RR		S	LL	RR
Testing / measuring	Testing HV cable	BA4/5	Injury (electrification)	4	3		1. Marking tested cable 2. Barrier at testing site 3. Work permit 4. Access control	Y Y Y N	4 1						
		contractor		4	3		1. Marking tested cable 2. Barrier at testing site 3. Work permit 4. Access control	N Y N Y	4 1						

Safety Analysis (SAFAN)



During construction - Fire

Guide Word	Scenario	Profile	Conseq.	Inherent risk			Safeguard	Eff	Current risk			Recommendation	Residual risk		
				S	LL	RR			S	LL	RR		S	LL	RR
Batteries	Short circuit between poles due to transport / manipulation	external	Battery container on fire	4	3		1. Battery delivered with low SOC 2. Battery delivered with poles disconnected	Y Y	4 1						
Cylinders	Gas torches used during crimping	contractor	Fire due to gas leak	4	4		1. Periodic check material 2. Excess flow valve 3. Work permit 4. Training 5. Extinguishers	Y Y Y Y	4 1						

Safety Analysis (SAFAN)



During commissioning – Electrocution

Guide Word	Scenario	Profile	Consequence	Inherent risk			Safeguard	Eff	Current risk			Recommendation	Residual risk		
				S	LL	RR			S	LL	RR		S	LL	RR
direct contact	Direct contact with live part in distribution panel	BA5	Casualty	4	4		1. Physical barrier: closed panels 2. Only BA4/5 personnel 3. Opening panel trips breaker 3. Installation with correct IP protection 4. Electrical building locked 5. GREI compliant 6. Work permit – validation	Y Y Y N N N Y	4	1					

Safety Analysis (SAFAN)



During operation – Electrocution

Guide Word	Scenario	Profile	Consequence	Inherent risk			Safeguard	Eff	Current risk			Recommendation	Residual risk		
				S	LL	RR			S	LL	RR		S	LL	RR
Vicinity	Vicinity of live part during periodic checks	BA5	Casualty	4	4		1. Physical barrier: closed panels 2. Only BA4/5 personnel 3. Opening panel trips breaker 4. Electrical building locked 5. GREI compliant 6. Work permit with cross check	Y Y Y N Y Y	4	1					

Applied to case study:
Battery park temporary energy storage

Battery park temporary energy storage

System security & operability (SYSOP)



Element 1: batteries & power conversion unit

Guide Word	Key word	Deviation	Conseq.	Inherent risk			Safeguard	Eff	Current risk			Recommendation	Residual risk		
				S	LL	RR			S	LL	RR		S	LL	RR
Identify	Misidentify battery container	Working on wrong battery container	Electrocution	4	4		1. Vital 7: testing 2. BA5 personnel 3. Work permit LMRA with cross check 4. systematic numbering	Y Y Y N	3	2		1. Consider to decouple all adjacent batteries	3	1	

System security & operability (SYSOP)



Element 2: Transformer & RMU

Guide Word	Key word	Deviation	Conseq.	Inherent risk			Safeguard	Eff	Current Risk			Recommendation	Residual risk		
				S	LL	RR			S	LL	RR		S	LL	RR
Control	Wrong control	Switching onto earth	Earth fault: High current, Damage to transformer	4	4		1. Global earthing grid 2. Mechanic and electric interlock in RMU 3. Breaker in RMU 4. Transformer dimensioned on max peak current PCU	N Y Y	3	2		1. Verify protection in batteries and implement disconnection upstream and downstream breakers	3	1	

Operator Task Analysis (OPTAN)

Generic example





Operator Task Analysis (OPTAN)

▣ Execution planned

Operator profiles:

- Control room operator (remote),
- Field operator

Duties:

- Normal operation unmanned site with automatic control
- (partial) disconnection for testing and maintenance, ...
- Emergency: fire detection battery container, blackout, ...



Operator Task Analysis (OPTAN)

▢ Hypothetical example:

Partial disconnection / shutdown by malfunction battery

1. Identify the battery container and according string
2. Verify disconnection sequence
3. Send open command to breaker(s)
4. Verify breaker position
5. Send open command relevant disconnecter PCU and/or RMU
6. Verify disconnecter position
7. Earth the system at point x
8. ...

Operator Task Analysis (OPTAN)



Control room operator (remote)

Duty: system switching

Key Task (Monitor)	Equipment	Y/N	Required knowledge	Recommendation
Is the faulty battery easily and uniquely identifiable?	Battery container with IDtag "X"	N	-Layout site -Structure of tag "X" -Identify malfunction	1. Consider separate alarm per battery/ PCU 2. Consider adding the tag to the battery containers 3. Implement a separate window with active alarms 4. Implement alarm hierarchy
Is the string with faulty battery easily identifiable?		Y	-Layout site -Structure of tag "X"	5. Consider graphical representation of strings 6. Digital document system recommended



Operator Task Analysis (OPTAN)

➤ (Nearly) all questions should be replied with “Y”

➤ Key tasks with “N”

→ Identification of possible operator errors

- Change procedure / visualisation / ...
- Investigate separate cross check possibilities
- Evaluation of economic feasibility



E-HAZOP

Summary

E-HAZOP



- Specific risk analysis for electric (High Voltage) risks
- Consists of 3 sub studies
 1. SAFAN (Safety Analysis):
RA layout installation on personnel: construction, commissioning & operation
 2. SYSOP (System security & Operability):
RA installation design & operation (HAZOP analogue)
 3. OPTAN (Operator task analysis):
RA operator tasks (local & control room)



Questions?

Abbreviations



Abbreviation	Description
HAZOP	HAZard & OPerability studies.
E-HAZOP	Electrical HAZard & OPerability studies.
SAFAN	SAFety ANalysis
SYSOP	SYstem Security & OPerability analysis
OPTAN	Operator Task Analysis
GREI	General Regulation of Electrical Installations
BESS	Battery energy storage system
AC	Alternating Current
DC	Direct Current
HV / LV	High voltage / low voltage
RA	Risk analysis