Demand Management for Power-Critical Off-Grid Industrial Applications

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Overview of the Challenge

Overview

The project tackles the issue of power reliability due to unexpected power shortages

- Focused, but not limited to, mining industry application
- Power shortages cause financial losses
- 15 seconds of power shortage → up to 30 minutes recovery → delays in the work of the plant → the whole infrastructure can be affected & significant loss of revenue!

Solutions?

Redundancy

- High cost
- Environmental impact

Spinning reserve

- The usage of generators is not optimal

BESS

- High cost

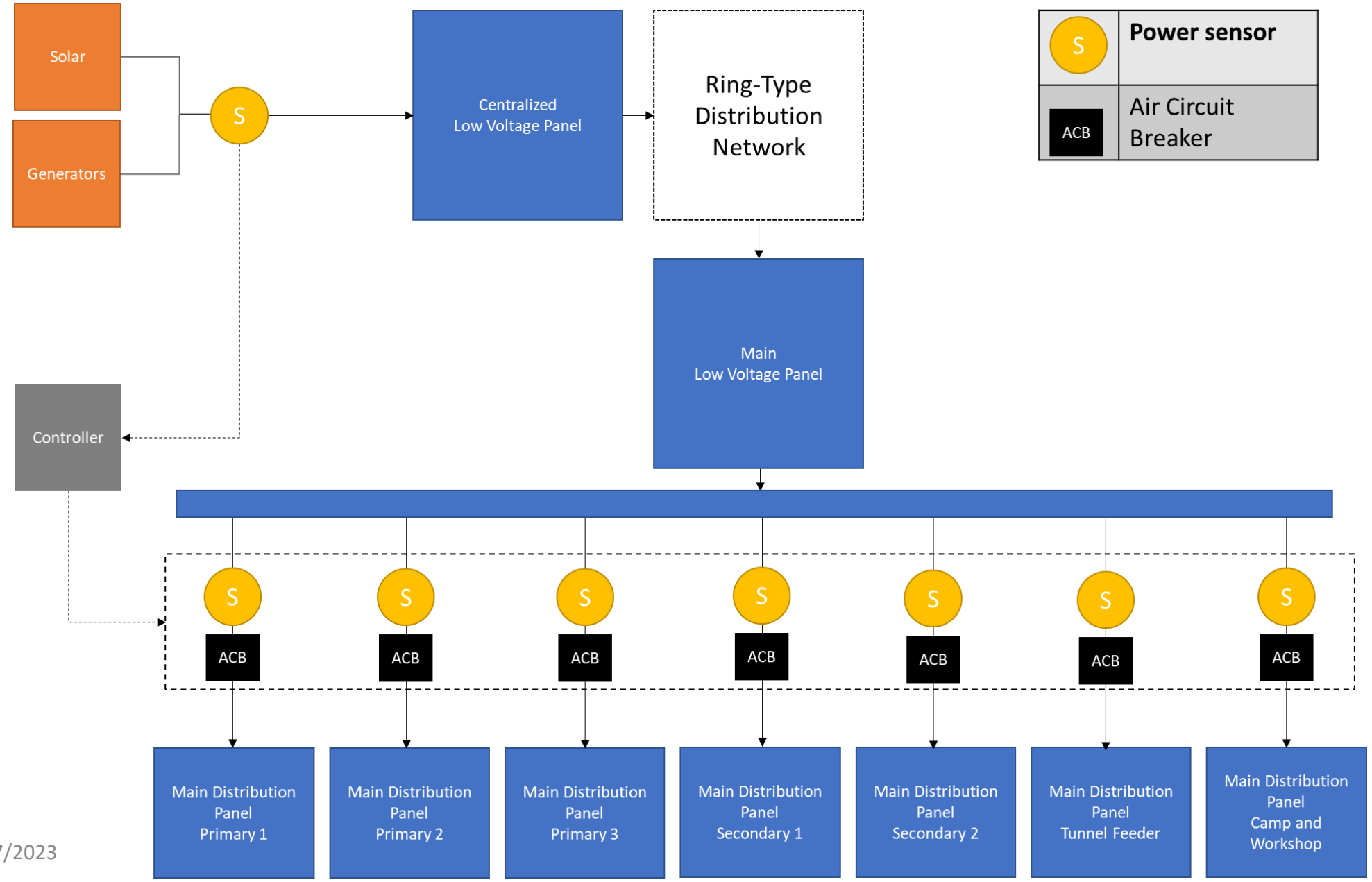
Proposed System

The proposed solution will allow to **buy time** to recover power availability while keeping the plant in operation.

Implementation of **load shedding mechanism** – disconnecting loads to balance the demand and generation.

System Design

- Plant Setup -


Solar
Generators
S
Centralized
Low Voltage Panel
Ring-Type
Distribution
Network
S
Power sensor
ACB
Air Circuit
Breaker
Main
Low Voltage Panel
Controller
S
ACB
Main Distribution
Panel
Primary 1
Main Distribution
Panel
Primary 2
Main Distribution
Panel
Primary 3
Main Distribution
Panel
Secondary 1
Main Distribution
Panel
Secondary 2
Main Distribution
Panel
Tunnel Feeder
Main Distribution
Panel
Camp and
Workshop

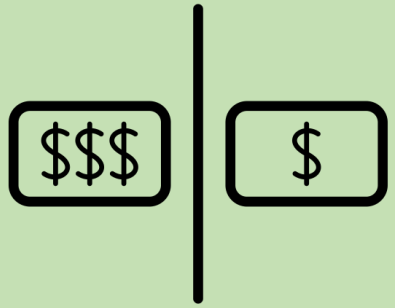
Disconnection priority of load types

	Load type	Load	Disconnection Priority
Mining machinery	Tunnel Feeder	50 kW	1
	Secondary 1	1,653 kW	2
	Secondary 2	234 kW	2
Site facilities	Camp and workshop	400 kW	3
Mining machinery	Primary 2	434 kW	4
	Primary 1	362 kW	5
	Primary 3	419 kW	5

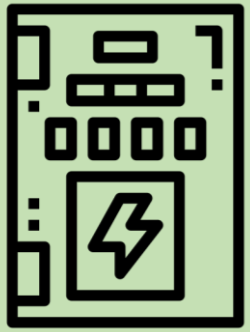
Stakeholder Expectations

Roundtrip response time of 10 milliseconds

Energy efficient system



Cheaper compared to other solutions



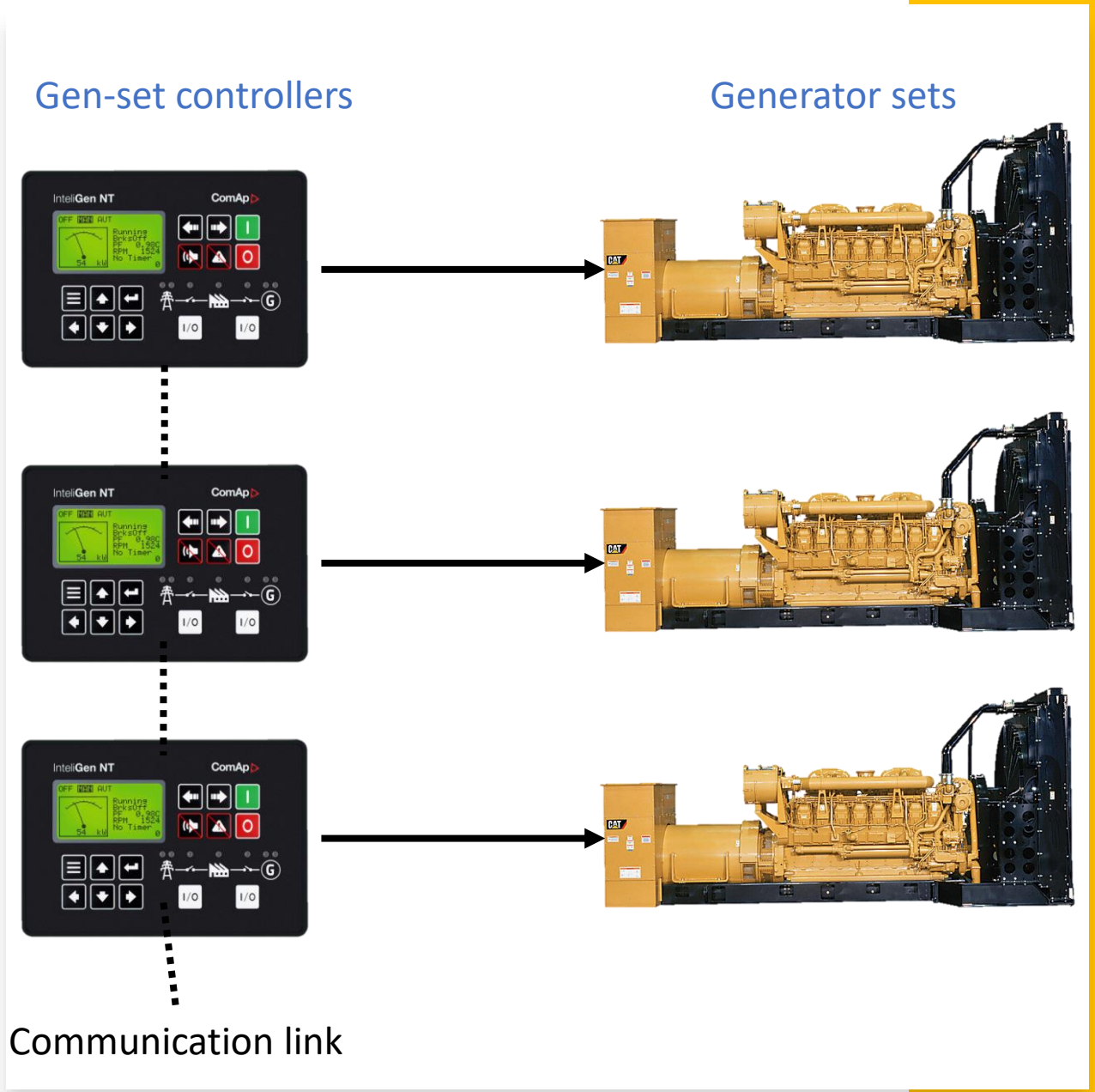
No interference to existing electrical equipment

Data security is preserved

Adherence to local regulations

Gen-set control

- They manage the power generated considering many variables as generator availability, generator and grid characteristics, load demand, etc.
- They log information about the status of the generators. This information can be accessed in real time via a communication link.

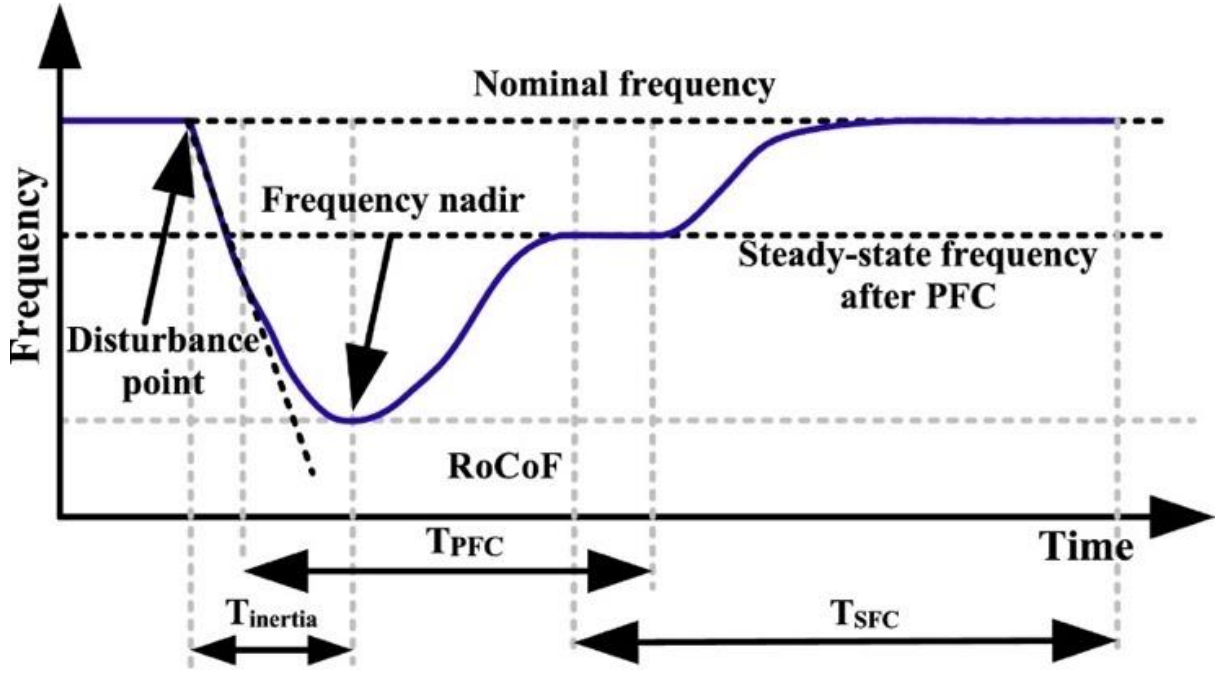


Inertial response in power systems

- In power systems, kinetic energy (KE) is stored in the rotating parts of synchronous generators (SG). **This plays an important role in frequency stability.**
- If a generator fails, the shortfall is initially offset by KE released by the generators, known as **system's inertial response**.

Frequency control in power systems

- A power disturbance impairs the equilibrium of generation and demand, causing a Frequency deviation. Primary Frequency Control (PFC) is in charge of restoring this equilibrium.
- If frequency exceeds permissible limits, additional measures out of the scope of PFC such as Load-Shedding are required.

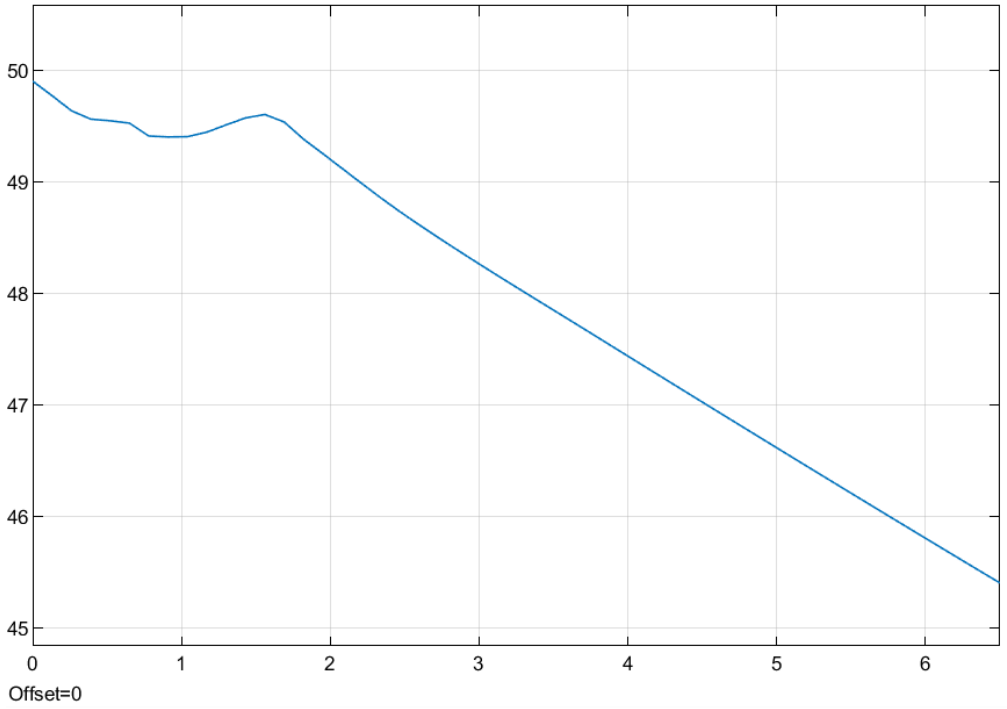


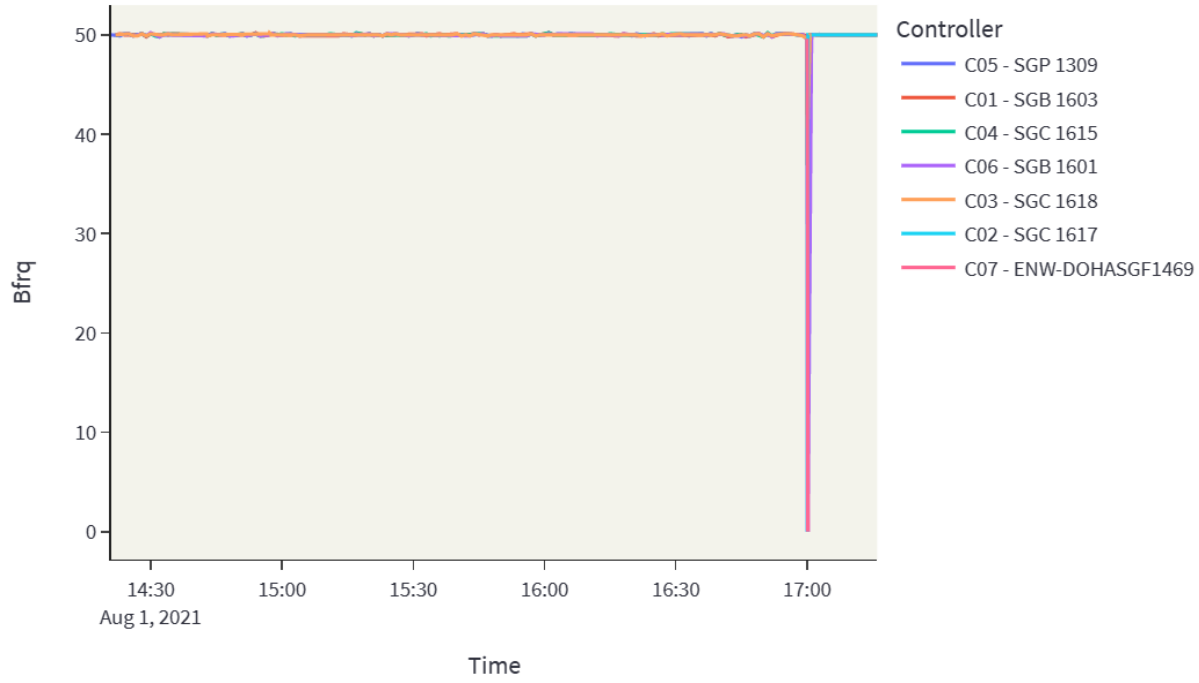
Requirements definition for DMS controller

- Reads data from Gen-Set controllers
- Detects when a power disturbance takes place
- Calculates appropriate amount of load to disconnect
- Sheds loads at a fast speed

Fault analysis

Frequency deviation shown in data





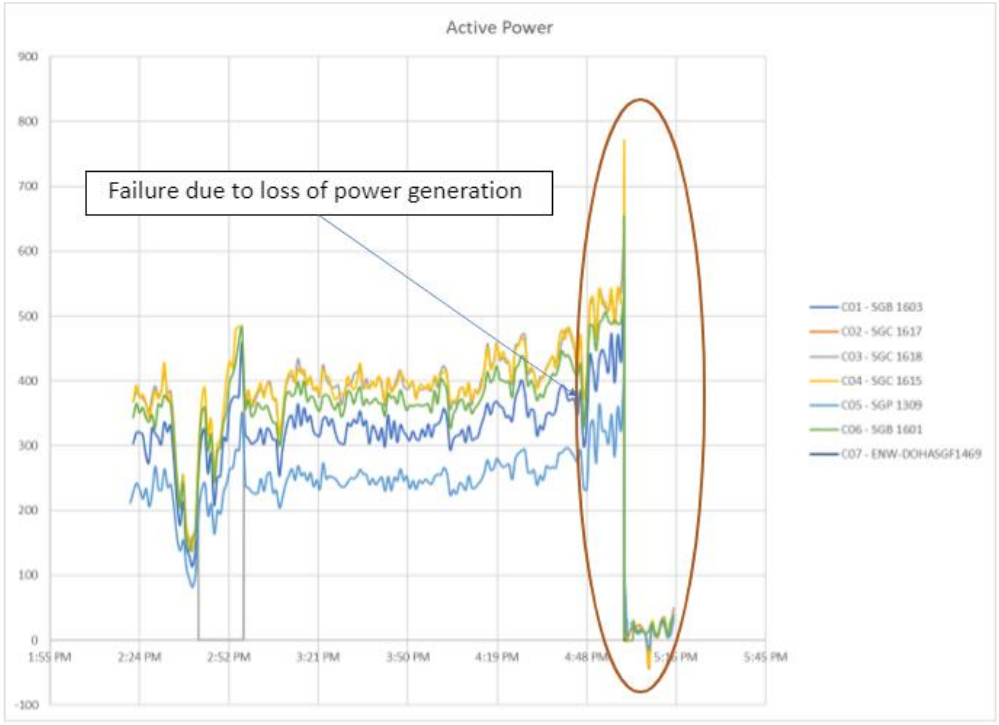
DMSystems

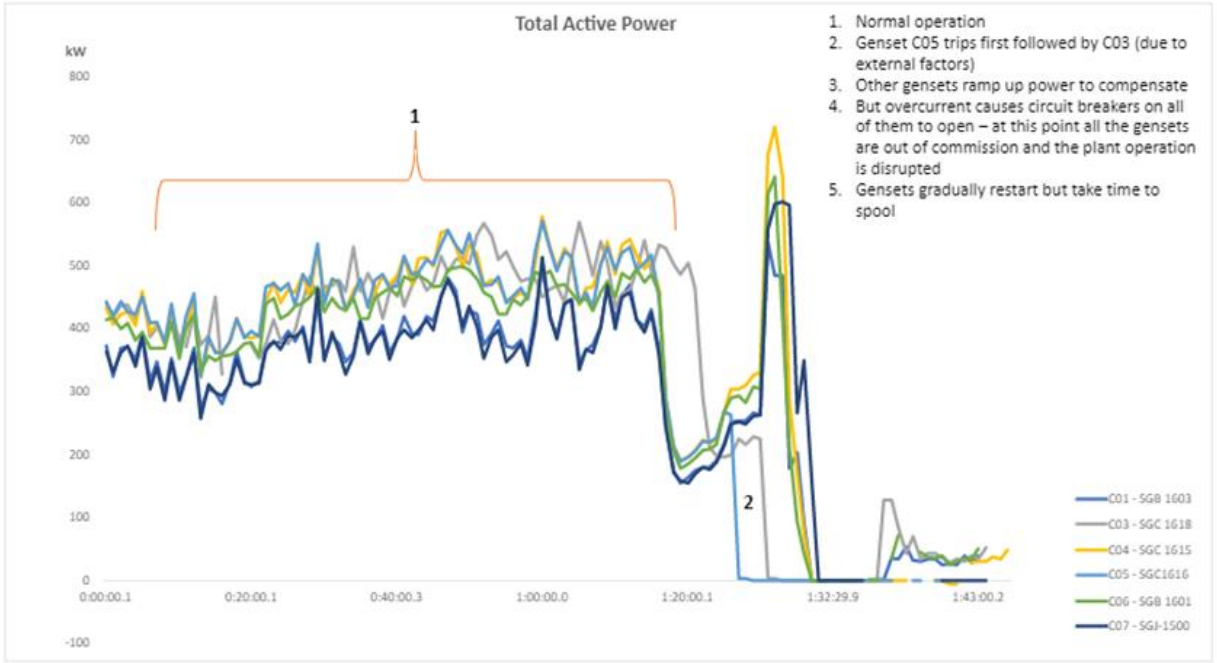
FAST RESPONSE DEMAND MANAGEMENT SYSTEMS

Simulation & Results

Fault analysis

Active power data from Gen-Set Controller

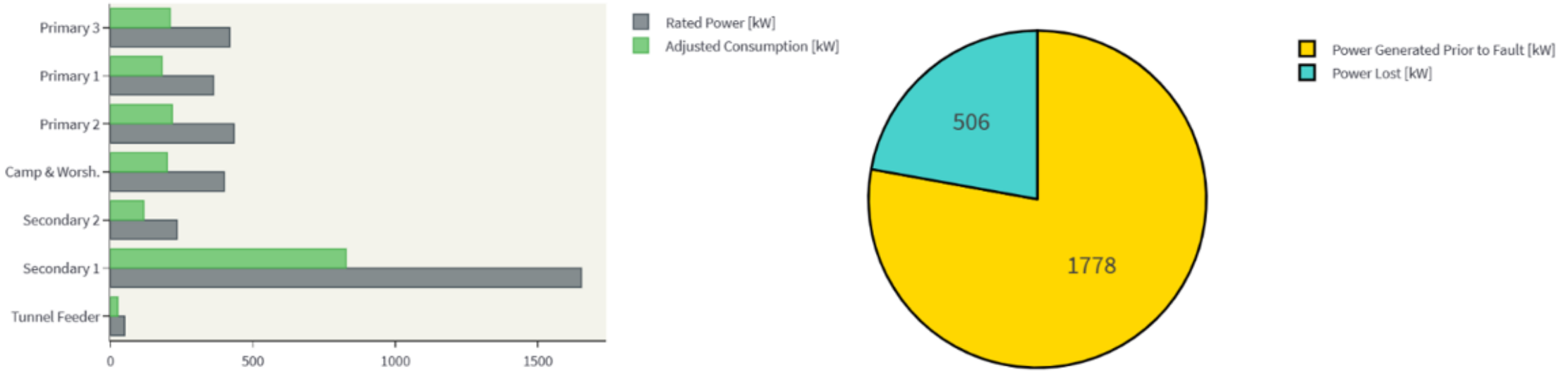




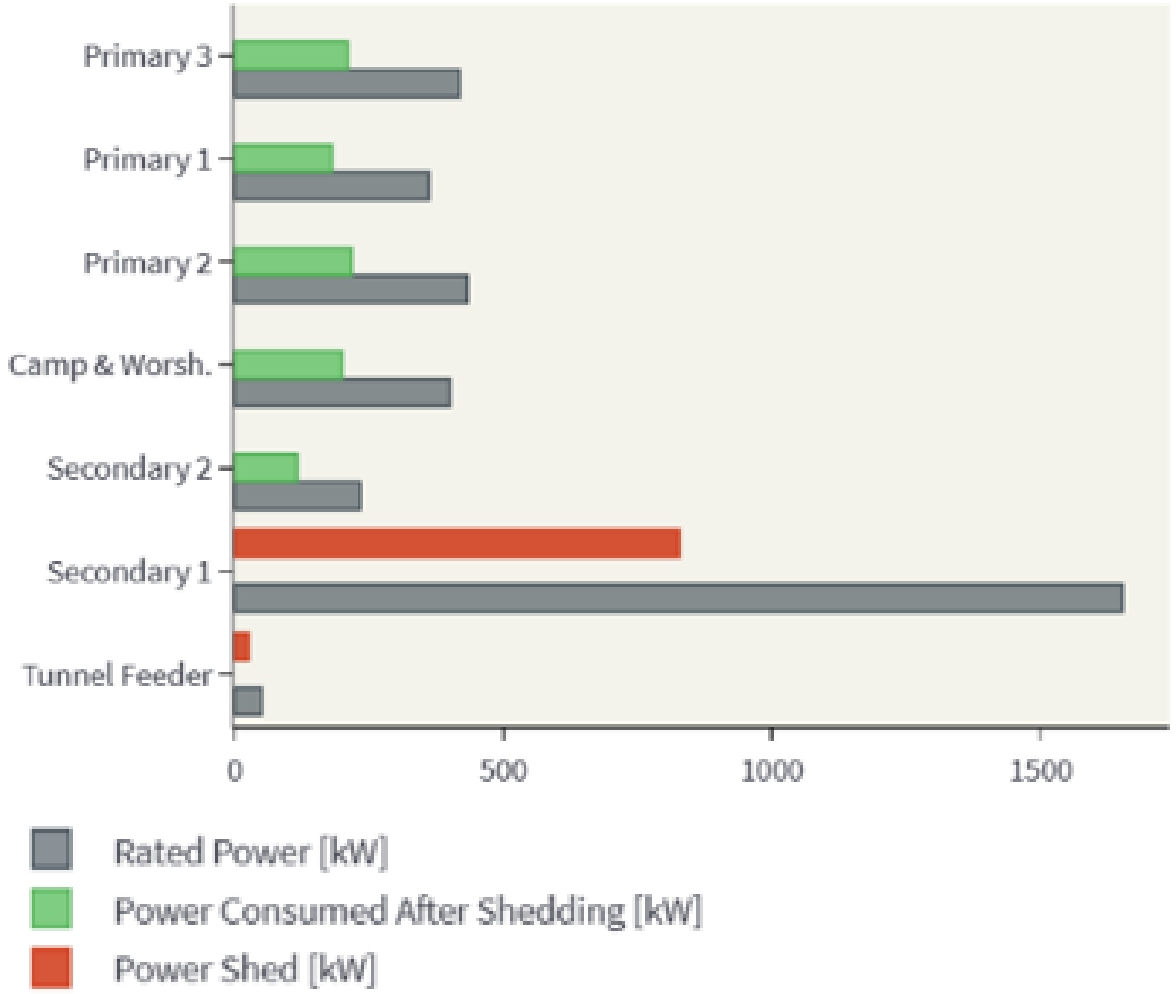
DMSystems

FAST RESPONSE DEMAND MANAGEMENT SYSTEMS

Load Shedding Strategy
1.- Identify the fault occurrences based on the failure alarms
2.- Sum the power generated by the active generators prior to the fault
3.- Sum the power generated after the fault
4.- Assume the power needed by the loads equals to the power generated prior to the fault
5.- Subtract the power generated after the fault from the power needed to meet the load demand
6.- Determine by how much the total load power should be reduced
7.- Determine which loads should be disconnected
8.- Send the appropriate load shedding commands



Load Rated Power. Load Adjusted Consumption. Power Generated. Power Lost

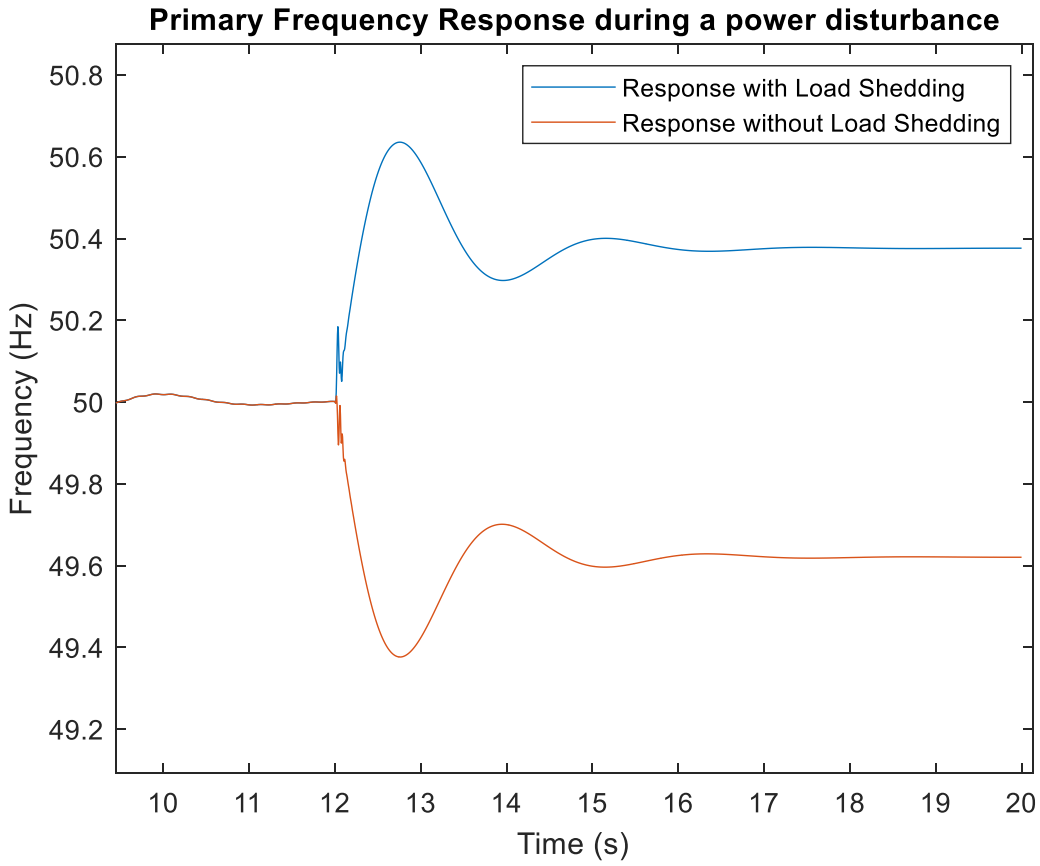


The set of commands to be sent to the circuit breakers

Status1	0
Status2	0
Status3	1
Status4	1
Status5	1
Status6	1
Status7	1

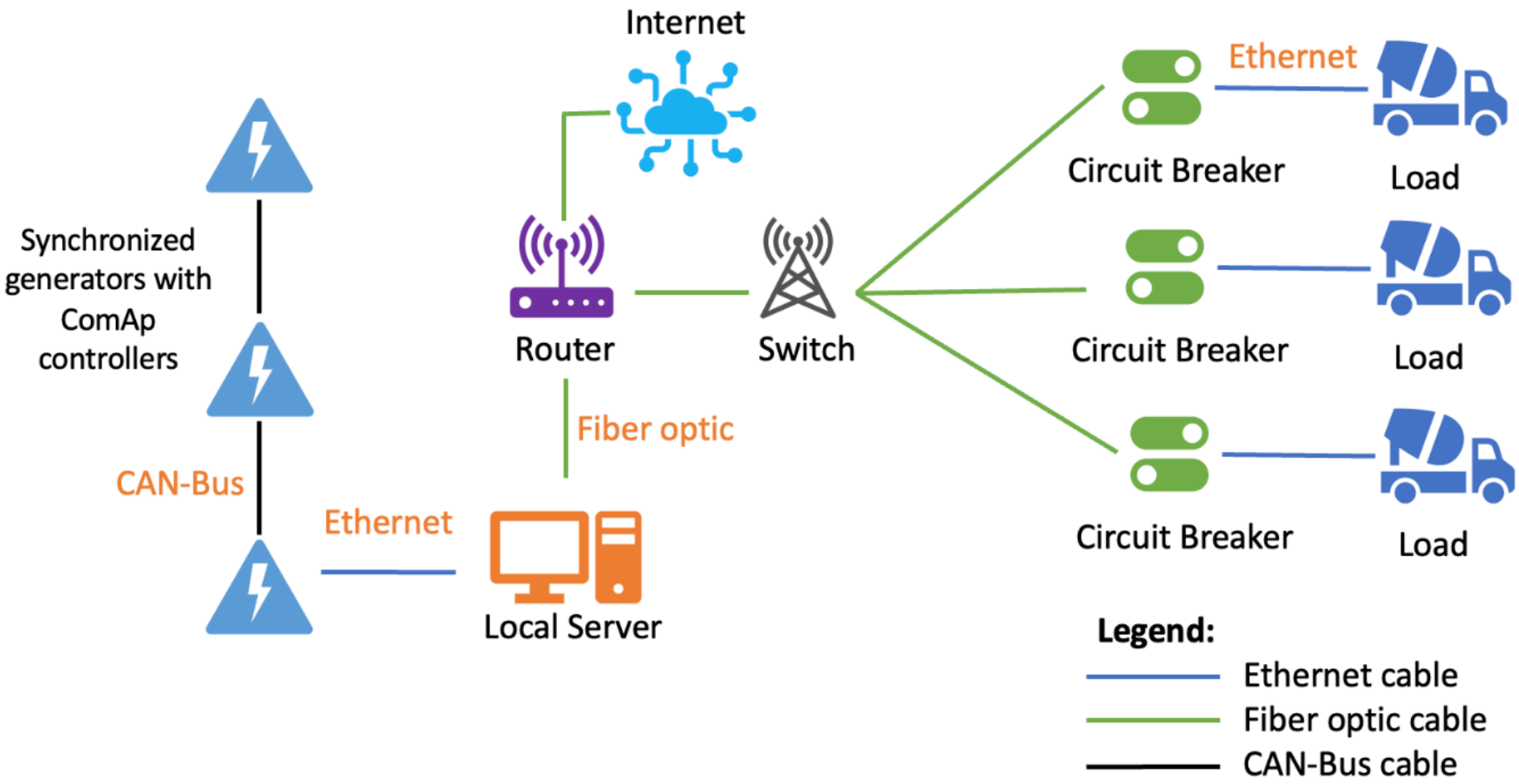
Simulation of Primary Frequency Response

- A Simulink model was built capable of replicating the frequency response of the system to power disturbances.
- Without Load-Shedding, the system frequency decreases (orange line) This requires Primary Reserve to stabilize the frequency. If there is not enough reserve, a blackout occurs.
- With Fast Load-Shedding, system frequency increases above nominal (blue line) because the load shed in the studied case is higher than lost generation capacity. The system can correct the frequency error later.



Communication Network

Detailed layout of the proposed communication network



Data Communication Protocol

Data communication with controllers:

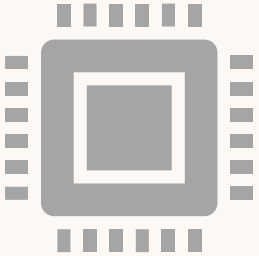
Modbus TCP/IP (Transmission Control Protocol/Internet Protocol)

Chosen over the Modbus RTU (Remote Terminal Unit)

Easier connection with the Ethernet cable

Easier to troubleshoot

Has a higher response time.



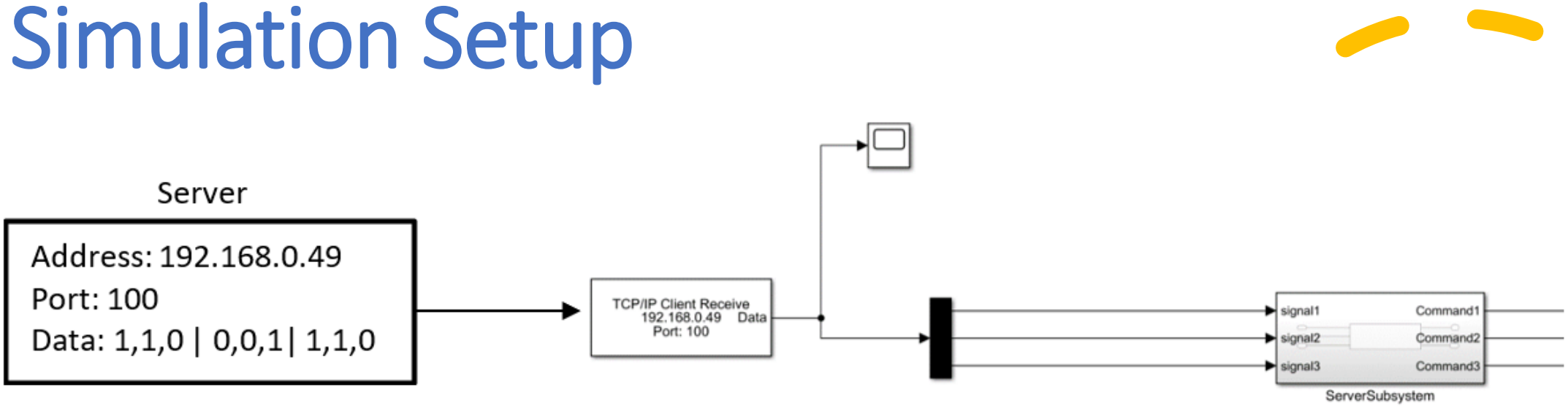
On TCP/IP protocol:

Has been used in previous works serving similar purpose

The initial communication is reassembled into packets by the Transmission Control Protocol (TCP) layer

The Internet Protocol (IP) then addresses all elements of each data packet's address to ensure that it reaches its intended destination

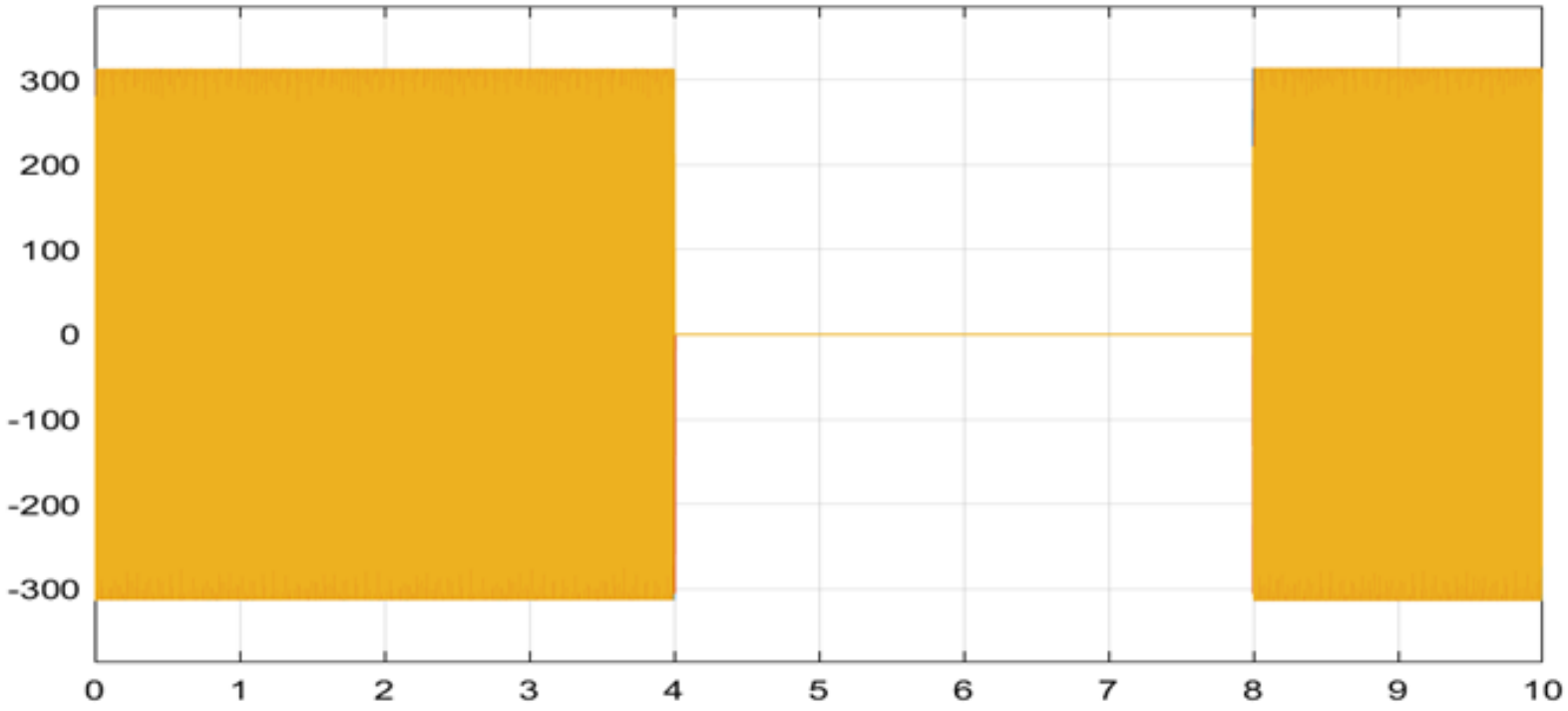
Simulation Setup



Parameters	
Data Size	3
Source Data Type	int8
Timeout	0.1 s
Block sample time	4 s

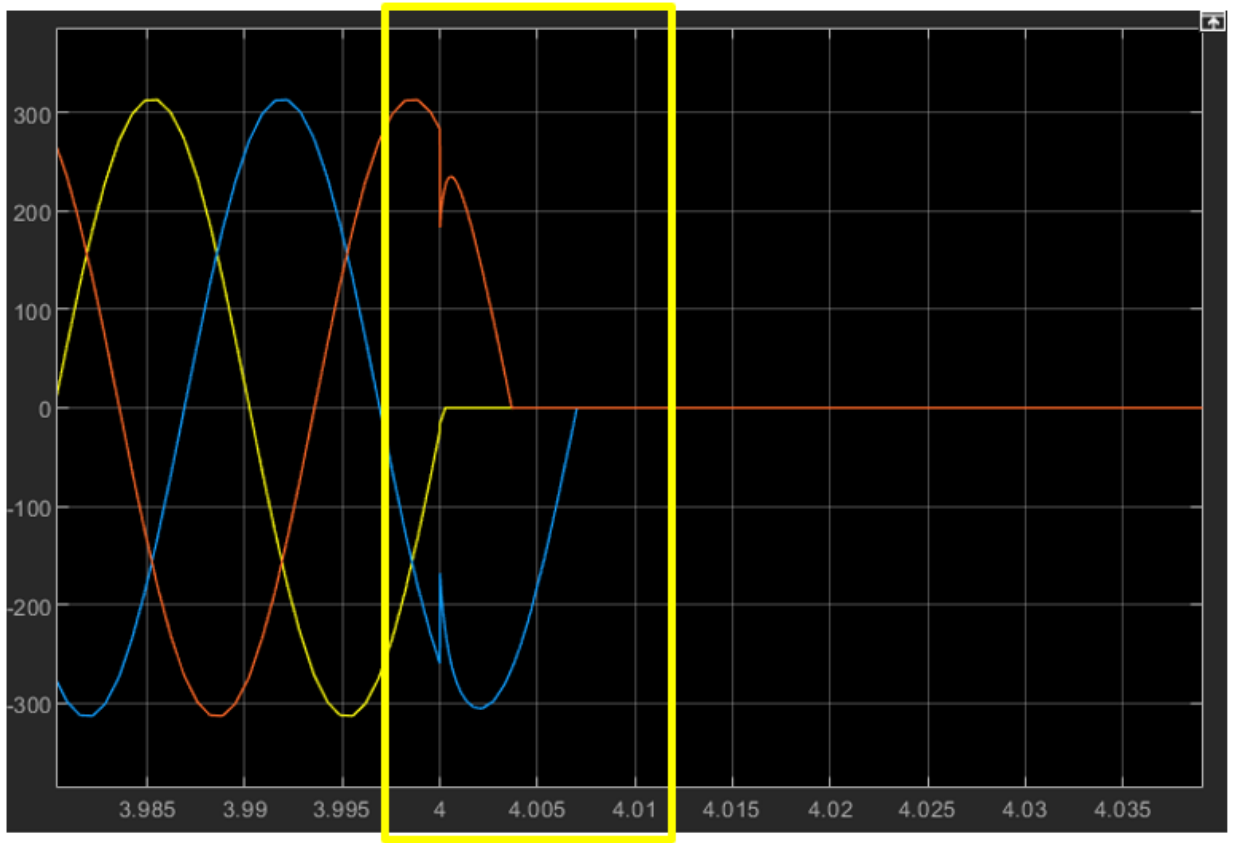
Simulation Result

Commands sent [t = 0s : 1, t = 4s : 0, t = 8s : 1]



Simulation Result

- Simulation’s response time: 7 milliseconds
- This response time is machine independent
- Caveat: this simulation does not consider the physical constraints of the components which might add delays, thus requiring a longer response time



Socio-economic Analysis

Financial Analysis

Comparison:

- Proposed system: demand management strategy – load shedding mechanism
- Alternative: adding diesel generator redundancy

Financial Analysis:

- CAPEX of load shedding mechanism with two communication networks options
- OPEX of load shedding mechanism VS OPEX of adding redundancy

CAPEX of the Load Shedding Mechanism with Fiber Optics

Average market values

97% is fiber optics

Less likely to be implemented → better to adopt fiber optics communication network for the whole plant

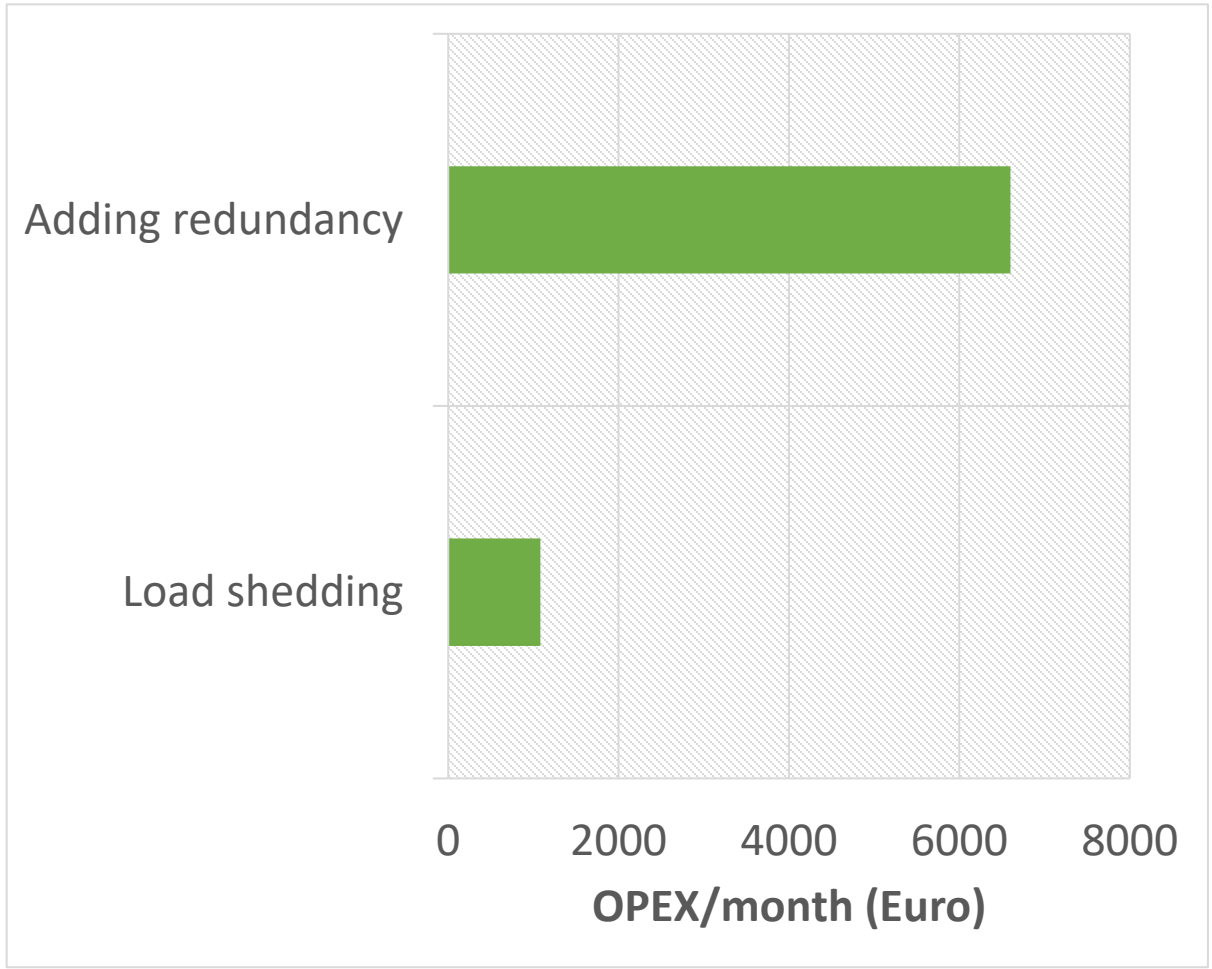
Component	Subcomponent	Unit	Unit price (€)	No. of units	Total price (€)
Control system	Raspberry PI 4B (8 GB)	Piece	72.00	1	72.00
	Voltage sensor	Piece	50.00	16	800.00
	Current transformer	Piece	40.00	16	640.00
	Subtotal				**1,512.00**
Fiber optic communication network	Cabling & installation	Meters	36.00	1,500	54,000.00
	Wi-Fi router	Piece	550.00	1	550.00
	Local PC	Piece	2,000.00	1	2,000.00
	Subtotal				**56,550.00**
TOTAL					**58,062.00**

CAPEX of the Load Shedding Mechanism with Ethernet

90% still comes from communication network

Less reliable as a lot of switches are needed → the goal of 10ms response time is hard to achieve

Component	Subcomponent	Unit	Unit price (€)	No. of units	Total price (€)
Control system	Raspberry PI 4B (8 GB)	Piece	72.00	1	72.00
	Voltage sensor	Piece	50.00	16	800.00
	Current transformer	Piece	40.00	16	640.00
	Subtotal				**1,512.00**
Ethernet communication network	Cabling & installation	Meters	7.00	1,500	10,500.00
	Ethernet switch	Piece	50.00	15	750.00
	Wi-Fi router	Piece	550.00	1	550.00
	Local PC	Piece	2,000.00	1	2,000.00
	Subtotal				**13,800.00**
TOTAL					**15,312.00**



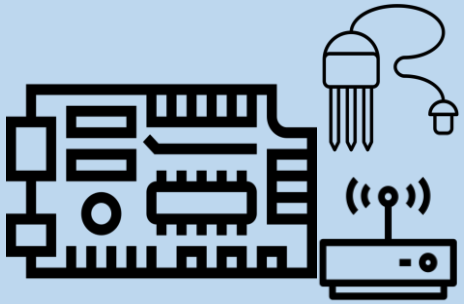
OPEX Comparison

- Calculated in a monthly basis
- OPEX of the Load Shedding Mechanism:
  - Standard energy management platform
  - Cloud subscription
  - Internet service provider
- OPEX of Adding Redundancy:
  - Monthly rent of Diesel Generator 650 kVA and 300 kVA
  - Size of the redundancy is based on 20% of the actual needed capacity to support the load
- **Load shedding mechanism is around 6x cheaper than its alternative**

Social Impact

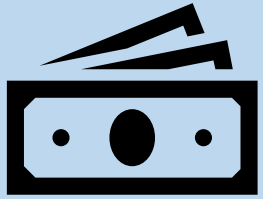
- **Stability of mining industry** drives infrastructure development and improves quality of life
- The system can be used in **other applications**, e.g. healthcare
  - Power shortages in hospitals can be fatal
  - An effective and rapid solution can potentially save lives
- The **money saved can be reallocated** to improving education and infrastructure in developing countries

Contributions of This Project



Fast and efficient load shedding mechanism to save time and reduce financial losses

Modern communication network enabling fast response



Financially feasible solution compared to alternatives and a good opportunity of investment

The solution can be used in different applications, e.g. healthcare

Thank You