Black start and island operation of distributions grids with significant penetration of renewable resources

Darío Lafferte

University of Kassel

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Dario Lafferte[1], Alexander Klingmann[1], Dirk Fetzer[1], Gustav Lammert[1],
Christian Hachmann[1], Tina Paschedag[1], Martin Braun[1,2]

[1] University of Kassel, Department of Energy Management and Power System Operation (e²n), Germany

[2] Fraunhofer-Institute (IWES) for Wind Energy and Energy System Technology, Kassel, Germany

Outline

1. **Introduction**
2. Black start and island Operation
3. Modelling
4. Simulation analysis
5. Conclusions

1. Introduction

Motivation:

- Increase of distributed generation capacity in distribution grids, such as PV systems
- Re-energising and island operation of distribution grids with significant participation of distributed generators (DGs)
- Bottom-up strategy for power system restoration
- A diesel emergency supply unit (ESU) as black start unit for re-energising of distribution grids
- Participation of local renewable power plants such as biogas power plants (BGP)

Considerations:

- Focus on frequency control
- Analysis performed in DIgSILENT *PowerFactory*
- ESU and BGP work in isochronous and droop speed control modes
- Loads are modelled considering cold load pick-up as well as frequency and voltage dependency
- DGs are modelled considering over- and under-frequency protections, P-f control and power ramp-up behaviour during reconnection according to the current German low voltage (LV) grid code
- Test system is based on real grid data from a German distribution system operator (DSO)

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2. Black start and island operation

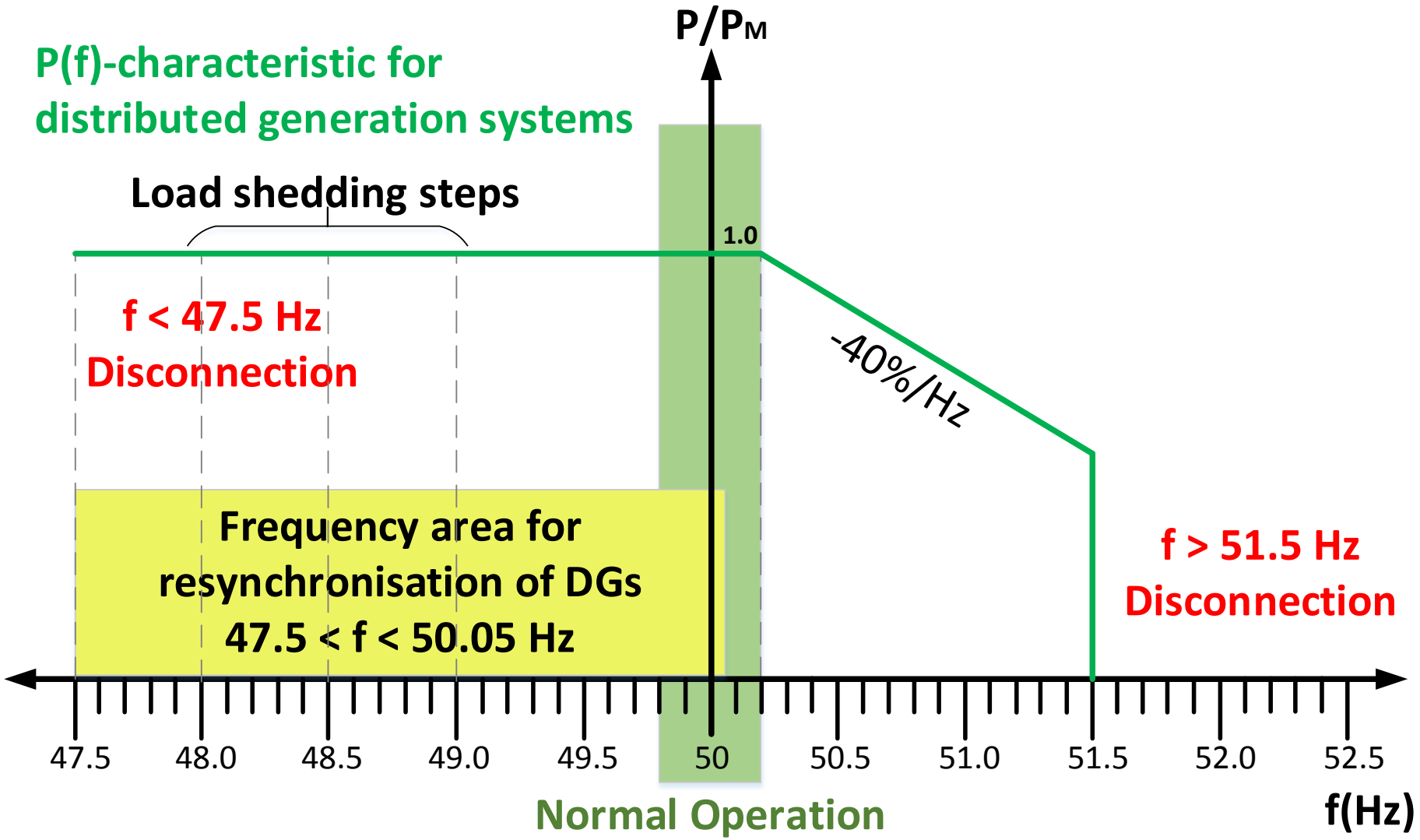
Black start:

- Black start (BS) is the capability of generation units to start-up by themselves without external help
- BS units are needed to re-start the electrical system into operation
- BS units are an important prerequisite for bottom-up restoration strategy
- For small or local grids, diesel systems (ESUs) can be used as black start units considering their limited power capacity and the diesel availability
- ESUs should be used to assist the starting process of local power plants with non-BS capability
- The main aim is to maintain voltage and frequency values to prevent protection tripping and damage

Island operation:

- After a blackout, the de-energised grid must be segmented in sub-grids for the re-energising process
- A sub-grid works in island operation if it operates autarkic and independently of the interconnected power system
- Each island grid needs at least one grid-forming unit
- Major challenge for island operation: Possible generation-consumption imbalance considering the presence of DGs
- Considering a high penetration level of DGs, an uncontrollable reconnection of DGs can compromise the success of the restoration process

2. Active power control concept according to German LV grid code



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1. Introduction

2. Black start and island Operation

3. Modelling

3.1 Test system

3.2 Low voltage loads

3.3 Distribution generation

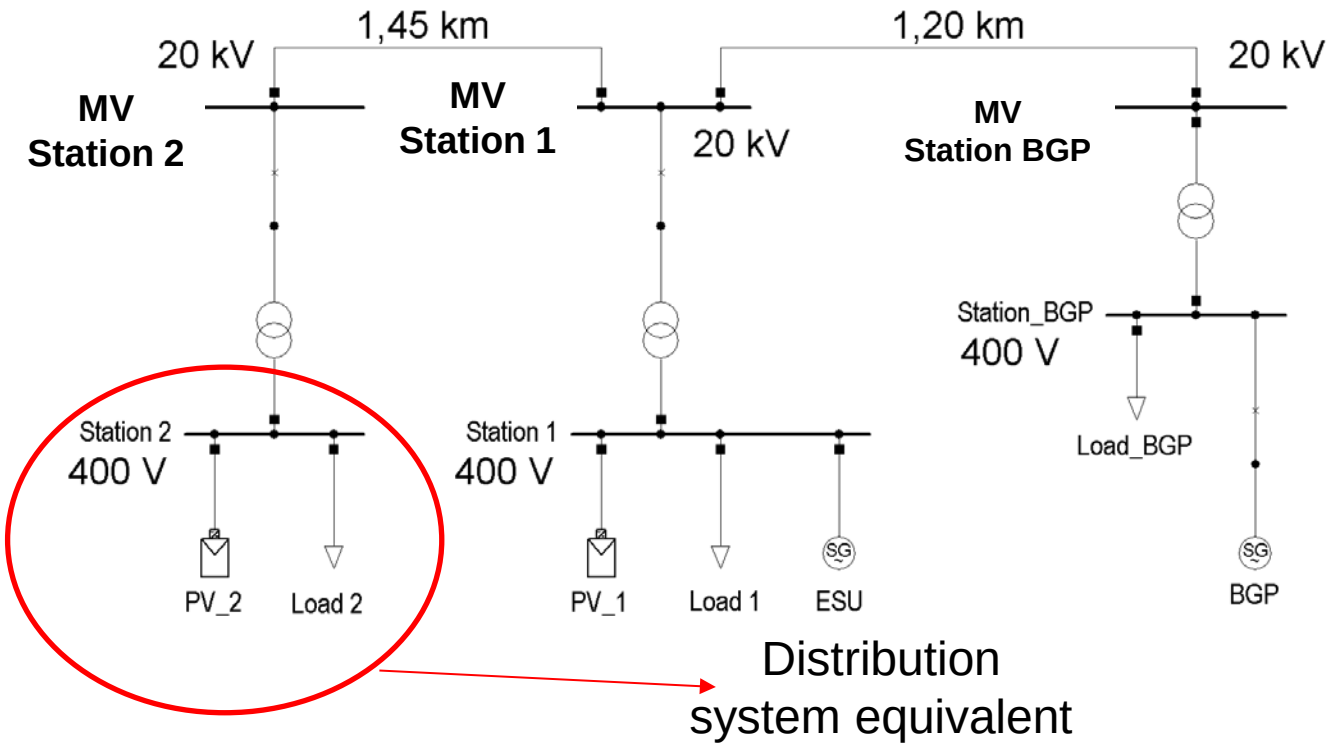
3.4 Diesel emergency supply system (ESU) and biogas power plant (BGP)

4. Simulation analysis

5. Conclusions

3.1 Test system

- The test system is based on real grid data of a German distribution system operator
- The test system represents a section of a rural distribution network, considering 2 LV grids (400 V), a biogas power plant (BGP) and their interconnection at the MV voltage level (20 kV)
- LV grids are represented by an aggregated dynamic distribution system equivalent with consumption and distributed generation at the LV side
- The dynamic of this distribution system equivalent represents the load and DGs behaviour during normal operation and after reconnection



- The generation in the test system consists of a diesel ESU, a BGP and distributed PV systems (DGs)
- Electrical cables are used as distribution lines

3.2 LV loads

- The aggregated consumption of each LV grid is modelled as an exponential load considering frequency and voltage dependency
- The cold load pick-up behaviour is considered after reconnection

$$P = P_0 \left(\frac{V}{V_0} \right)^{\alpha} \cdot \left(1 + k_{\mathrm{pf}} \cdot \Delta f \right)$$

$$Q = Q_0 \left(\frac{V}{V_0} \right)^{\beta} \cdot \left(1 + k_{\mathrm{qf}} \cdot \Delta f \right)$$

$$P_{\mathrm{Load}}(t) = P \left(1 + a \cdot e^{-\left(\frac{t - t_0}{\tau} \right)} \right)$$

$$Q_{\mathrm{Load}}(t) = Q \left(1 + a \cdot e^{-\left(\frac{t - t_0}{\tau} \right)} \right)$$

where:

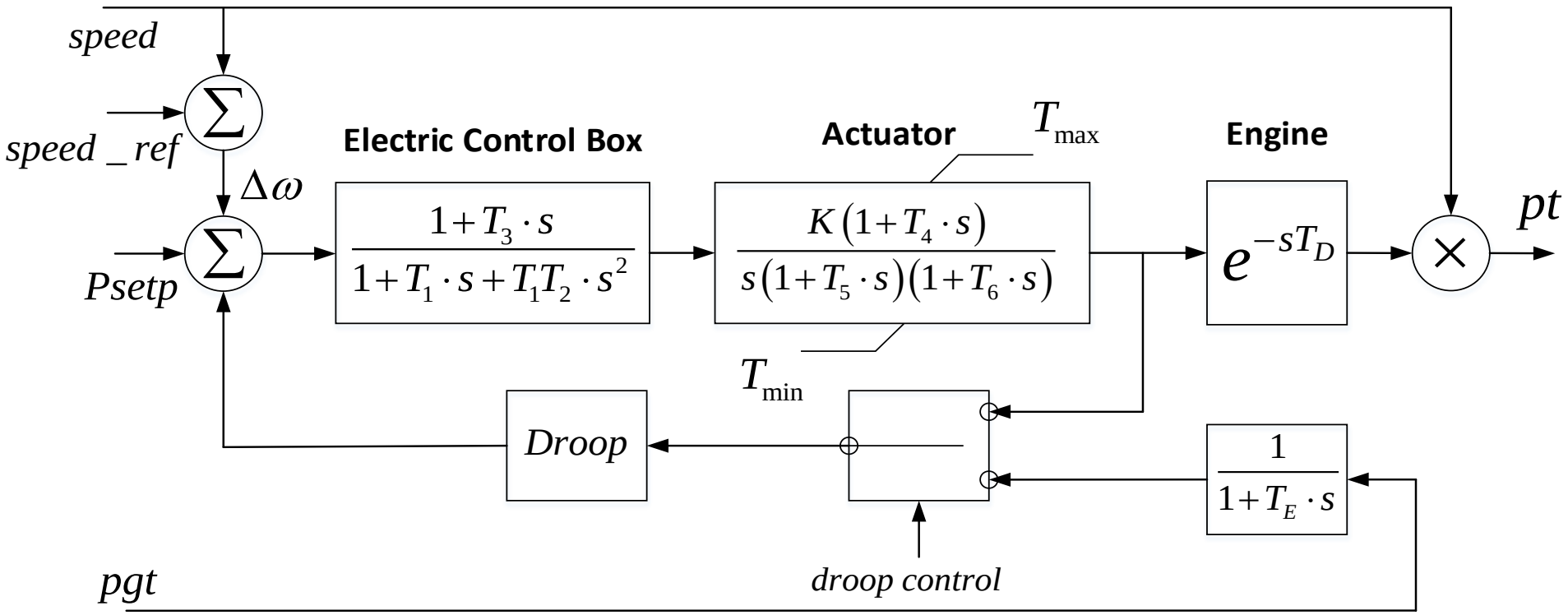
- P and Q represent the active and reactive power consumed by the aggregated LV load
- P_0 and Q_0 are the active and reactive under the reference voltage V_0 referring to the nominal operating condition
- α and β represent the voltage dependency
- k_{pf} and k_{qf} characterise the frequency dependency
- P_{Load} and Q_{Load} represent the active and reactive power consumption during cold load pick-up
- a represents the peak value due to cold load pick-up
- τ is the time constant of the cold load pick-up event

3.3 Distributed generation

- DGs are represented by an aggregated generation model based on WECC PV model
- 2 operation modes are available: normal operation and reconnection
- DGs include:
  - Over- and under-frequency protections
  - Active power reduction at over-frequency (P(f) characteristic)
  - Active power ramp-up behaviour after reconnection
- Focus on reconnection behaviour
- Reconnection if frequency stays between 47.5 and 50.05 Hz for more than 60 seconds
- Reconnection through an active power ramp limitation of 10% of nominal power per minute for a period of ten minutes

3.4 Diesel emergency supply system (ESU) and biogas power plant (BGP)

- ESU and BGP both are modelled as standard combustion engine with a rated power of 250 kVA
- The governor model for each system allows isochronous and droop speed control modes
- Synchronous generator is implemented according to commercial generator data



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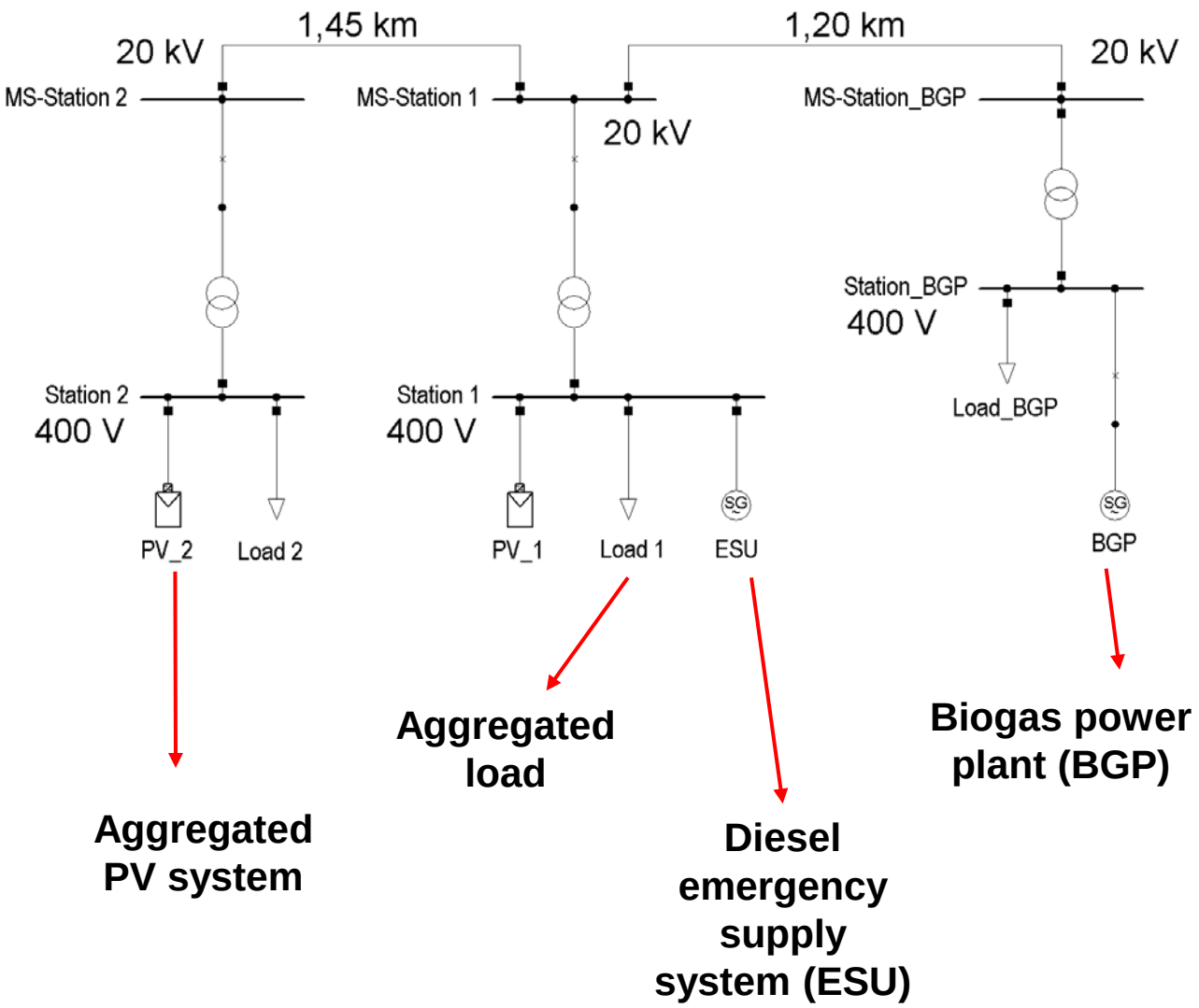
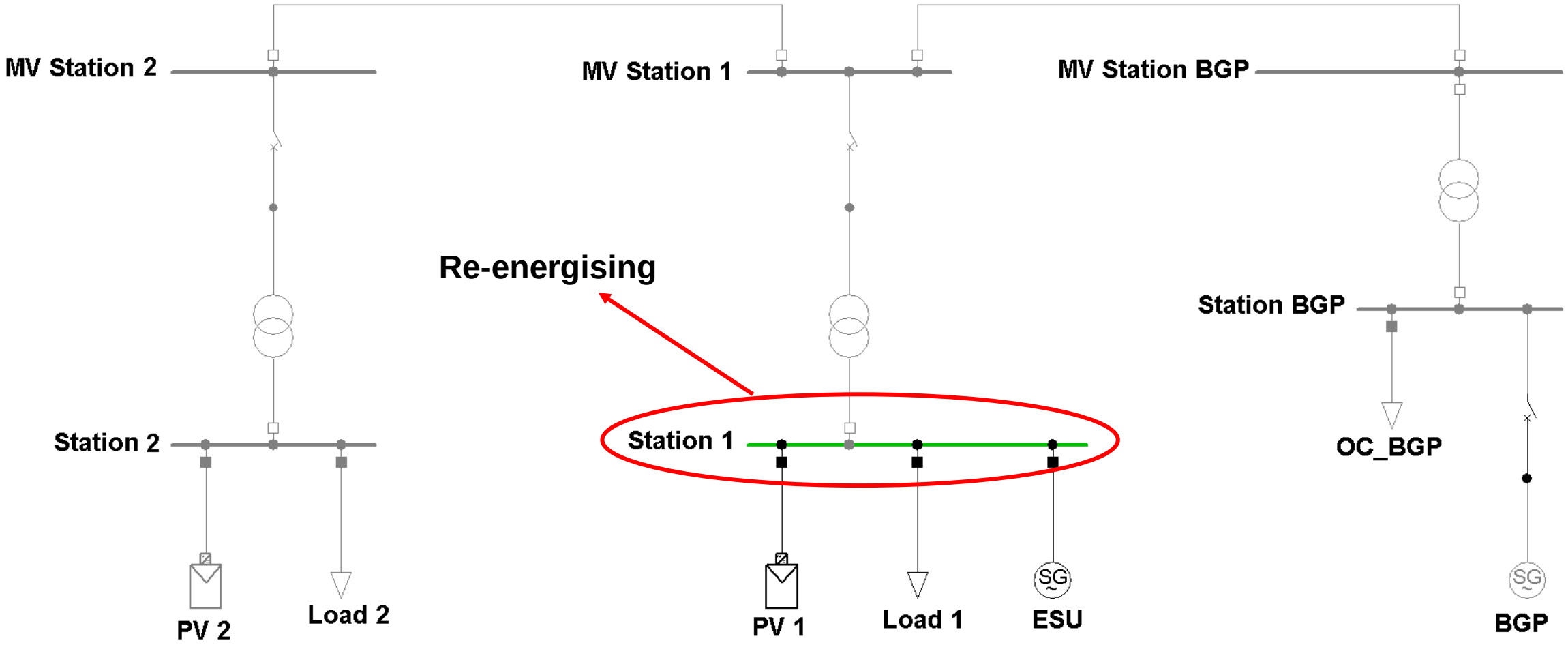
4. **Simulation analysis**
   - 4.1 Black start
   - 4.2 Expansion of the island at the MV level and integration of BGP
   - 4.3 Further expansion and pick-up of loads of the MV island grid
   - 4.4 Disconnection of ESU
5. Conclusions

4. Simulation Analysis

- 20 kV test system based on real grid data and implemented in DIgSILENT *PowerFactory*
- Station 1 and 2 represent two rural LV grids
- The aggregated load for each LV grid has a peak consumption of 160 kVA with a power factor 0.95
- The aggregated DGs for each LV grid have a nominal power of 33.33 kVA and work with unity power factor and maximal active power injection
- The ESU as well as the BGP have a rated power of 250 kVA with a nominal power factor 0.8
- The BGP has a self-consumption of 10 kVA
- For the MV distribution lines, electrical cables are used
- The starting situation is an entire power outage



4.1 Black start



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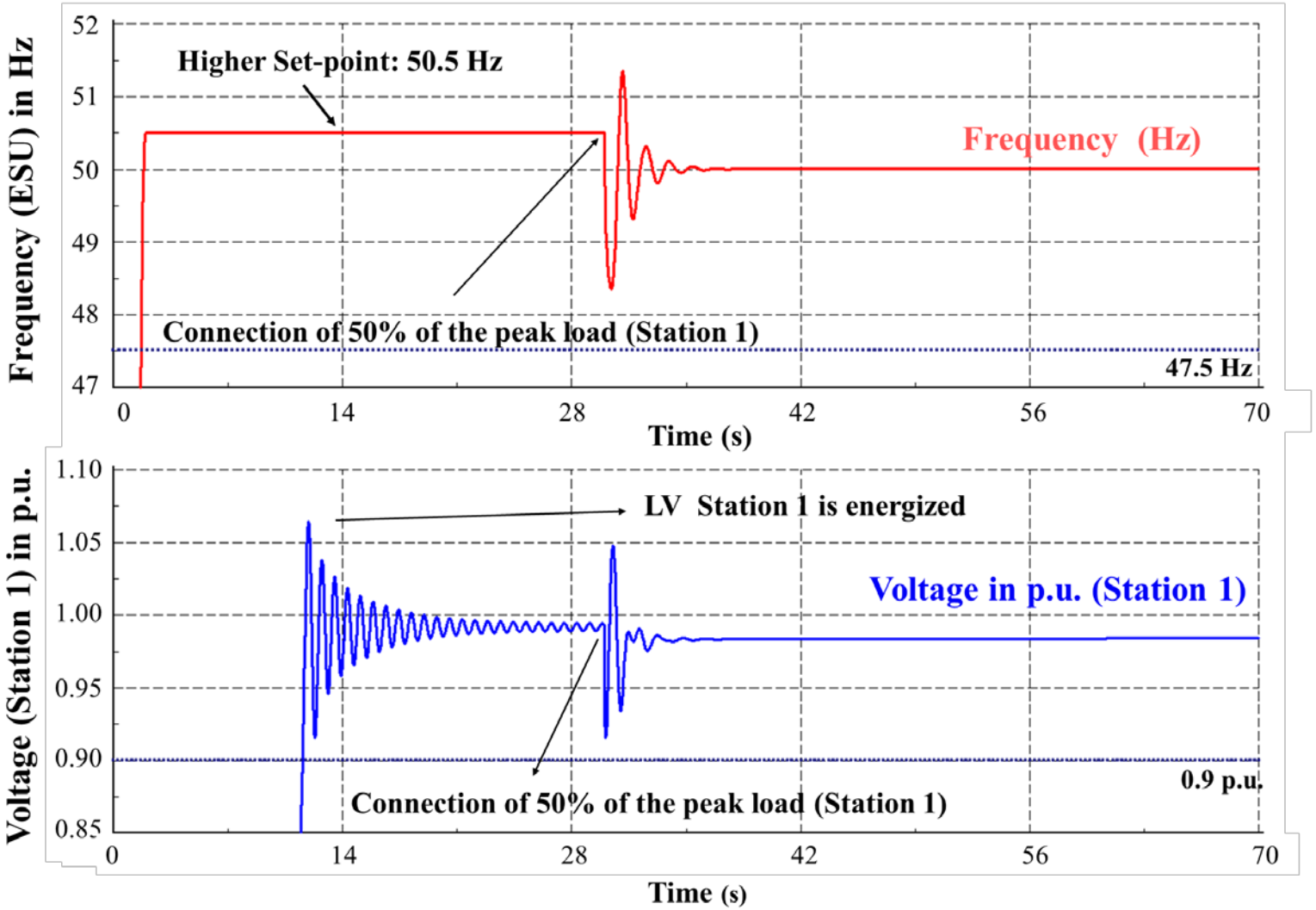
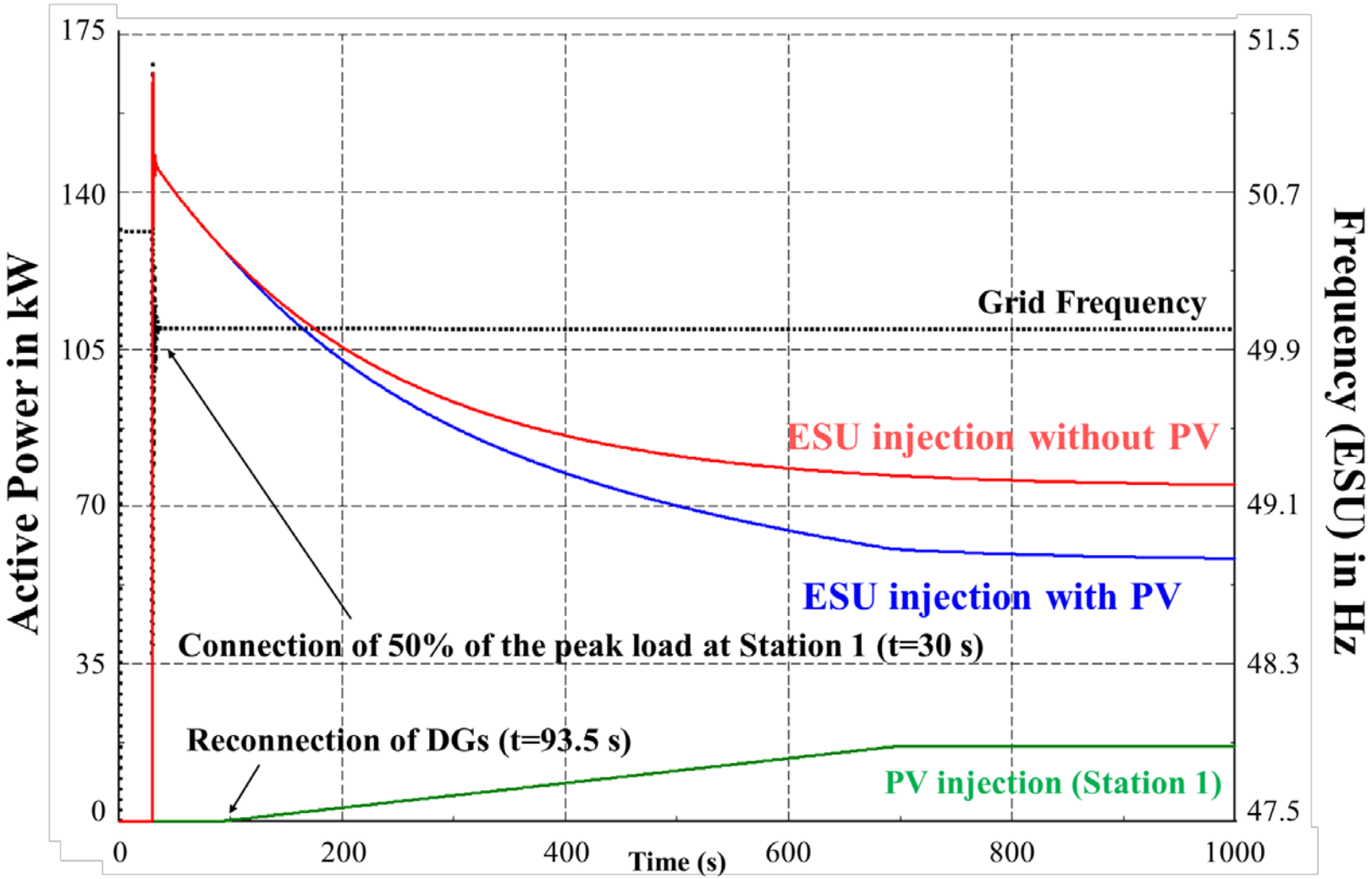
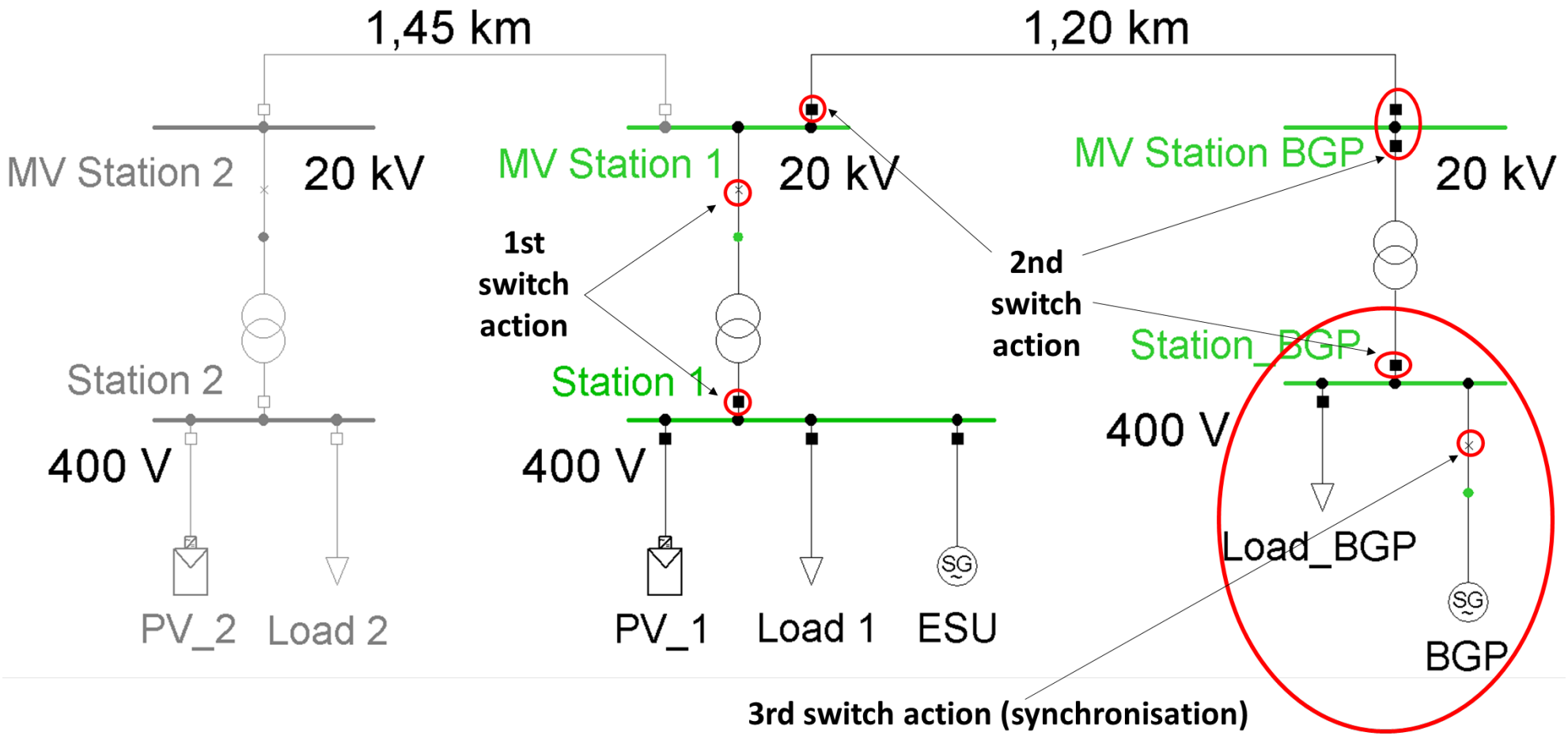


- ESU performs a black start and re-energises the LV grid at Station 1
- At t=0, ESU is started
- AS soon as ESU has reached nominal speed, the excitation system is activated
- 50% of the nominal load at Station 1 is reconnected (t=30s)
- ESU works in isochronous speed control
- Cold load pick-up is considered after reconnection
- Maximal PV injection is simulated
- PV systems work according to the German LV grid code (active power ramp limitation of 10% of nominal power per minute for ten minutes)

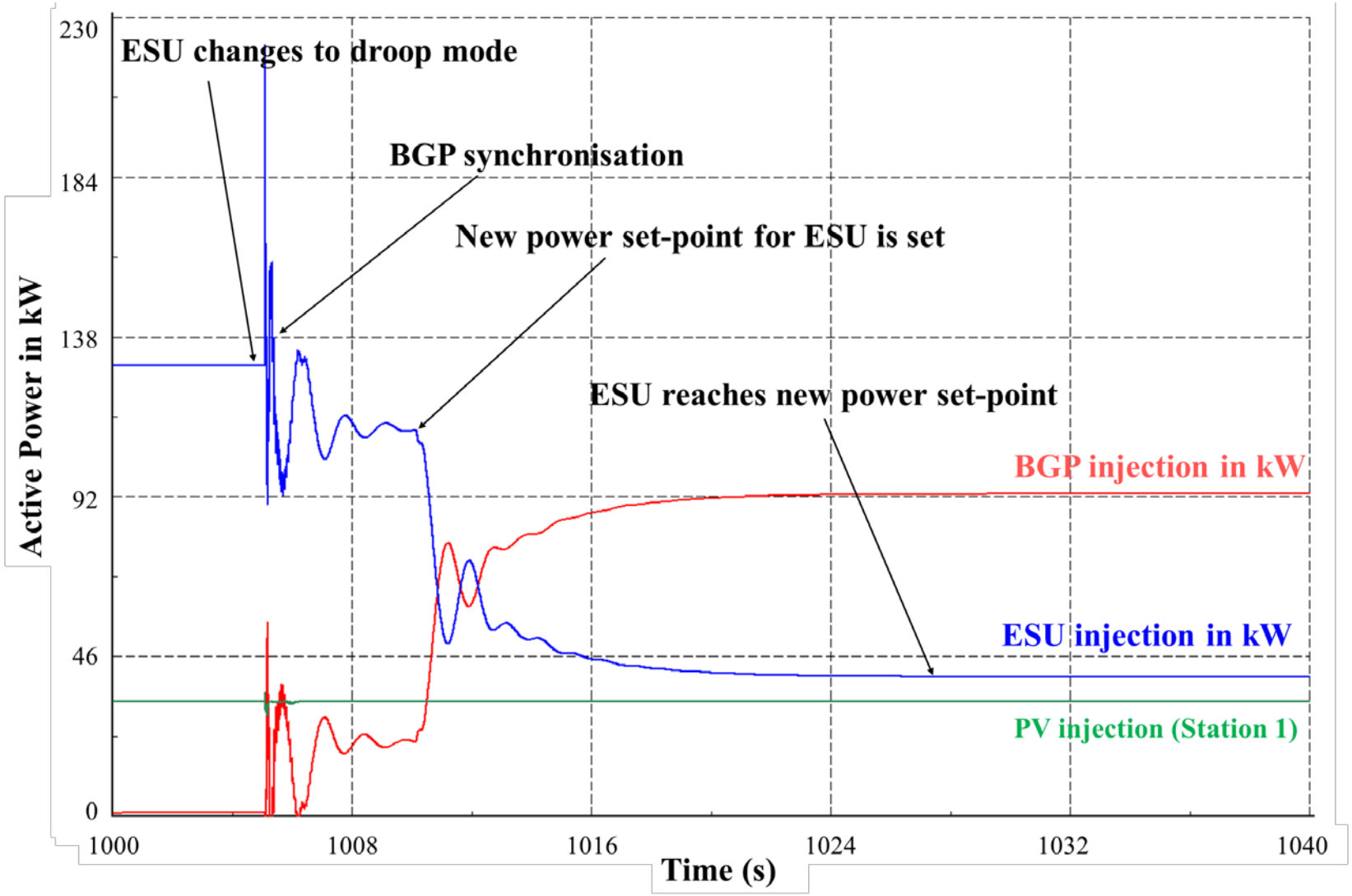
4.1 Black start



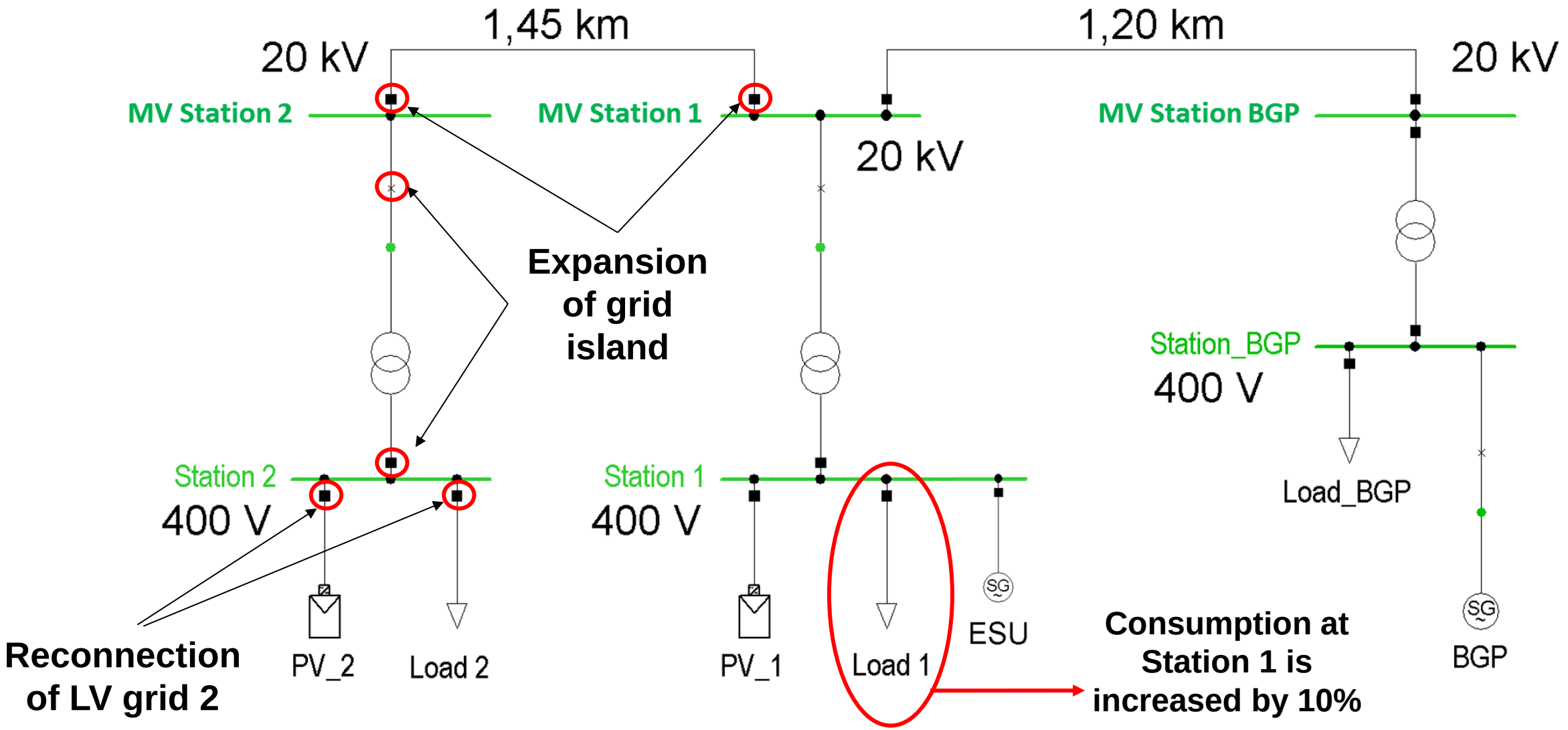
4.2 Expansion of the island at the MV level



4.2 Integration of the biogas power plant (BGP)



4.3 Further expansion and pick-up of loads of the MV island grid



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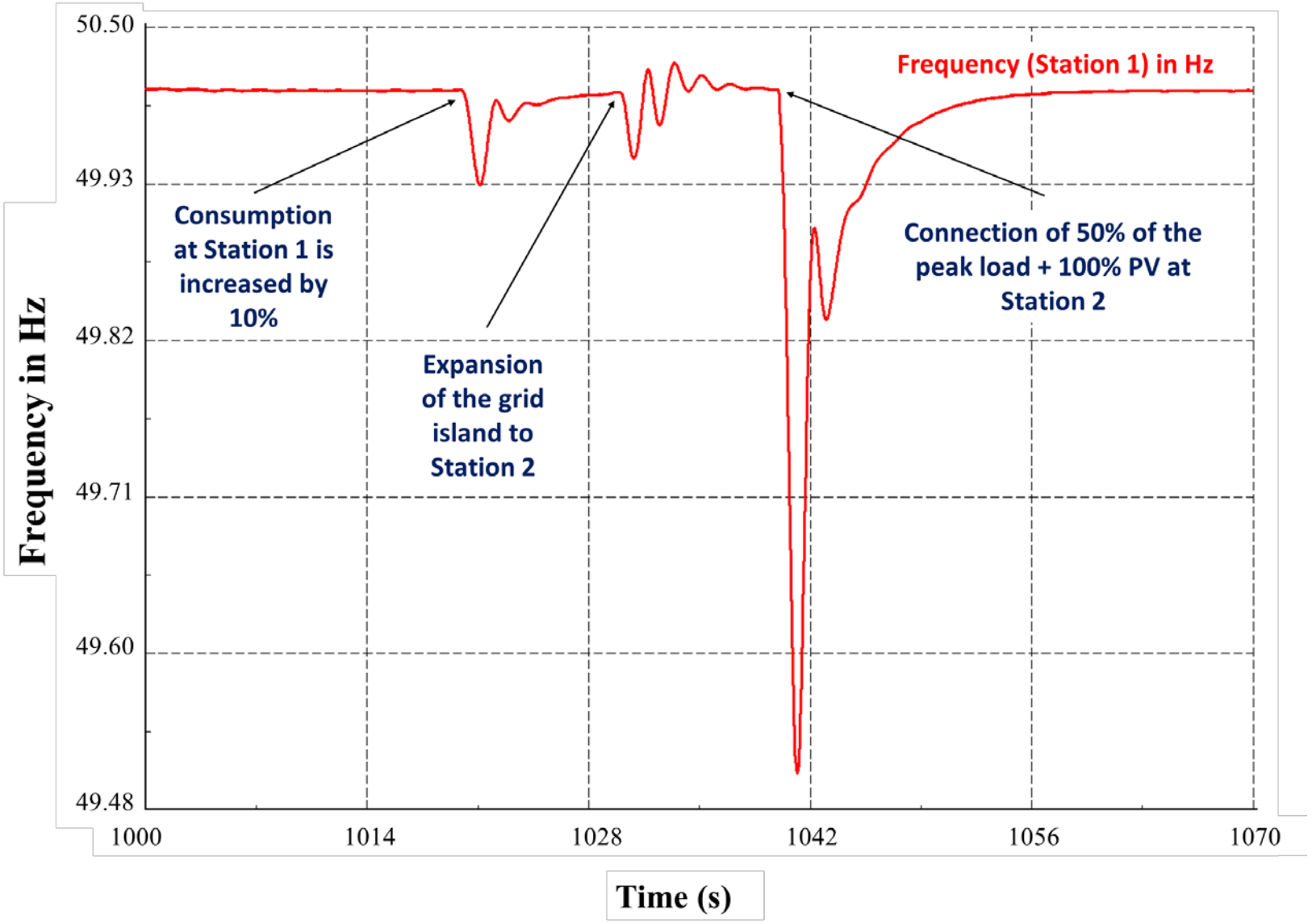

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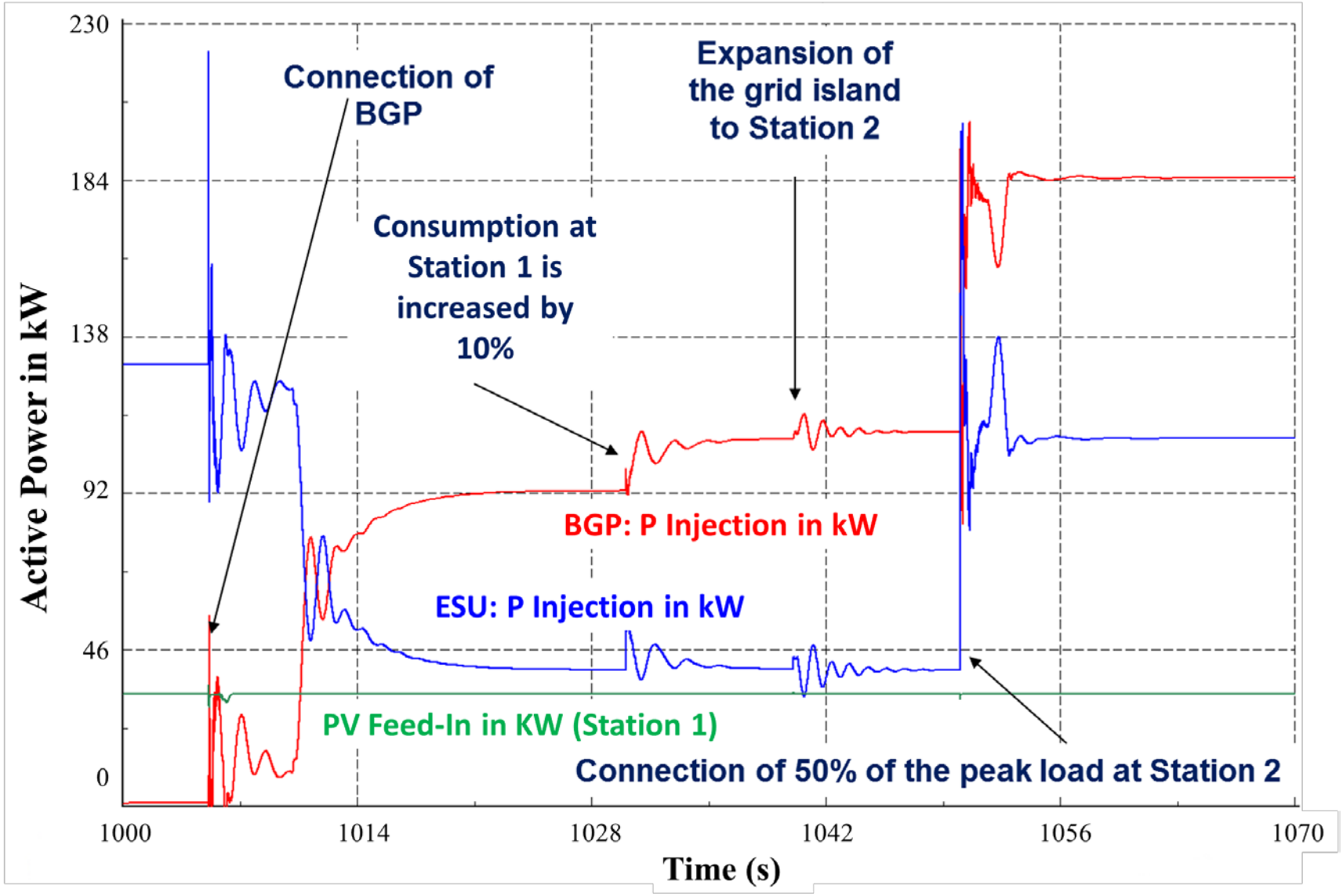
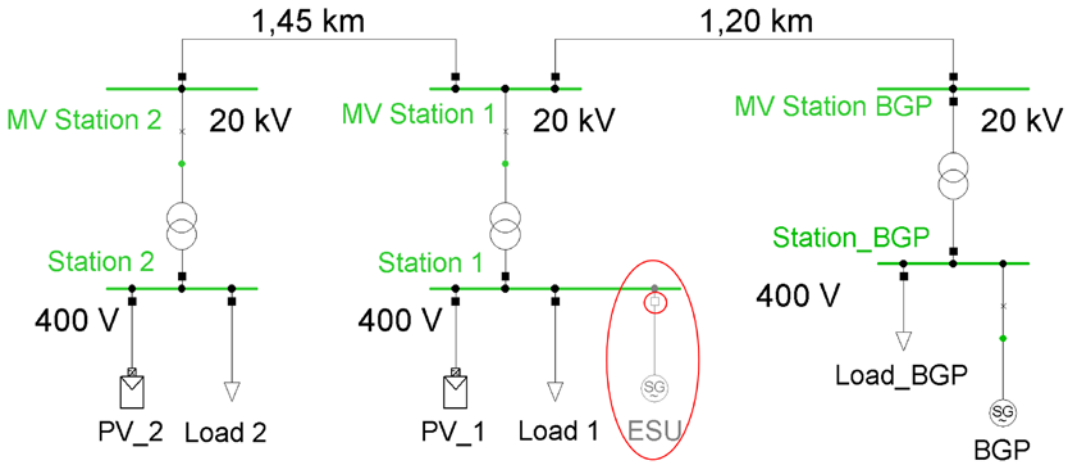
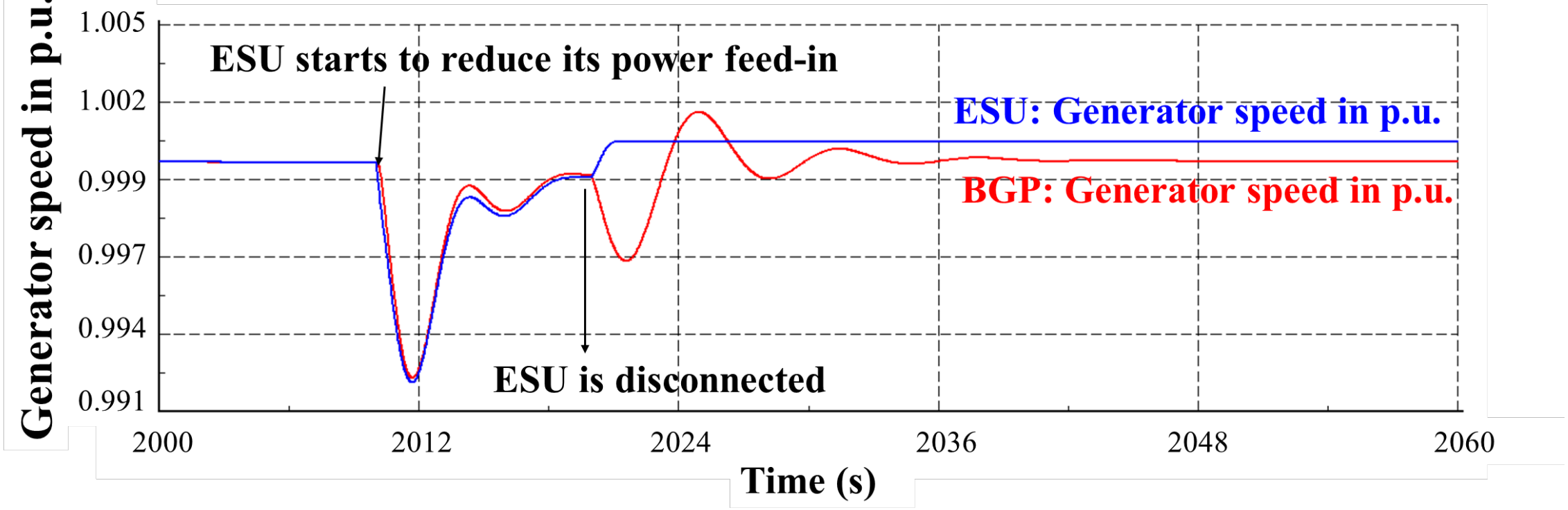


4.4 Disconnection of diesel ESU

- ESU reduces its power feed-in
- ESU is disconnected to re-energise further LV grids
- BGP takes over the frequency control
- Frequency droop due to ESU power feed-in reduction





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5. Conclusions

- Technical feasibility of black start and island operation of distribution grids
- Grid-forming unit needs to work in isochronous frequency control mode
- It is recommendable to reconnect transformers and electrical cables (distribution lines) at the same time to compensate the charging current of cables
- If a further generation plant (e.g. BGP) is synchronised with the island, the ESU should change to droop control mode in order to save fuel by setting a new power set-point
- It is feasible to operate an island grid with a BGP, if it is capable of operating as grid-forming unit

5. Conclusions

- The feasibility of this approach is subjected to grid code requirements. E.g. PV feed-in regarding grid frequency behaviour during normal operation and after reconnection

- PV systems with old LV grid code requirements could deteriorate the restoration process due to their uncontrollable reconnection

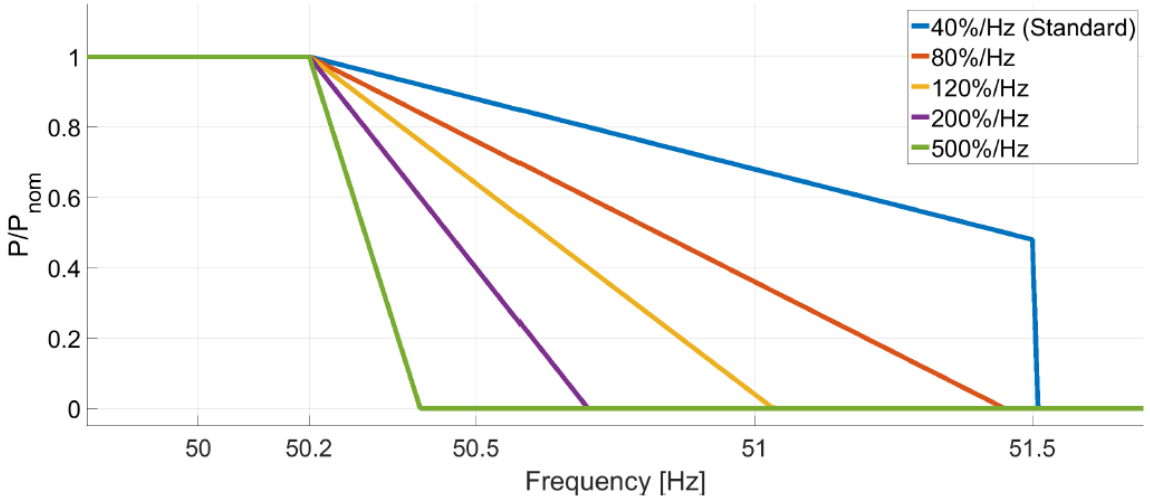
- Distributed renewable generation units can improve the restoration process, if island operation is allowed and black start capability is available

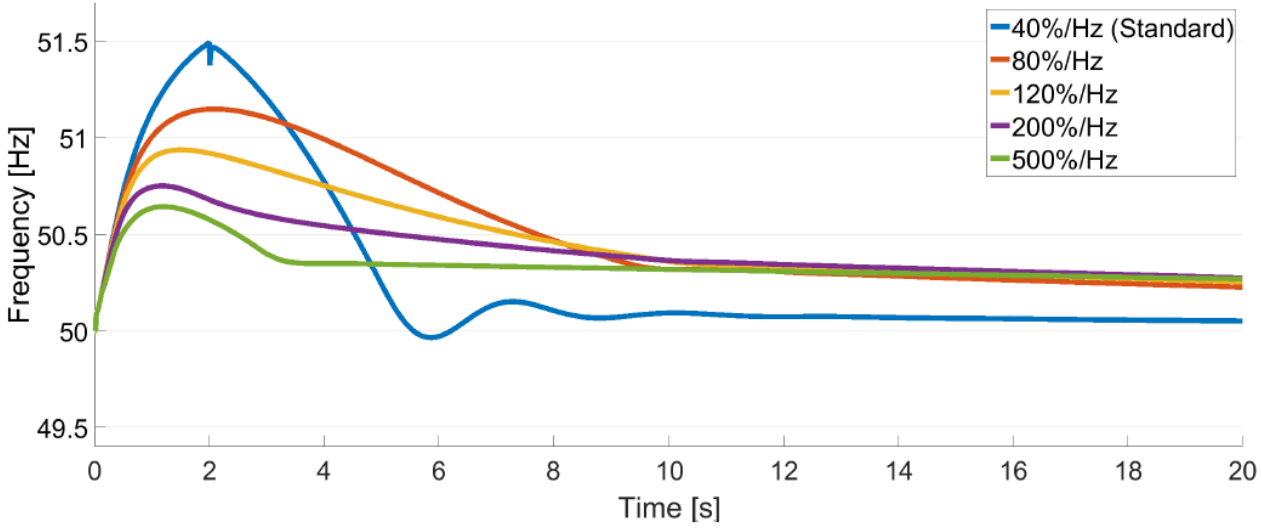
- Considering the permanent increase of DGs, DSOs in collaboration with TSOs could define reconnection steps of generation units at the distribution level to enhance the overall restoration process

5. Feedback for India

- For smart grid operation, PV systems need frequency and voltage control functionalities and dispatch control
- Grid-forming characteristics for PV systems → island operation

- Improve grid code requirements





Source: C. Hachmann, G. Lammert, D. Lafferte, M. Braun, "Power system restoration and operation of island grids with frequency dependent active power control of distributed generation," NEIS Conference 2017, Hamburg, Sept. 2017.

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UNIKASSEL VERSITÄT

Contact

Prof. Dr. Martin Braun
Chair of Energy Management and Power System Operation

- Mail: martin.braun@uni-kassel.de
- Phone: +49 561 804 6202

Dr. Dario Lafferte
Mail: dario.lafferte@uni-kassel.de
Phone: +49 561 804 6653

www.e2n.uni-kassel.de

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