Study Committee B5

Protection & Automation

Paper ID: 10709

Protection in Island Systems operating with high RES penetration: Case Study Astypalea

Dimitris Lagos[i], Alkistis Kontou[i], Panos Kotsampopoulos[i], George Korres[i], Nikos Hatziargyriou[i], Vasileios Papaspiliotopoulos[ii], Vasileios Kleftakis[ii], Despoina Koukoula[iii], Theodora Patsaka[iii]

[i]National Technical University of Athens, Greece [ii]Protasis, Greece [iii]Hellenic Electricity Distribution System Operator, Greece

Motivation

- Social, economic and environmental drivers lead islands' decarbonization, using hybrid production stations with battery energy storage systems (BESS) and RES, aiming at high RES penetration (>60% annually).
- Operating at high RES penetration levels is a challenging task that should be addressed properly.
- Case Study: Astypalea, Future plans in Astypalea:
  - Installation of hybrid station comprising a PV plant, a WT and a central BESS,
  - replacement of 1500 combustion engine vehicles with 1000 electric vehicles

Fig. 1 Case Study: Astypalea Island

Frequency Security Concerns

- Replacement of Conventional Units with Inverter based units lead to:
  - Frequent mismatches in power equilibrium.
  - Low levels of physical inertia.
- Which can result in:
  - High Rates of Change of Frequency (RoCoF), critical Frequency nadirs
  - Possible Maloperation of protection devices that can cause
    - Disconnection of consumers (UFLS relays)
    - Disconnection of generators (Loss of Mains relays – RoCoF & Vector Shift (VS))

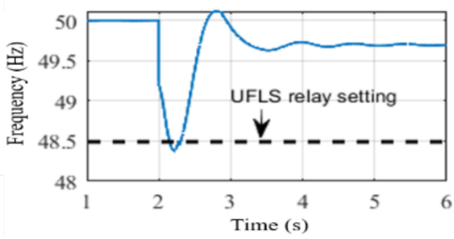

Fig. 2 Frequency transient at the disconnection of a WT in high RES penetration

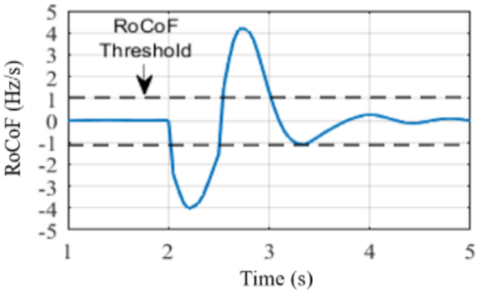

Fig. 3 RoCoF transient at the disconnection of a WT in high RES penetration

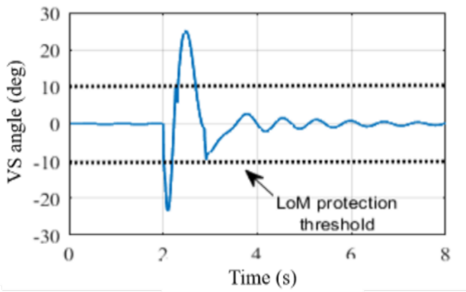

Fig. 4 VS relays angle transient at the disconnection of a WT in high RES penetration

Mitigation measures

- Provision of **fast frequency containment reserves** by inverter interfaced units, especially the central battery storage system.
- Installation of **synchronous condensers with flywheels** to increase system's physical inertia.
- **Synthetic inertia** provision by inverter interfaced units has been proposed in research to mitigate the frequency transients.

http://www.cigre.org

Study Committee B5

Protection and Automation

Paper ID: 10709

Protection in Island Systems operating with high RES penetration: Case Study Astypalea

continued

Existing Protection Scheme in Island Systems

- Existing protection scheme (overcurrent relays, fuses)

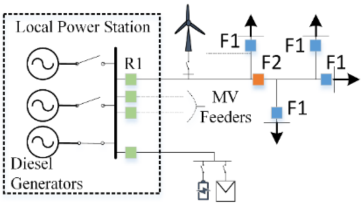

Fig. 5 Overview of existing short circuit protection in Astypalea.

Protection concerns under high RES penetration

- **Low short circuit currents** when the islands are dominated by inverter based generation.

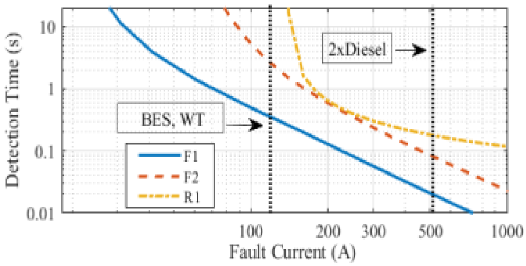

Fig. 6 Comparison of fault currents at different operating states.

- Downstream DERs decrease fault currents (**protection blinding**)

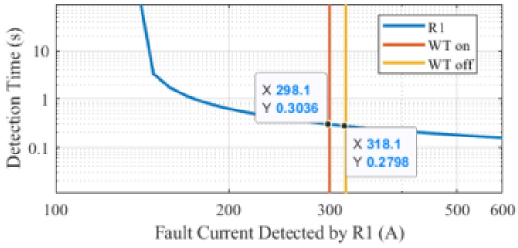

Fig. 7 Protection Blinding effect due to the WT contribution at faults at the end of the feeder.

- Fault direction variation can lead to erroneous tripping of protection equipment (**sympathetic tripping**)
- **Improper coordination between protection equipment and Fault Ride Through (FRT)** requirements can lead to the disconnection of critical units during faults.

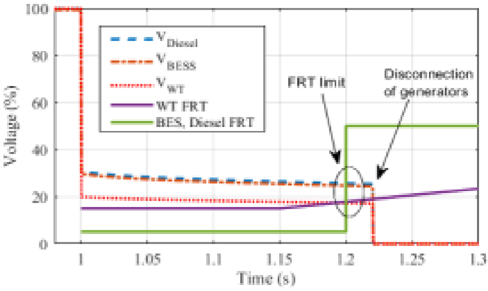

Fig. 8 Disconnection of critical units, since their FRT requirements are surpassed prior to the fault clearance

Possible Mitigation measures

- **Oversize** inverters, **install** synchronous condensers
- **Adaptive protection scheme**
  - replace fuses with directional relays,
  - install communication infrastructure
  - modify relays' settings according to the operating state

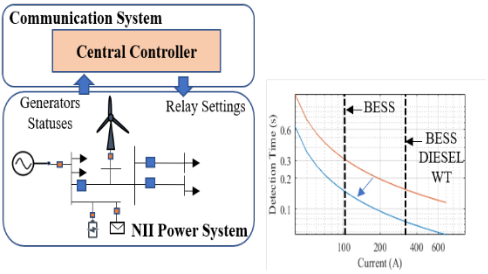

Fig.9 Adaptive Protection scheme

http://www.cigre.org

Study Committee B5

Protection and Automation

Paper ID: 10709

Protection in Island Systems operating with high RES penetration: Case Study Astypalea

continued

Experimental setup & test results

- **Hardware in the Loop (HIL)** techniques have been used to bridge the gap between simulation and field testing

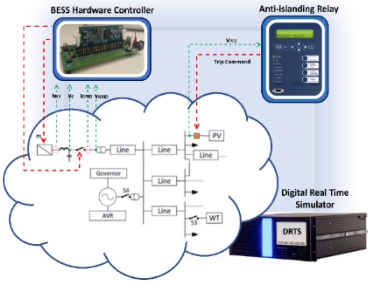

Fig. 10 HIL testbed for the evaluation of frequency control and its interaction with LoM protection

- Comparison of frequency control approaches in BESS controller (**Fast FCR, Synthetic Inertia (SI)**) when the WT is disconnected at high RES penetration

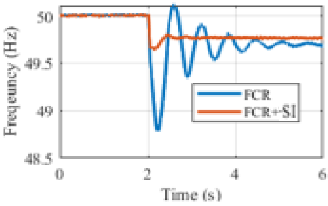

Fig. 11 Frequency transient comparison based on the services provided by the BESS unit

- The critical frequency transient after the WT outage, when the BESS provides only fast FCR, resulted in disconnection of the PV plant too, due to erroneous tripping o the industrial LoM protection .

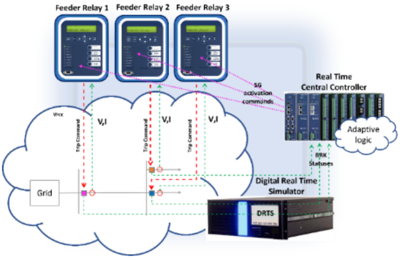

Fig.12 HIL testbed for the evaluation of adaptive protection schemes

- Evaluation of adaptive protection in a HIL testbed with industrial relays, controllers and communication protocols.

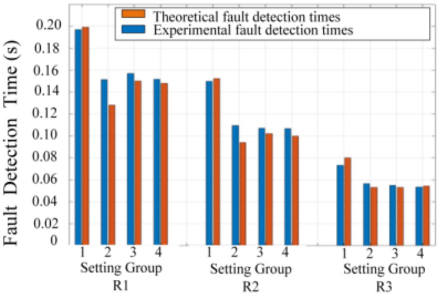

Fig.13 Comparison of theoretical and experimental fault clearance times with adaptive protection.

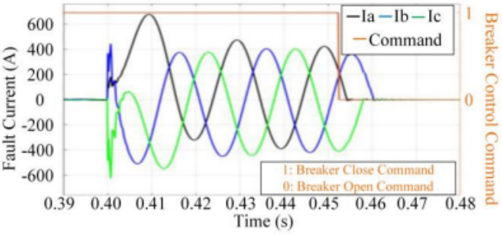

Fig.14 Fault Clearance by an industrial relay in the HIL testbed

Conclusions

- Operating on high RES penetration levels (over 60%) is a challenging and critical task
- Due to low inertia levels, advanced grid support services by inverter units are required, especially from the BESS unit.
- Protection against short circuits is an important task that faces difficulties due to the lower short circuit currents, the presence of multiple energy sources and the coordination with the FRT requirements of the generators.
- Adaptive protection schemes can address protection challenges.
- Hardware in the loop techniques can be used for the thorough testing and evaluation of novel protection/control solutions applied in islands with high RES penetration.

http://www.cigre.org