EXTENDING THE ROLE OF RES GRID SIDE CONVERTERS TOWARDS GRID SUPPORT AND POWER QUALITY IMPROVEMENT

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PRESENTATION OUTLINE

• RES STATUS IN CYPRUS
• WHAT IS EXPECTED FROM RES?
• LIVE PV SYSTEM DEMONSTRATIONS
• FROM PASSIVE TO ACTIVE RES – POSSIBLE CONTROL OPERATIONS WITH EXISTING GSCs
• CONCLUSION
RES STATUS IN CYPRUS – JULY 2018 [INSTALLED MW]

Total installed RES: 245.3 MW

Source: https://www.cera.org.cy/el-gr/elektrismos/details/statistika-ape
WHAT IS EXPECTED FROM RES?

- The increasing integration of RES requires a continuous and dynamic revision of the grid codes issued by local, national and international regulatory authorities.

- RES are no longer passive elements in an electrical power network. They are utilised as ancillary services for the mitigation of evolving contingencies for example, in the event of system faults.

- Grid regulations determine the desired operation of RES under normal and abnormal grid conditions. This is necessary in order to regulate more efficiently as well as to diversify the role, operation and contribution of RES on electrical grids as needs arise. Examples:
  - Fault ride through capability, voltage control, accurate injection of real and reactive powers, load balancing, Immunity to disturbances such as presence of harmonics, DC offset, compensating harmonics and DC offset etc.

- The power electronic based grid side converter (GSC) technology is the key element for the efficient and reliable integration of the distributed RES to the grid.

- Grid codes are therefore continuously revised so that the gsc can properly deal with grid disturbances and to actively contribute to the future power systems, smart grids and micro grids.

- The grid interconnection of res is therefore a dynamic process that requires continuous improvements and advancements in order to allow even higher penetration and active grid support.
EXAMPLES OF GRID CONNECTED PV SYSTEMS

- COMMERCIAL NET METERING
- RESIDENTIAL NET METERING
- COMMERCIAL NON NET METERING (WITH SEPARATE METER)
- RESIDENTIAL NON NET METERING (WITH SEPARATE METER)
GRID SOURCE CONVERTER (GSC) CONTROL FOR DISTRIBUTED RES – PRINCIPLE OF OPERATION

Three-phase Grid Side Converter (GSC)

- LC Filter
- DC-Link
- PWM Modulation
- Q-Profile (FRT)

Current Controller

- i_L
- θ_PLL

PQ Controller

- θ_PLL
- i_ref
- Q_ref
- P_ref (for PV)
- P_ref (for WPS)

Synchronization (PLL)

- |V_grid|
- Sampling

GSC Controller

- v_PCC
- v_ref

Multi-strings PV

Solar Power System

PCC

Wind Power System (WPS)

DC-DC converter

Wind side converter

Filter

Generator

Wind turbine

PV string

or

PV strings

or

Solar PV

v_sub

or

Ref: Z. ALI, DIVERSIFYING THE ROLE OF RES WITH ADVANCED CONVERTER FUNCTIONALITIES AND PERFORMANCE FOR IMPROVED GRID SUPPORT AND OPERATION”, PhD THESIS, FREDERICK UNIV., 2018
• AS LONG THE VOLTAGE REMAINS ABOVE THE CHARACTERISTIC LINE THE RES SHOULD REMAIN CONNECTED AND NOT DISCONNECT. IN THIS WAY, IT SUPPORTS THE GRID DURING THE RECOVERY PHASE FOLLOWING FOR EXAMPLE A FAULT THAT CAUSED A VOLTAGE DIP

EXAMPLE OF FIXED REACTIVE POWER COMPENSATION CURVE

- Effect on voltage at PCC.

- Reactive power compensation should be used to provide voltage control.

- However, it is currently used in an attempt to limit the voltage drop at the PCC – not very effective; unfair real power loss, voltage limit violation.

- The adopted compensation scheme is fixed for all the PV systems/prosumers and does not consider the location or distance of the prosumer from the secondary transformer. It does not even consider what the actual voltage is at PCC.

- The effectiveness of such a fixed reactive support scheme on the voltage regulation across the feeder may be limited since the voltage drop is directly related to the distance from the transformer.
ALTERNATIVE APPROACH TO REACTIVE POWER COMPENSATION

- DISTANCE DEPENDENT REACTIVE POWER COMPENSATION (DDRPC) SCHEME
- TAKES INTO CONSIDERATION THE DISTANCE OF RES FROM THE SS/FEEDER
- AIM IS TO AVOID UNNECESSARY COMPENSATION, MINIMISE REAL POWER RES LOSSES
- SIMULATION RESULTS HAVE IDENTIFIED THE INEFFECTIVENESS OF CURRENT PRACTISE AND THE REQUIREMENT FOR IMPROVEMENT RPC

IMMUNITY TO ABNORMAL GRID CONDITIONS

• The contribution of renewable energy systems during unwanted grid events such as the presence of harmonics, interharmonics, phase unbalance, faults, DC offset, voltage sags etc., as well as the requirement for optimum interaction with micro grids and smart grids, are areas in which the RES can play an active and supportive role.

• The power electronics components required for engaging in the operations necessary for any of the above-mentioned grid modes/functionalities are already installed within the GSC and this provides great flexibility since advanced features can be incorporated for the benefit of the grid without needing extra hardware and cost.
OPERATION OF GRID-CONNECTED RES WITHOUT ADVANCED FUNCTIONALITIES AND CONTROL TECHNIQUES—VULNERABLE TO ABNORMAL GRID CONDITIONS (1/2)

• Before t=0.6 s, the grid voltage is free of harmonics and DC offset and is symmetrical. Synchronization signals (i.e., the estimated grid frequency and the amplitude of the grid voltage) are accurate and free of any oscillations. In addition, the injected RES currents are also symmetrical with THD less than the 5 % allowable limit.

• At t=0.6 s, the grid voltage becomes distorted with 5% 5th and 3% −7th harmonic to which, synchronization works with accuracy, however, the injected currents suffer from distortion.

• At 0.65 s 4.2th and 7.6th interharmonics are injected with a magnitude of 5.3% and 4.1%. Oscillations are observed on the estimated frequency and the q-component of the grid voltage. In addition, the THD of the injected current increases.

• At 0.7 s a two-phase to ground fault occurs, which results in violation of the frequency operating window (47 Hz<f<52 Hz) as imposed by the local grid regulations and the THD drastically goes high.

• This fault may also cause the disconnection of RES due to the overcurrent protection of the GSC.
OPERATION OF GRID-CONNECTED RES WITHOUT ADVANCED FUNCTIONALITIES AND CONTROL TECHNIQUES-VULNERABLE TO ABNORMAL GRID CONDITIONS (2/2)

• At 0.75 s, DC offset along with 4.2\textsuperscript{th} and 7.6\textsuperscript{th} interharmonics occur, for which, the synchronization signals suffer from undesired oscillations and the THD of RES current exceeds again the allowable limit.

• The low quality currents injected by the RES, the slow dynamic response and the high frequency overshoots, especially under a large-scale RES penetration, can seriously affect the power quality and operation of the whole power system.

• Thus, there is a need to develop advanced and less complex algorithms that present fast synchronization and accurate operation under harmonics, interharmonics, DC offset, unbalanced and other grid disturbances.
PLL RESPONSE TO: TWO-PHASE TO GROUND FAULT WITH A PHASE CHANGE OF -10°

• The frequency overshoot for the proposed HIHDO-PLL is lower among all the PLLs, hence it can be used for the synchronization of grid connected RES without violating the grid frequency limits. Furthermore, the frequency settling time for HIHDO-PLL is lower compared to DNαβPLL and EPMAFPL.

• PLL would thus continue to read grid information accurately allowing in this way the GSC to remain in operation.

MITIGATING FOR GRID ABNORMAL CONDITIONS (2/4)

PLL RESPONSE TO: THREE-PHASE TO GROUND FAULT

PLL RESPONSE TO: FREQUENCY CHANGE EVENT UNDER BALANCED AND HARMONIC FREE GRID CONDITIONS

PLL RESPONSE TO: FREQUENCY VARIATIONS IN THE PRESENCE OF 5TH & 7TH HARMONICS, 3.2TH & 4.6TH INTERHARMONICS AND DC OFFSET

Improving the Power Quality (1/2)

Injection of positive, negative, harmonic, and DC currents using MFCC

Validation of advanced control scheme for improving the power quality of grid under DC-shifted prosumer's load

**Validation of advanced control scheme for the compensation of asymmetric prosumer's load**

<table>
<thead>
<tr>
<th>Type A</th>
<th>PV injecting symmetric currents</th>
<th>Operating Conditions</th>
<th>Asymmetric, DC and harmonic load</th>
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<tbody>
<tr>
<td>PV operating as per proposed APQC</td>
<td>No injection from PV</td>
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CONCLUSION

IT IS POSSIBLE TO UTILIZE THE EXISTING ELECTRONICS OF RES FOR:

• SECURING THE DESIRED OPERATION OF RES (P AND Q INJECTION) UNDER NORMAL AND DISTURBED/ABNORMAL GRID CONDITIONS

• SECURING THE ACCURATE OPERATION OF RES IN THE PRESENCE OF HARMONICS, INTERHARMONICS AND DC OFFSET

• IMPROVING THE POWER QUALITY BY:
  • CONTROLLING THE VOLTAGE
  • COMPENSATING FOR HARMONICS, INTERHARMONICS AND DC OFFSET
  • GRID CURRENT BALANCING
THANK YOU