Increasing the RES Hosting Capacity of the Cyprus Distribution System

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Abstract

The Renewable Energy Sources (RES) penetration in the power system of Cyprus has dramatically increased over the last years. As a result, the system is already facing significant challenges limiting the RES hosting capacity of the Distribution Network (DN). The major limitation factors are network congestion and voltage security. In this paper, alternative solutions for increasing the RES hosting capacity in DNs are reviewed, and a methodology is introduced to evaluate their effectiveness. More specifically, different inverter settings and an advanced centralised voltage control from power transformers are used to mitigate voltage-related issues, while network reinforcements and upgrading the operating voltage are considered for further increase in hosting capacity. The solutions and evaluation methodology are tested using a real MV network of the Cyprus distribution system and the strategic plan of the Cyprus Distribution System Operator (DSO) for maximizing RES hosting capacity is outlined.

1 Introduction

The RES penetration has experienced a remarkable increase worldwide in recent years. The installed capacity of Photovoltaic (PV) systems within the Cyprus distribution system has surpassed 650 MW, with an additional 350 MW expected to be connected by 2026. This RES penetration is substantial, considering that the historically maximum load demand is only 1.2 GW. Consequently, the Cyprus power system is currently grappling with significant challenges that hinder further increase in RES penetration [1]. The RES installed capacity in many areas of the island has already reached hosting capacity which is limited due to network congestion or voltage security issues. Therefore, it is imperative to devise solutions that will enable the expansion of the distribution system's RES hosting capacity.

Several solutions have been proposed in literature for planning PV-rich distribution networks [2]. In this work, emphasis is given to the planning recommendations for the short-to-medium term up to 60% PV penetration, which mainly includes the exploitation of the current network capabilities. These capabilities look into adopting new stricter grid code requirements for Inverter-Based Resources (IBRs) and implementing 'intelligent' centralised voltage controls on power transformers [2].

Previous works have evaluated the impact of RES penetration on the Cyprus distribution system and proposed solutions to increase hosting capacity. In [3], the authors focused their analysis only on the impact of different COSF(P) reactive power compensation schemes for decentralised voltage control. While, in [4], the analysis evaluated the impact of RES penetration on the neutral voltage in unbalanced three-phase low-voltage networks.

In this paper, several solutions proposed in the literature are reviewed, and a methodology is introduced to evaluate their effectiveness on increasing the hosting capacity in the Cyprus DNs. A Monte-Carlo approach is implemented to assess the effectiveness of the proposed solutions on the Cyprus DN using historical data. The security assessment is performed with automated simulations using Python with DIgSILENT PowerFactory. Finally, drawing insights from the results of this evaluation, a plan for the Cyprus DSO is strategically formulated to maximize the hosting capacity for RES. More specifically, the paper contributions are twofold: i) propose a Monte-Carlo based methodology for assessing the effectiveness of the solutions for increasing the RES hosting capacity in DNs; and, ii) evaluate the suitability of the solutions for the Cyprus DN and inform the DSO strategic plan.

The rest of the paper is organized as follows. Section 2 demonstrates the proposed solutions for increasing hosting capacity. Then, in Section 3, the Monte-Carlo-based methodology to compare the alternative solutions is explained. In Section 4, the case study and the methodology are described, while in Section 5, the proposed solutions for increasing Hosting Capacity are evaluated. Finally, Section 6 summarizes the main findings and insights.

2 Review of Solutions for Increasing RES Hosting Capacity

Depending on the system characteristics, different network criteria must be satisfied for accepting a new RES connection request. These criteria usually are equipment loading below 100%, voltage range within nominal limits, and maximum voltage difference below 2% before and after IBR connection [5]. Consequently, solutions must mitigate the impact of additional RES on the system regarding voltage security and equipment loading to increase hosting capacity effectively.

2.1 *IBRs Decentralised Voltage Control*

Currently, in Cyprus, all IBRs are required to perform voltage control by using the COSF(P) characteristic presented in Fig. 1. This functionality requires IBRs to start absorbing reactive power when the active power output of the IBRs exists 40% of their installed capacity. This is an open-loop approach, with all the benefits and problems related to it.

In other grid codes, the Volt-Var (Q(V)) control method depicted in Fig. 2, is required [5]. The IBRs absorb or inject reactive power depending on the voltage at the IBR terminal. This is a closed-loop approach, where the control variable (voltage) is used as feedback.

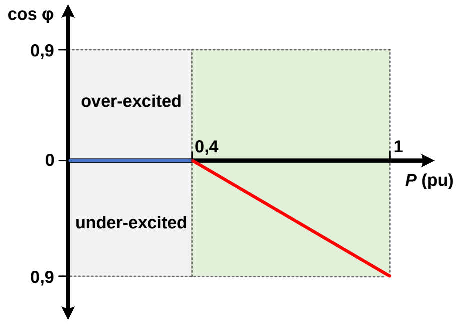

Figure 1: COSF(P) characteristic

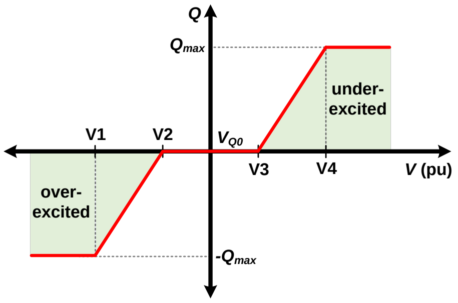

Figure 2: Q(V) characteristic

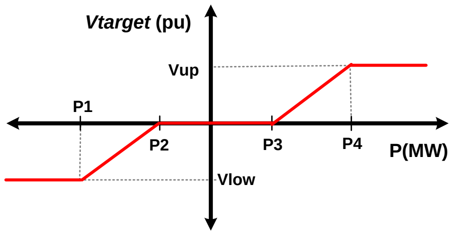

Figure 3: Reverse line drop compensation (RLDC) characteristic

2.2 *Centralised Voltage Control*

In many countries, power transformers at transmission substations have on-load tap-changing capabilities. However, their target voltage is usually constant, lacking flexibility during different operating conditions. Reverse line drop compensation (RLDC) methods can be used for maintaining voltages within nominal limits at different conditions. RLDC characteristic is shown in Fig. 3, and it can be seen that the target voltage of the power transformers is adapted according to the active power flow through the power transformer. Therefore, during excessive reverse active power, the power transformer target voltage is reduced, thus reducing the voltages across the MV feeders. On the contrary, during high loading conditions, the target voltage increases to compensate for voltage drop in the DN.

2.3 *Network Upgrades*

Network reinforcement has traditionally been used to increase equipment's current capability. This solution is very effective for congestion avoidance, but its effect on voltage issues is moderate. On the other hand, upgrading the operating voltage can greatly impact RES hosting capacity since voltage and congestion-related issues can be mitigated. Since 2004, the Cypriot DSO has decided to gradually increase the operating voltage of the MV distribution systems from 11kV to 22kV. Hence, a noticeable portion of the installed equipment is already rated at 22kV, even though it is operated to 11kV. Both solutions, especially voltage upgrade, have significant capital costs since the majority of the equipment must be replaced.

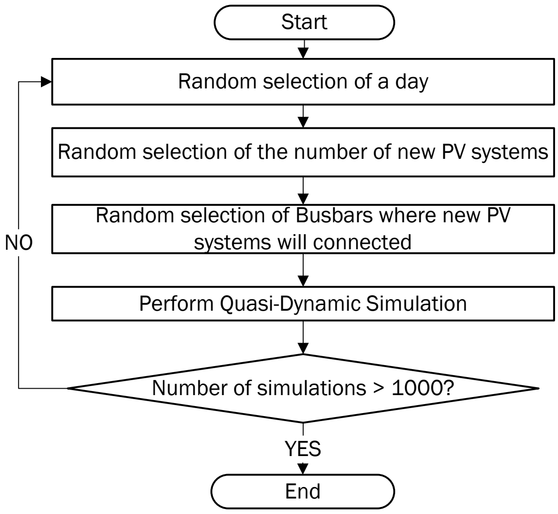

Figure 4: Hosting capacity assessment flowchart employed for each scenario

3 Comparison Methodology

A Python script has been developed, using DIgSILENT PowerFactory as the computational engine, to evaluate the hosting capacity of MV distribution networks using different solutions. First, the number of potential solutions are defined (called scenarios). The flowchart shown in Fig. 4 is then used for each scenario to analyse its performance in increasing the hosting capacity. The methodology follows a Monte-Carlo approach with the random variables being the operating conditions (historical day), the number, location, and size of new PVs. Thus, for each scenario, 1000 quasi-dynamic (time sweep load flows) simulations are performed using historical data selected randomly. For each simulation, 6 hours in each day are analysed (4p.m, 8p.m, 12p.m, 4a.m, 8a.m, 12p.m). For each iteration, the number of new PV systems is selected using a uniform distribution from 3 to 10 and the locations where the new PV systems are connected are uniformly selected among all possible busbars. Finally, the installed capacity of the new PV systems is randomly selected using a uniform distribution from 500 to 5000kWp.

At the end of each scenario analysis, the aggregated results from the 6000 hours are used to check the number of violations and other technical parameters of the system. The comparison between scenarios allows providing insights on the available solutions for the specific MV distribution network.

4 Case Study

In this section, the Cyprus MV test system and the scenarios used to assess the performance of the methodology are shown.

Table 1: Description of scenarios

Scenario	IBR setting	Centralised voltage control
BaU	COSF(P)	Constant
SC1	Q(V)1	Constant
SC2	Q(V)2	Constant
SC3	Q(V)3	Constant
SC4	Q(V)1	RLDC
SC5	Q(V)2	RLDC
SC6	Q(V)3	RLDC

4.1 *MV Distribution System*

An 11kV distribution network in Cyprus, presented in Fig. 5 has been modelled with data provided by the Cyprus DSO. The DN consists of 4 feeders, feeding 176 distribution substation loads. There are 8 PV units already installed with 9 MW installed capacity. The DN is fed by two parallel transformers, each with 16 MVA and equipped with OLTC capabilities. The historical active and reactive power measurements at the beginning of each feeder for 2023, have been distributed along each feeder according to the nominal capacity of each distribution substation. All simulations have been performed using the DIgSILENT PowerFactory software [6].

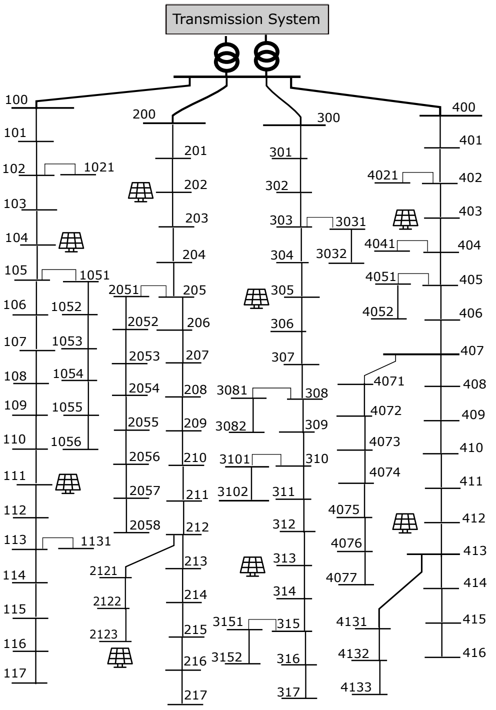

Figure 5: MV distribution network model

4.2 *Scenario Description*

The scenarios selected for this case study are presented in Table 1. The settings selected for each scenario and for each type of solution are detailed below.

- IBR Voltage Control Settings:
  - **COSF(P)**: according to Fig. 1
  - **Q(V)1**: $V_2 = 0.97p.u,\ V_3 = 1.03p.u,\ Droop = 40\%$
  - **Q(V)2**: $V_2 = 0.98p.u,\ V_3 = 1.02p.u,\ Droop = 50\%$
  - **Q(V)3**: $V_2 = 0.99p.u,\ V_3 = 1.01p.u,\ Droop = 50\%$
- Centralised Voltage Control through OLTC control
  - **Constant**: Target Voltage 1.01p.u
  - **RLDC**: P1=-8MW, P2=-2MW, P3=2MW, P4=8MW, Vup=1.01p.u., Vlow=0.99p.u.
- **Network Reinforcement**: All overhead transmission lines and underground cables have been replaced with the next available equipment with higher ampacity. These scenarios are denoted with 'A'.
- **Voltage Upgrade**: Equipment with rated voltage of 11kV is upgraded and operated at 22kV. These scenarios are denoted with 'U'.

5 Results

The total number of violations for each scenario is demonstrated in Fig. 6. It can be seen that the number of violations is significantly reduced in all scenarios when network reinforcement (A) and voltage upgrade (U) solutions are applied. The impact of voltage upgrade is more profound, as it mitigates both voltage and loading violations. In addition, in scenarios SC4U, SC5U, and SC6U the number of voltage-related violations (maximum voltage and/or maximum voltage difference) is almost eliminated.

The number of feeder loading violations has been significantly reduced in all scenarios with voltage upgrade, while a noticeable reduction is observed in the network reinforcement scenarios. Also, the impact of installing an additional power transformer in the transmission substation is depicted with orange colour in Fig. 6. The additional power transformer mitigates the majority of power transformer loading violations.

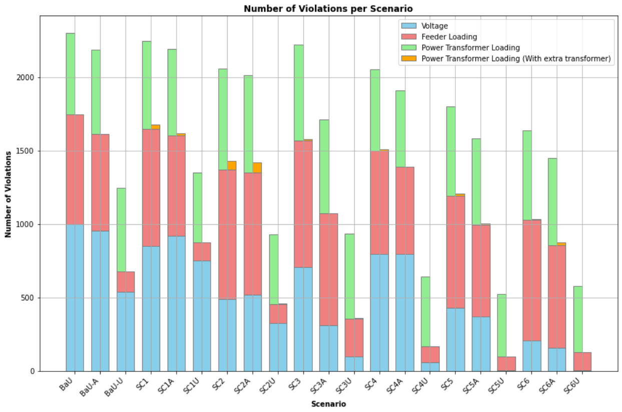

Figure 6: Number of violations

The impact of the evaluated solutions on the maximum voltage difference before and after the IBR connection is presented in Fig. 7. It can be seen that with network reinforcement and voltage upgrade, the voltages are concentrated closer to the allowable limits (0.02 p.u). In addition, it is evident that solutions that combine RLDC and strict volt-var control from IBRs (purple and blue dots) have a more beneficial impact on resulting voltages.

Figure 7: Maximum voltage rise

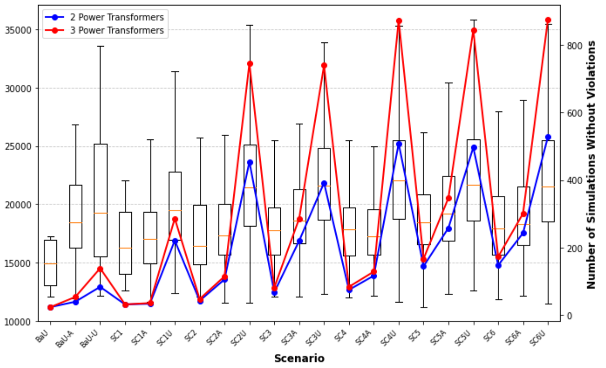

Figure 8: Hosting capacity

The impact of the analysed solutions on equipment loading is similar with Fig. 7. However, it should be noted that IBRs voltage control settings and centralised voltage control solutions do not influence equipment loading noticeably.

The hosting capacity of each scenario with an additional 16MVA power transformer is presented in Fig. 8. It is evident that hosting capacity increases by applying network reinforcement and voltage upgrade solutions. Also, stricter volt-var settings and RLDC have beneficial effects on hosting capacity. Although the increased hosting capacity is not significant, it is important to highlight that the number of simulations without any violations is increased with the voltage upgrade solution.

The hosting capacity improvement is more evident with the addition of a power transformer (red line) than with the current transmission substation capacity (blue line). This is because the applied solutions have minimized the violations within the distribution system. Thus, the major limiting factor is now the transmission substation capacity.

6 Conclusions

The Cyprus Power System's hosting capacity must be increased to accommodate the significant number of predicted new RES connections. Based on the results of the analysis, it is recommended that the Cypriot DSO should focus on exploring the current network capabilities. Hence, the IBRs settings should be modified from the COSF(P) to Q(V) with strict settings (Q(V)2 or Q(V)3). Modifying the settings of the already installed PV systems is very difficult; thus, only new systems will be equipped with the new settings. In addition, by applying RLDC centralised control method, voltage-related issues will be minimized.

For further RES penetration, DSO should focus on upgrading the operating voltage of the network as already planned. This will have a huge impact on both equipment loading and voltage issues. Emphasis should also be given to the transmission substation capacity. In large distribution networks with numerous MV feeders, there is an increased possibility that power transformers could be overloaded before the hosting capacity of the distribution system is exhausted. Thus, the Cypriot DSO and the transmission system operator (TSO) should coordinate to develop their networks in a timely and strategic way to eliminate network limitations.

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