Increasing Hosting Capacity of Uncontrollable Distributed Energy Resources in Isolated Power Systems

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***Abstract*—Due to the push for more sustainable generation, small-scale distributed energy resources (DERs) penetration has increased significantly. Most countries have no remote monitoring and control requirements for DERs below a certain size. Therefore, they can be labeled as uncontrollable DERs (UDERs). In isolated systems, the UDERs hosting capacity is limited due to frequency stability concerns, as it is impossible to modify or curtail their generation in a centralized manner. In this paper, we propose the utilization of the active power over-frequency reduction curve for increasing the hosting capacity of UDERs in isolated power systems. Cyprus's power system has been used to evaluate the proposed solution's performance. The optimal settings of the curve have been identified, and it was found that UDERs hosting capacity can be increased significantly with the proposed methodology.**

***Index Terms*—uncontrollable distributed energy resources; hosting capacity; grid code requirements; frequency stability; islanded systems.**

I. Introduction

The huge rise in electricity prices and environmental concerns have significantly increased the number of new installations of small-scale residential PVs in Southern Europe. In most countries, the grid code requirements for small-scale PV systems under a certain capacity do not have any remote monitoring and control requirements. Thus, they can be considered as uncontrollable distributed energy resources (UDERs) [1]. The massive penetration of UDERs can impose significant challenges on system operators. These challenges vary from network congestion to problems in the real-time balancing of generation and demand. The latter can be very critical in isolated power systems, since exporting or importing capabilities are unavailable.

Therefore, in isolated power systems, the UDERs' hosting capacity, that is, the maximum installed capacity that does not violate any operational limits of the system, is limited [2]. These limits are defined by the transmission system operators (TSOs) to maintain frequency stability, especially during low-load conditions. In Cyprus's small isolated power system, this limit is static and has been set to 145 MW of installed capacity for UDER PVs, to satisfy the minimum stable generation limit (more discussion in Section II) [3]. However, the installed capacity of the UDERs has already reached 145MW. As a result, the local system operators have recently announced that further UDERs cannot be connected to the system.

This limit has not been explicitly defined in other countries, but the local authorities are already imposing some measures to avoid reaching increased levels of UDERs. In Hawaii, an energy storage system (ESS) is required for the economic viability of new small residential installations [4]. In Germany, all new small DERs have to be controllable or a constant limit of 70% is applied to their nominal active power [5]. In the Netherlands, the parliament had approved the net-metering scheme's phase-out to promote ESS [6].

Currently, several methods can be used for controlling the active power injection of UDERs systems:

- **Direct control through the Distribution Management System (DMS) SCADA:** UDERs can be connected to the SCADA DMS system operated by the distribution system operator (DSO) through remote monitoring and control. However, this method is very costly, requiring remote terminal units (RTU) to be installed for each UDER.
- **Indirect control through Ripple or IoT technology:** Ripple control technology has been traditionally used for activating or deactivating loads based on specific tariffs or during emergencies. This technology requires only an additional receiver to be installed along with each UDER. The disadvantage of this technology is that can only turn on/off UDERs. Internet of Things (IoT) technology offers increased efficiency and capabilities but at higher communication and local processing requirements. Thus, IoT requires additional capital and operational costs. Smart Meters can be considered in this category. IoT has the additional drawback of cyber security constraints since it doesn't use dedicated communication networks.
- **Using Energy Storage Systems (ESS):** ESS can be installed along with each UDER system to limit the energy injected into the grid. However, this solution is

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very expensive. A large centralized ESS could be installed to increase the system load virtually. However, according to European legislation, operators cannot own or operate ESS [7].

The above-mentioned options require additional equipment to be installed with UDERs, increasing costs. Also, centralized control of many small-scale DERs for security purposes is challenging since it requires a robust and secure communication network.

In this paper, we propose using the well-known ‘Active power over-frequency reduction curve’, currently used for frequency support during emergencies, to alleviate the need for controlling UDERs during low-load/high-RES conditions. This is achieved by allowing the system to operate in an acceptable over-frequency state, using the frequency as the communication signal. In this manner, the hosting capacity of UDERs systems in isolated power systems is increased without the need for additional equipment. The satisfactory performance of the proposed solution has been verified for different UDERs installed capacity and settings. For the analysis, Cyprus’s low inertia isolated power system has been used.

The rest of the paper is organized as follows. Section II explains the need for controlling DERs in isolated systems, and a brief description of the active power over-frequency reduction curve and the proposed methodology is presented. In Section III, the Case Study is described, while in Section IV, the effectiveness of the proposed solution is evaluated. Finally, Section V summarizes the main findings and insights.

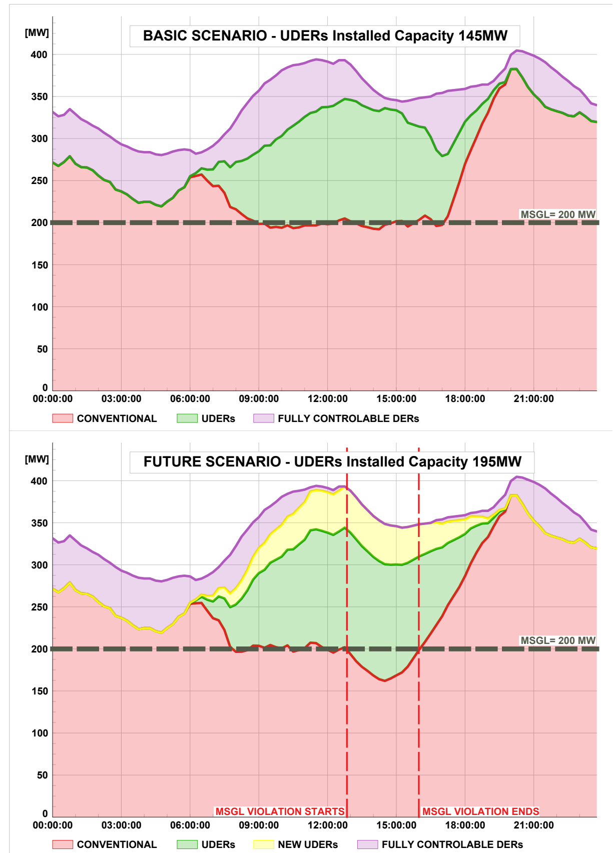

Fig. 1. Generation Profile: a) Basic Scenario; b) Future Scenario

II. Background Information

A. The need for controlling DERs

The requirement for controlling small-scale DERs is imposed due to frequency stability issues. Low inertia - isolated power systems require a minimum number of synchronous generation units to maintain power system stability during generation outages. At the same time, the synchronized units must always operate at least above their minimum active power generation limits (MAPGL). Therefore, the system load consumption must be larger than the sum of the MAPGL, which is known as the minimum stable generation limit (MSGL) of the systems, plus the power generated by the DERs. However, during low-loading conditions when the load becomes lower than the aforementioned sum, there is a need to either curtail the DER power or use ESS to store the excess without violating the MSGL [3]. Reducing the power of the conventional units is not possible (since they operate near their MAPGL) and remove one of the units is not possible due to inertia constraints.

However, in most countries, only large DERs are required to have the ability to receive active power set points and thus are eligible for curtailments. The large penetration of UDERs may jeopardize the power system stability if we cannot curtail their power. In this case, the system frequency will increase, leading to a sustained over-frequency event that can lead to a blackout. It should be noted that the requirements for curtailments of power generated from DERs are expected to increase significantly.

This is demonstrated in Fig. 1. In the *Basic Scenario*, the MSGL is not violated because the fully controllable DERs can perform the required curtailments. However, if the installed capacity of UDERs increases further, as shown in the *Future Scenario* with an additional 50MW of UDERs, the MSGL is violated even though the controllable DERs are fully curtailed. During this violation, the conventional units are operating at their MSGL and the DERs cannot be curtailed; thus, the excess power will lead to a sustained and increasing over-frequency event.

B. Active Power Over-frequency Power Reduction Curve

Most of the grid codes require from all DERs the capability of reducing their active power output based on the system frequency. This is applied using the ‘active power over-frequency reduction curve’ shown in Fig. 2 [5]. DERs must decrease their active power when the frequency is above FR based on a constant droop characteristic. At the same time, when the frequency is below FL or above FH the unit has to be disconnected instantaneously. With this functionality, DERs proportionally support the system to maintain frequency stability close to the nominal value during over-frequency events.

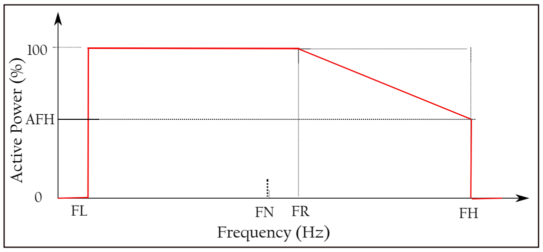

Fig. 2. Active power reduction curve during over-frequency conditions

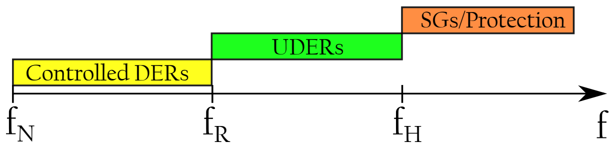

Fig. 3. Activation periods for different types

C. Proposed modified Active Power Over-frequency Power Reduction Curve behavior

The proposed implementation strategy concept is to force UDERs to perform balancing while the conventional generation units constantly operate at their minimum active power limits. To achieve this, the synchronous generators should have a deadband at which their active power output should remain constant irrespectively of the system frequency. The deadband should be from fN (nominal frequency) to fH including the FR frequency (see Fig. 2). In addition, this methodology should only be applied after all the fully controllable DERs have reduced their active power to zero as shown in Fig. 3. In this way, the large commercial DERs are curtailed before the small residential UDERs. In this manner, fairness is relatively maintained between the different types of energy producers from RES.

The proposed implementation strategy is presented in the flowchart of Fig. 4. In summary, when the MSGL is reached at fN, the active power of the controllable DERs is gradually curtailed. If further energy has to be curtailed, the frequency deadband of the synchronous generators (SGs) must be activated. As a result, the frequency of the system will be increased above fR, where UDERs will start to reduce their active power according to Fig. 2. If further energy must be reduced, even when the total active power from all DERs has been curtailed at fH, a synchronous generator can be disconnected or it will be disconnected due to their overfrequency protection settings (usually set at 51.5Hz). For this methodology to work, the assumption is made that the automatic generator control (AGC) is modified to allow the operation of the system in over-frequency conditions within specific limits.

III. Case Study

The Cyprus power system has been utilized to evaluate the impact of the modified active power over-frequency reduction functionality on the hosting capacity of UDERs of isolated

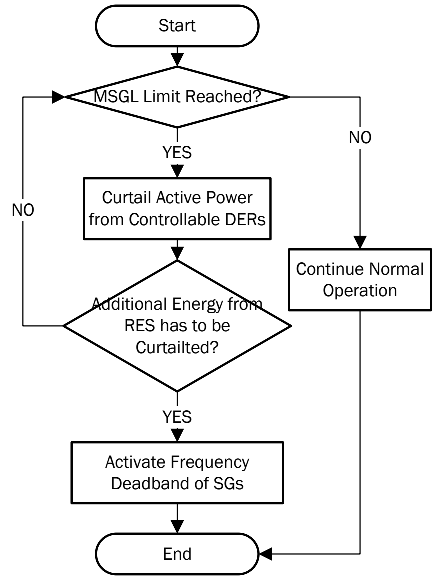

Fig. 4. Implementation strategy flowchart

TABLE I
WECC DER Model - Frequency Related Parameters and Values - Standard Settings

Functionality	Parameter	Value
Under Frequency Protection	FL	47.5 Hz
Over Frequency Protection	FH	51.0 Hz
Frequency Reduction	FR	50.2 Hz
Droop	Ddn	40 %

power systems. The Cypriot transmission system was modeled in detail with data provided by Cyprus Transmission System Operator (TSOC). All simulations have been performed using the DIgSILENT PowerFactory simulation software [8].

A. Operating Conditions

The operating condition from the lower demand of 2022 (450 MW occurred in April) has been used as a reference. The generation profile is presented in Fig. 1b (Future Scenario). In this scenario, the total installed capacity of UDERs is increased to 195MW. Thus, the UDERs limit of 145MW is violated. The analysis is performed at 14:30, which is the time when the MSGL has the larger violation. At that time, two Steam Turbines at Vasilikos Power Station and two at Dhekelia Power Station were operating at their minimum stable generation limits. As a result, during the analysis, the conventional generators are generating approximately 200 MW.

B. Distributed Energy Resources Modelling

The WECC PV and Type-4 WPP generic models have been used for this study [9]. The parameters related to the active power over-frequency capability curve are shown Table I. The additional UDERs have the same ‘standard settings’ as those presented in Table I, unless stated otherwise in the analysis.

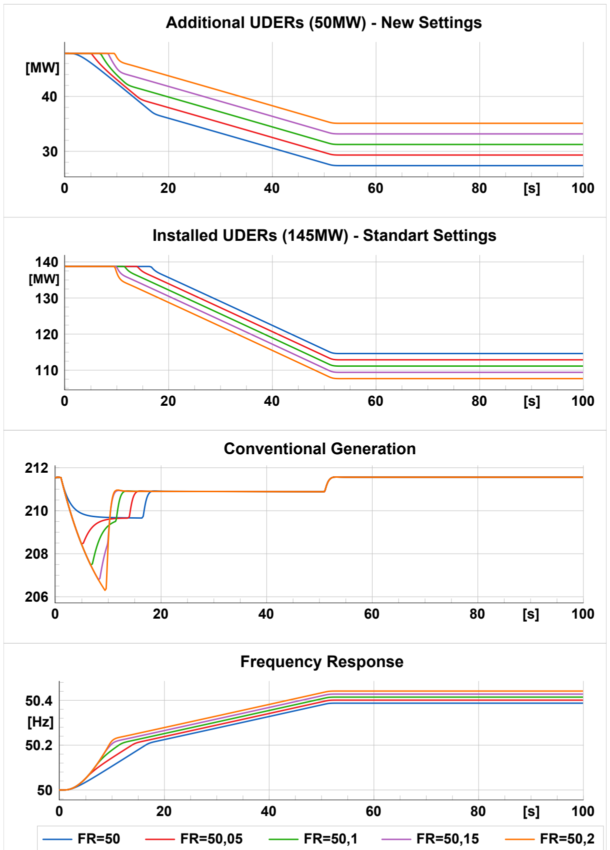

Fig. 5. Impact of FR on the frequency response of the system

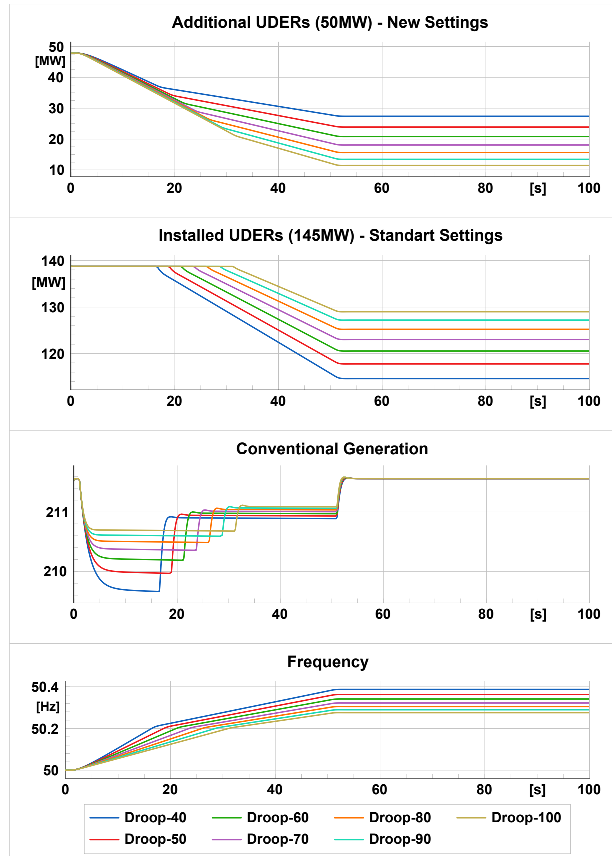

Fig. 6. Impact of droop on the frequency response of the system

IV. Results

In this section, the results of the analysis are presented. The analysis focuses on identifying the optimal settings for the additional UDERs (not already installed) and the effect of the proposed methodology on the hosting capacity of UDERs.

A. Impact of Active Power Capability Curve Settings

A sensitivity analysis has been performed to identify the optimal settings of the modified active power capability curve for the additional UDERs on power system frequency stability. An additional 50MW of new UDERs have been installed in the system.

1) Impact of FR: A sensitivity analysis has been performed for the setting FR from 50Hz to 50.2Hz. It can be seen from the results in Fig. 5 that the FR value slightly affects the frequency response of the system. Even with the more relaxed setting of FR equal to 50.2Hz, which is the standard setting, the settling frequency is almost the same with the most strict setting of 50Hz. Also, it can be seen that while FR for the new UDERs is increasing, the active power reduction from the already installed UDERs is reducing. This is due to the fact that the new UDERs reduce their active power output when their FR is small, thus containing the frequency rise. Based on these results, the value of 50.05Hz is selected as a compromise between faster response and coordination.

2) Impact of Droop: Afterward, the same analysis was performed, but in this case, the FR value was set to 50.05Hz, and a sensitivity analysis was performed on the Droop value of the additional UDERs. The analysis results are shown in Fig 6. It can be seen that the droop setting of the UDERs has a significant impact on the system frequency response. With a droop setting of 40%, the new UDERs have reduced their active power output by 20MW, while with a droop of 100%, the respective reduction is 25MW. Also, there is a noticeable difference on the settling frequency depending on the droop setting. However, in any case, the frequency response is contained below 50.5Hz, and the conventional generation units are always operating above their MAPGL.

B. Impact of UDERs Installed Capacity

The main target of the proposed solution is to increase the hosting capacity of UDERs. Therefore in this section, the analysis of part A is repeated with constant settings Fr=50.05Hz and Droop=80% for the additional UDERs.

It can be seen from the results in Fig. 7, that while UDERs penetration increases, the settling frequency increases. However, in all cases, the additional UDERs have reduced their active power output below 50MW. This demonstrates that the proposed methodology can increase the hosting capacity of UDERs since their active power output is reduced significantly when RES power curtailments would have been performed.

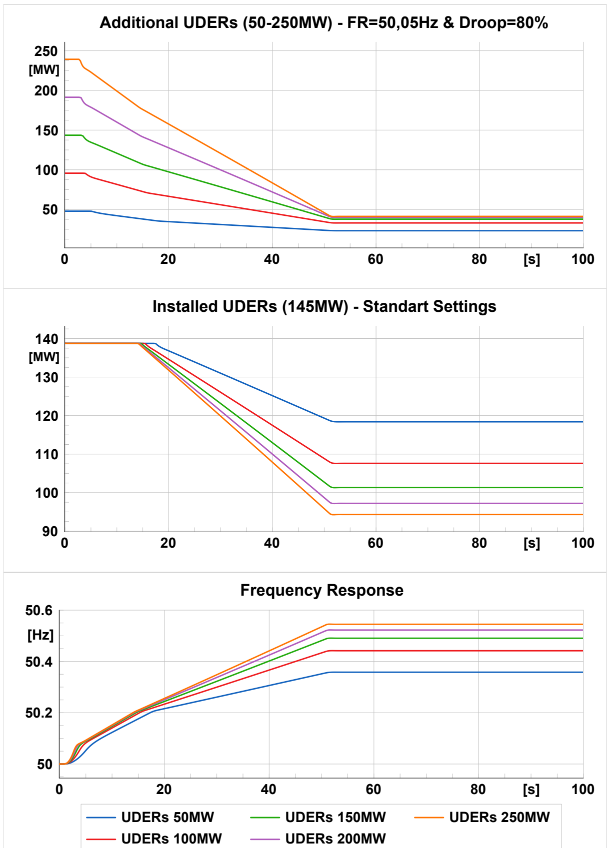

Fig. 7. Impact of the UDERs installed capacity on the effectiveness of the proposed methodology

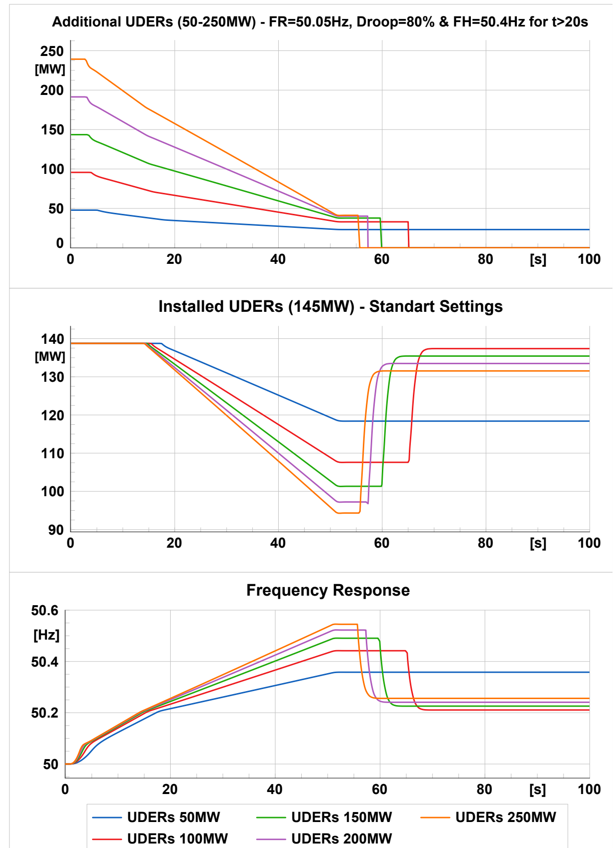

Fig. 8. Impact of time-delayed (t=20s) overfrequency protection at FH on hosting capacity of UDERs

It can be seen from the results that in all cases the frequency stabilizes above 50.2Hz (upper normal operation limit). For this reason, in this paper, we proposed using a time-delayed (t=20s) overfrequency protection at 50.4Hz. In this manner, during sustained overfrequency events caused by the proposed methodology, the UDERs will be disconnected. It should be noted that overfrequency protection (FH) must remain to ensure rapid DER disconnection of DERs during large events. The analysis results are presented in Fig. 8. It can be seen that when the frequency exceeds 50.4Hz for a duration of more than 20s, the additional UDERs are disconnected. The time delay can be increased depending on the system operator's needs. As a result, the system frequency reduces. However, the already installed UDERs with the standard settings increase their active power according to the system frequency. In general, this additional time delay protection is very useful, since even in UDERs penetration of 250MW, the settling frequency is slightly above 50.2Hz.

V. Conclusions

In this paper, we showcase how the decentralized control of active power in UDERs can help increase the hosting capacity of UDERs. The major advantage of this methodology is that it does not require any additional equipment. Also, any concerns related to cyber security issues and controlling many small DERs are mitigated. The analysis showed that this method could significantly improve the hosting capacity of UDERs.

VI. Acknowledgment

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