# Impact of FFR in Distribution System Reliability

Savvas Panagi[1] and Petros Aristidou[2]

[1,2]*School of Electrical and Computer Engineering, Cyprus University of Technology, Limassol, Cyprus*

[1]*Email: savvas.panagi@cut.ac.cy*

**Abstract**

This paper presents an analysis focused on enhancing distribution system reliability in low-inertia power systems, particularly addressing challenges arising from increased penetration of renewable energy sources (RES). Low-inertia systems often have to curtail power generation from RES and activate under-frequency protections, compromising distribution system reliability. By using fast frequency response (FFR) to limit the Nadir during disturbances, distribution system reliability increased. The simulation results from a real Cyprus power system try to present quantitative results to present the magnitude of the problem and the improvement of the utilization of the system through the use of the FFR.

## 1 Introduction

Low-inertia systems suffer from increased RES penetration and are therefore forced to curtail power generation from RES to meet minimum requirements. At the same time, after a significant disturbance, under-frequency protections are activated to ensure system frequency stability. Both actions are undesirable in power systems and affect the distribution system's reliability. The main parameters that affect the above situations are inertia and FCR reserve, which will be explained in more detail in the next section.

There are several ways to utilize converter-based units to mitigate the problem. Converted-based units do not have any electromagnetic coupling, so they can only provide emulated reserves. In [1], authors give a brief explanation of how inertia and FCR affect the lowest frequency value after a disturbance (Nadir) and increase the minimum reserve requirements. Moreover, they explain some frequency control methods, like virtual synchronous machines, synthetic inertia control, and fast frequency control, to improve the system's operation. In [2], a methodology for sizing and placing distribution energy storage systems to improve the performance of distribution networks is given. In [3], the authors focused on fast frequency response (FFR) to increase the frequency stability of the system, emphasizing as main challenges the placement, capacity, and operating strategy.

This analysis adopts FRR with a similar operation mode proposed in [3] and goes a step further by trying to analyze the impact it has on the distribution system. In contrast with [2], which tries to minimize voltage deviation, power losses, and line loading, the current work analyzes Nadir improvement. By reducing the Nadir, the under-frequency activations were also limited, and this increased the reliability. FFR is considered one of the most economical methods of limiting the Nadir during a disturbance because of its short support duration.

The contributions of this paper are:

- Insights on the interaction between Inertia, FCR, and Nadir
- Reliability analysis of distribution system in case of disturbance and the impact of FFR.

This paper is structured as follows: In section 2 a brief explanation of frequency sensitivity analysis and FFR control strategy is given. Section 3, examines how the customers of the distribution system are affected by frequency disturbance events and the impact of FFR on reliability improvement during these situations. All test-case simulations were performed on a real power system.

## 2 Frequency sensitivity

In the current section, a frequency analysis is established to emphasize the problems caused to the distribution system of a low-inertia power grid. The correlation of FCR and kinetic energy with Nadir during a disturbance was a significant part that must be considered. Hence, a detailed explanation of how each parameter of them affects the power system is analyzed. Then, a basic overview of FFR and a control strategy are given through a disturbance event example.

### 2.1 Correlation of FCR and Kinetic Energy with Nadir

Frequency Containment Reserve (FCR) is a reserve that attempts to keep the network's frequency within predetermined levels [4]. It usually has a response time of a few seconds to stabilize the frequency and is divided into $FCR_D$ and $FCR_N$, two separate reserves for distribution and normal operation accordingly. This reserve mainly affects Nadir and the post-fault frequency steady state. Meanwhile, inertia refers to the energy stored in large rotating generators and certain industrial motors [5,6]. This stored energy can be precious in situations of power imbalance because of its immediate response. This energy reserve mainly affects RoCoF and Nadir.

In Fig. 1, a detailed frequency analysis of an isolated power network at various values of FCR and inertia is shown. The primary issues highlighted by the correlation analysis between FCR and kinetic energy are:

1) The system becomes even more sensitive, and more and more frequently, under-frequency protections are activated: Traditional power grids fully operate with high inertia and FCR due to the non-inclusion of inverter-based resources (green area). In this area, most of the disturbances have a high Nadir value and, by extension, less or no activation of the under-frequency protections after a disturbance. Modern power systems have a significant generation percentage from RES. Therefore, FCR capacity and inertia decreased (yellow area), while at the same time, Nadir decreased.

2) Operators are forced to curtail RES penetration: In many cases, during peak RES power generation periods, the power grid may need to operate at its minimum requirements, and therefore Nadir decreases even more (red area). However, the red area is prohibited as it operates outside the grid code, leading operators to curtail RES generation to avoid this situation.

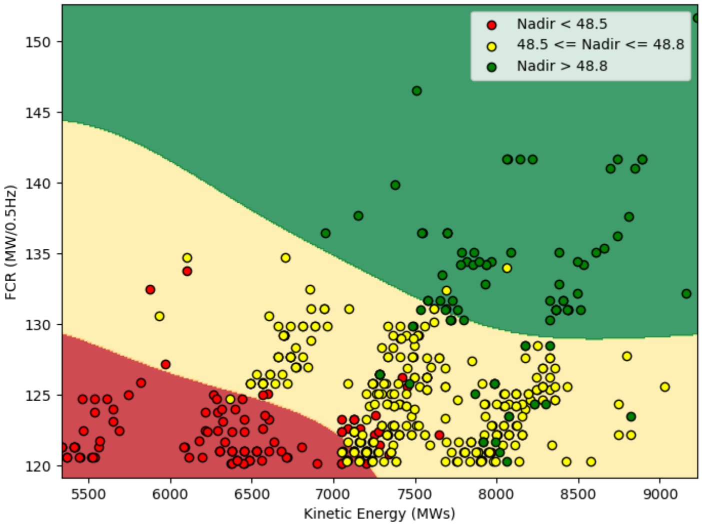

Figure 1: Disturbance scenarios

The above two problems directly affect the distribution network since both sudden under-frequency protection activation and RES production curtailments affect the distribution system customers. Hence, this situation has various socio-economic effects but also reduces the reliability of the system.

Instead of the FCR capacity and inertia, the FCR response time of the units is also an important parameter that affects Nadir. As we can observe in Fig. 1, there are scenarios with greater inertia and FCR where they present a lower Nadir than scenarios with lower inertia and FCR, and vice versa. This is a result of the response time of the units providing FCR.

## 2.2 FFR Implementation

The goal of FFR is to provide a quick reserve during disturbances by injecting power into the power grid to reduce Nadir [4,6]. FFR acts as a complement to $FCR_D$ and inertia but cannot replace them and thus does not alleviate the minimum needs for these reserves [4]. The FFR reacts in less than a second and has a support duration of around 30 seconds [6]. Figure. 2 presents the FFR controller that is used. When the frequency decreases beyond a limit, which is defined based on the specification limits of each operator, the controller immediately sends set points for maximum activation. After a brief period of time, the controller gradually decreases the set points in a linear manner so that the power system can adjust to the ESS disconnection.

To better understand how the use of FFR can help, we perform a detailed analysis of a test case to meet the system's requirements in Fig.3a, with the blue line, a low inertia situation is presented, while after a disturbance, Nadir falls below 49 Hz, leading to the first-stage UFLS. To overcome this unwanted event, operators can increase FCR (dashed red line) or increase inertia (green dashed line). Both solutions are not acceptable, as they have to curtail RES penetration. Instead of these solutions, using power injection from ESS (light green line) can achieve the desired results without curtailing RES generation. It is important to note that RoCoF and post-fault frequency steady state are not affected, and this confirms the non-replacement of minimum FCR and inertia requirements. In the Fig. 3b, the FFR operation is presented.

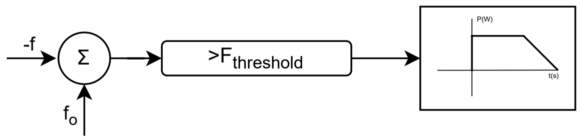

Figure 2: FFR controller

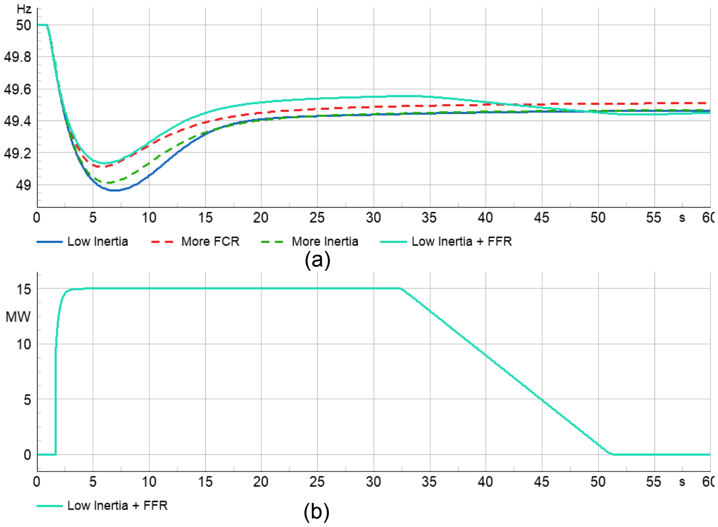

Figure 3: Frequency sensitivity analysis

# 3 Distribution System Reliability Analyzed

## 3.1 Test System

The frequency sensitivity analysis was established in a simplified Cyprus power system using PowerFactory DIgSILENT software and the Python programming language, the latter employed specifically to accelerate the process.

The diagram depicted in Fig. 4, illustrates the single-line representation of Cyprus's power system, which encompasses a total of 26 generators [7]. Additionally, the system incorporates wind farms, 14 stages of load and PV customers in the distribution system, and a BESS that is modeled to provide FFR. In addition, the UFLS scheme is implemented in the system, where, based on a frequency value, a priority order protection is activated to disconnect the corresponding segment of the distribution customer. At the same time as load shedding, the corresponding percentage of PV generation in the distribution network is also disconnected, this represents the twofold cost incurred when activating certain protective relays. In the single-line diagram with a black fill square, the switch breakers are represented.

The BESS model used in this study is a dynamic model (provided by DIgSILENT PowerFactory [8]), where the existing FCR controller is modified with a new FFR control model based on Fig. 2.

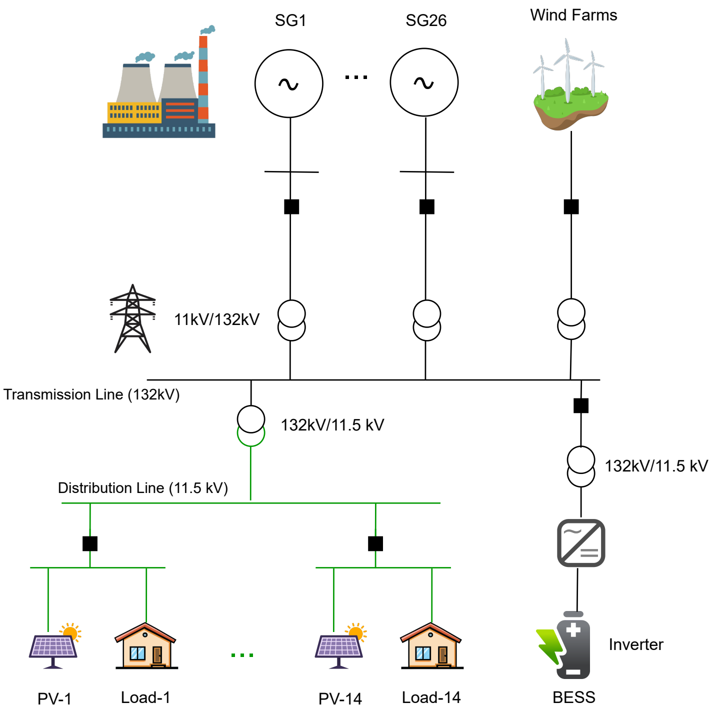

Figure 4: Test system single-line diagram

### 3.2 Parameters and Process

The parameters that are considered in the system are based on a real operation condition of the Cyprus power system with small modifications. To evaluate the impact of RES penetration on the distribution system reliability we have assumed several power dispatch scenarios to limit the randomness that a single test case gives. The above interpretation was also confirmed in section 2.1 since different power dispatch leads to a different Nadir value as discussed.

A flow chart of the whole simulation process is presented in Fig. 5. Firstly we considered 100 different scenarios with a constant load value of 700MW which is the average load of the Cyprus power system for each PV penetration, 0%, 10%, 20%, 30%, and 40%. In all 500 generated scenarios, we consider a constant disturbance event of 90MW. Power dispatch scenarios are not fully random generated but consider the minimum FCR and inertia requirements of the system to not violate the grid code in RoCoF and post-fault frequency steady state limits. Finally, all scenarios simulated for different FFR maximum power 0MW, 5MW, and 10MW. All the parameters that are used summarized in Table.1.

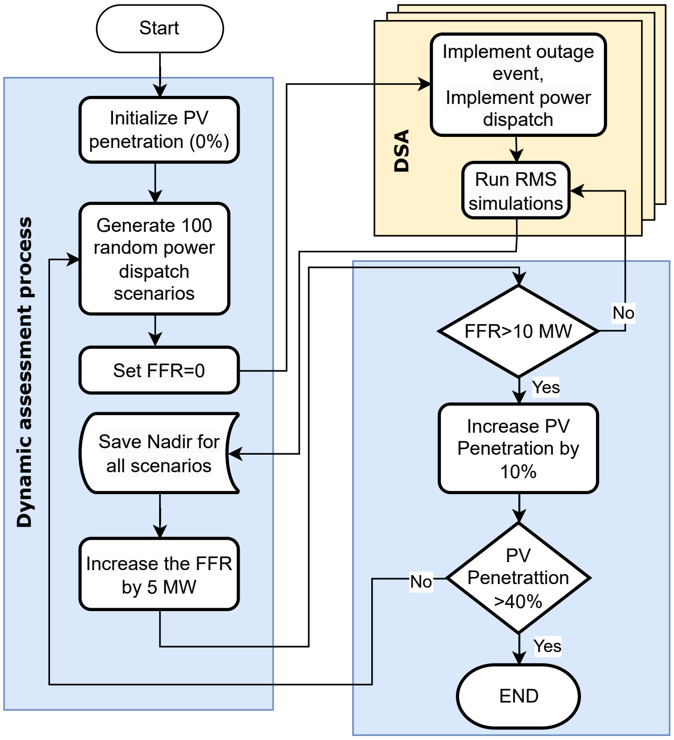

Figure 5: Simulation analysis process

Table 1: Simulation Parameters

| Parameters | Value |
|---|---|
| Load power | 700MW |
| Power disturbance event | 90MW |
| Minimum FCR at 0.5Hz | 83MW |
| Minimum post-fault kinetic energy | 2250MWs |
| Post-fault frequency steady state | 49.5 Hz |
| FFR maximum activation time | 0.8s |
| FFR support duration | 30s |
| $1st$ stage UFS | 49 Hz |
| $2nd$ stage UFS | 48.9 Hz |

### 3.3 Results

The results are presented in Table. 2, while a visualization in bar chart format is given in Fig. 6 and 7.

It is obvious that when FFR is not operating, the expected happens, as RES penetration increases load and PV shedding increases. At 40% RES generation, an average of 5% of total load and total PV and more specifically, 32.4 MW and 13.4 MW corresponding, are disconnected after a disturbance, which is a significant shedding. In the same test case scenarios, when 10 MW FFR operates in the system, the disconnections are reduced at a rate of around 1% of the total PV and load, which is a better performance of the distribution system than the 20% of RES without FFR. Generally, based on the results, it's clear that we can increase 20% of PV penetration and have better results when 10 MW FFR is used instead of keeping the system with 20% less PV. Moreover, the results show that, as the FFR power increased, the Nadir also increased, and less shedding occurred in the system. This phenomenon increased the distribution system's reliability. However, the FFR power requirements to meet certain reliability levels are not within the scope of the current analysis.

In the same way, results confirm that instead of increasing FCR and inertia by curtailing PV generation, it is better to utilize FFR, which reduces under-frequency protection activated and mitigates the PV curtailments at high production periods.

Finally, the question often arises: Is it possible to further increase RES power generation? The answer lies in the possibility of reducing conventional units even more, thus increasing RES until meeting the minimum requirements of RoCoF and post-fault frequency state. However, it's crucial to ensure that the corresponding FFR needs are met to fulfill Nadir requirements simultaneously.

Table 2: Summarize Simulation Results

| **PV Penetration** | **FFR (MW)** | $Load_{\textbf{shedding}}$ **(MW)** | $PV_{\textbf{curtail}}$ **(MW)** |
|---|---|---|---|
| 0% | 0 | 1.1 | 0 |
| | 5 | 0.5 | 0 |
| | 10 | 0.3 | 0 |
| 10% | 0 | 6.8 | 0.7 |
| | 5 | 3.6 | 0.4 |
| | 10 | 0.5 | 0.1 |
| 20% | 0 | 17.2 | 3.5 |
| | 5 | 8.6 | 1.7 |
| | 10 | 1.9 | 0.4 |
| 30% | 0 | 26.2 | 7.9 |
| | 5 | 12.5 | 3.8 |
| | 10 | 5.9 | 1.8 |
| 40% | 0 | 32.4 | 13.4 |
| | 5 | 20.9 | 8.4 |
| | 10 | 9.5 | 3.8 |

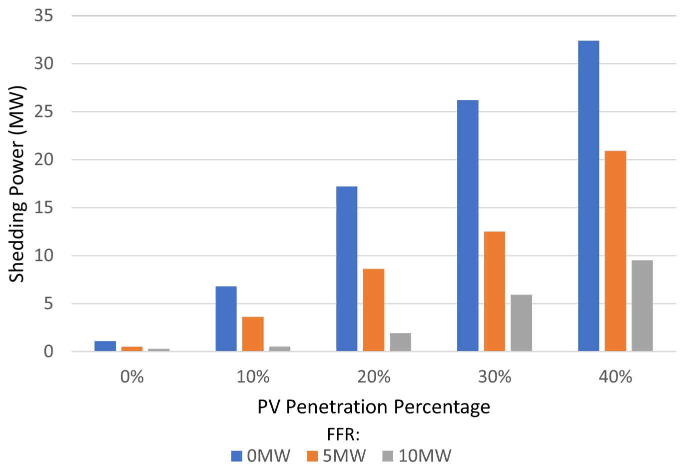

Figure 6: Load Shedding Results

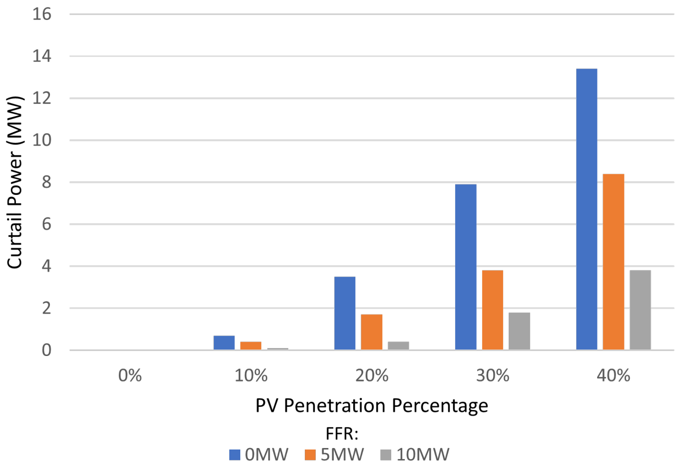

Figure 7: PV Curtail Results

## 4 Conclusion

This paper summarizes the correlation of the problem that the frequency disturbance causes in the distribution network. Using a real power system, the simulations show the magnitude of the problem. By utilizing FFR, RES penetration can be increased and at the same time, reliability level can be improved.

## 5 Acknowledgments

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