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# Frequency Control in Isolated/Islanded Microgrid through Voltage Regulation

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## ABSTRACT:

Remote communities can obtain electricity from isolated microgrids, which have shown to be a dependable and effective alternative. Even with adequate frequency control reserves, isolated microgrids' frequency can experience significant excursions and easily deviate from nominal operating conditions due to the low system inertia and quick changes in the output power of wind and solar power sources. As a result, it is difficult to keep frequency close to its nominal value. Given the high variability of renewable generation output power, committed units participating in frequency regulation would not remain fixed between two time intervals. From the secondary control perspective, the generation scheduling of dispatchable units obtained from a conventional Unit Commitment (UC) is considered fixed between two dispatch time intervals, yielding a staircase generation profile over the UC time horizon. In isolated microgrids with significant penetration of renewable power, the current work presents strategies to overcome these challenges in main and secondary frequency regulation.

A frequency control technique is developed that can be easily adapted to a variety of isolated microgrid types while employing the system's sensitivity to operating voltage. The proposed controller has a number of benefits, including the ability to integrate a substantial amount of irregular renewable energy sources in isolated or island microgrids without the need for large storage facilities for energy and the ability to provide quick and error-free frequency regulation regardless of the generator control mechanism. Only local voltage and frequency are used as feedback by the controller, and no additional communication infrastructure is needed. A modified version of the CIGRE benchmark is used to assess and validate the controller's performance. Additionally, a small-perturbation stability study is done to show how the proposed control

## I. INTRODUCTION

A microgrid is typically described as a collection of DG units and loads, such as solar panels, wind turbines, diesel generators, etc., that are coupled to the primary grid at the Point of Common Coupling (PCC) [1,3]. Microgrids can range from being as small and straightforward as a single customer microgrid to being as big and complicated as a whole substation.

Microgrids can run in both grid-connected and islanded modes, and they can switch back and forth between them [8, 9]. Some microgrids, such as those designed for distant communities [5] or industrial sites may not have access to the main grid; these microgrids always function in islanded mode and are known as isolated microgrids1. The voltage and power consumption in the grid-connected mode of the main grid sets the frequency, and the microgrid merely provides pre-specified auxiliary services. On the other hand, different

DERs are in charge of managing the voltage and frequency during islanded operation.

Due to the crucial demand-supply balance that must be met locally, controlling microgrids in islanded mode of operation is difficult. Furthermore, the system's inertia is lower than it is for conventional power systems, particularly when intermittent RES penetration is high and the majority of DERs are electronically interfaced with the system. In these circumstances, the generation uncertainty is substantial, necessitating precise and quick control mechanisms to ensure stable and dependable operation.

The officially recognised definition of power system stability, which is "the ability of an electric power system, at a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact" [11], is what is meant by stable operation in microgrids. In isolated microgrids, disturbances take on a variety of shapes and are often divided into major and small disturbances. Continuously fluctuating loads, for instance, are an example of a little disturbance, whereas the loss of generators, loads, or feeder short circuits can be considered a big disturbance. The isolated microgrid should be able to maintain stability in both Outlines, which entails being able to dampen changes in the system operating state and return to a new, satisfactory equilibrium point.

Different states of the system may be impacted by instability, as well as different manifestations of it. When one speaks of the "states of the system," they are specifically referring to the voltages and system frequencies that determine the operating point of the system. As a result, it's important to recognise the many kinds of instability that could develop in a remote microgrid. However, since this work is still in progress and is being overseen by an IEEE Power & Energy Society (PES) Task Force, there isn't any pertinent literature on the subject just yet. As a result, the definitions and ideas presented in [11] are the foundation of this thesis. The following criteria are used in this paper to categorise power system instability:

- The physical origin of the instability
- The relative size of the disturbance
- The components that are involved in the process, and the time span that determines the instability
- The numerical methodology to calculate or predict the instability

As a result, instabilities fall into a variety of categories, as seen in Figure 1.2. More than one sort of instability may be triggered in a situation of instability. In fact, one type of instability can frequently give rise to another type. Therefore, in order to provide effective controls, careful studies should be conducted to understand all types of instabilities in isolated microgrids.

## II. LITERATURE REVIEW

Recently, the IEEE 1547 Standard [6] has defined a microgrid as an electric power system that has distributed resources and loads, has the ability to work in connected and isolated modes, and is intentionally planned to serve nearby loads. From the grid point of view, four modes of operation are defined for microgrids [3]: grid connected, transition-to-islanding, isolated, and reconnection mode. Each mode of operation has its own rules and challenges.

Isolated microgrids may have a high penetration of RES and have lower system inertia than large, linked power networks. As a result, they are less able to handle system disturbances, with frequency instability being a major worry in isolated microgrids. Primary frequency regulation, or adjusting the mechanical input power of conventional generators using their governors, is the process used in traditional power systems to correct for power imbalances between generation and load. A large variety of strategies have been proposed and put into practise for traditional primary frequency control, as discussed in [25].

In the context of microgrids, a failure in the high voltage cables connecting the system to the main transmission grid on December 22, 2005 highlighted the lack of traditional control functions in the system on the Danish Bornholm Island [26]. As a result, the island distribution system was cut off from the rest of the world. The whole distribution system was forced to shut down because local regulators were unable to cope with the rapid variations in output power of the wind generators during that time. To address some of aforementioned issues, numerous control approaches have been put forth for microgrid operation [27–29]. These can be categorized in two groups, namely, decentralized and centralized controls [23]. For each category, many different control strategies have been proposed [30]. The focus of this section is on decentralized control techniques, with centralized controls briefly discussed.

## III. OBJECTIVES

The examination of recent technical literature demonstrates the necessity to advance isolated microgrids' primary and secondary frequency control methods. The key goals and contributions of this thesis in this context are as follows:

1. Create a cutting-edge VFC for units using inverters or diesel engines in remote micorgirds. The controller adjusts the system demand and, as a result, balances the power imbalance using a load voltage regulation method. With the help of DER inverters and diesel generator exciter systems, the load voltage regulation will be carried out without the need for system-wide communication.

2. Utilising the created UC model, look at how different frequency control techniques, such as single unit control, droop control, or isochronous load sharing (ILS) control mode, affect the best possible dispatch solution.

3. Create a hybrid droop-based frequency controller for isolated microgrids powered by inverters and research the effects of different droop-based frequency control techniques on the stability and transient response of such systems.

4. Create a novel mathematical formulation of the frequency control mechanism that is integrated into a UC framework for isolated microgrids, resulting in a more affordable dispatch solution, and add a new reserve power constraint to the UC model to represent the corresponding frequency control mechanism, resulting in a more accurate dispatch solution.

5. For medium voltage distribution networks, create a thorough dynamic and static simulation model of the CIGRE benchmark system [22] so that timedomain and steady-state simulations can be used to analyse and illustrate the suggested frequency control paradigms. For both synchronous machines and inverters, precise models of the voltage and frequency control systems will be created.

## IV. METHODOLOGY

### A.Voltage-based Frequency Controller

This chapter explains how voltage regulation can be used to control the frequency of an isolated or islanded microgrid. The voltage sensitivity of loads in isolated microgrids is utilised in the suggested plan. Through a variety of simulation studies in the PSCAD/EMTDC software environment based on a realistic microgrid test system, the performance of the proposed controller is assessed and validated. Small-perturbation stability analysis is used to show the proposed controller's beneficial effects on system damping.

### B. Load Voltage Dependency

The following equation [57] can generally be used to model loads in power systems, especially microgrids:

$$P_L = P_{L0}\left(\frac{V_L}{V_{L0}}\right)^{np}$$

### C.Voltage-Based Frequency Controller

The suggested VFC for an isolated microgrid is depicted in Figure 1. The system frequency deviation from the nominal set-point f serves as the input signal to the controller. The gain KVFC controls the damping factor offered by the VFC, and the frequency error is sent through a proportional-integral (PI) controller to ensure that the steady state error is zero. To account for the phase difference between the voltage regulator input and output, the signal is sent through a lead-lag block; in practise, many lead-lag blocks may be utilised to provide the optimal response. The output signal is constrained by the limits VFCmax and VFCmin to keep the voltage within a desirable range. The voltage regulator Vref's reference set-point signal and the VFC's output signal are then combined. In an inverter-based system, the voltage regulator would be the voltage control block, therefore the VFC would be incorporated in the inverter control system as shown in Figure 3. In a diesel-based system, the voltage regulator is the synchronous machine excitation system, as shown in Figure 2.

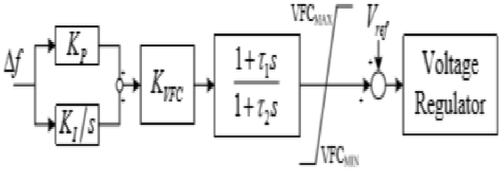

Figure 1: The proposed VFC for a system voltage regulator, such as the one for a synchronous machine.

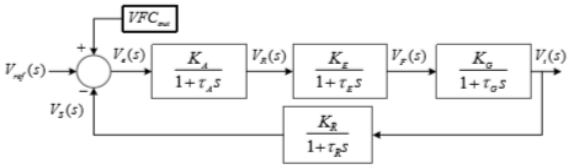

Figure 2: Block diagram of the proposed VFC and its integration with a synchronous machine

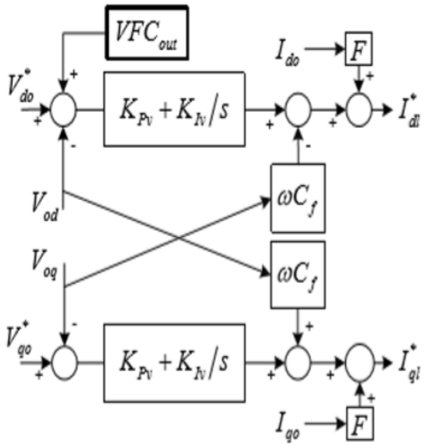

Figure 3: Block diagram of the proposed VFC and its integration with a VSC.

### D.Effect of VFC on Stability Under Small Perturbations

Eigenvalue studies are used to do small-perturbation analysis when the system is linearized around a nominal operating point [57]. Due to the complexity of the system model, this approach is only helpful for systems that are in balanced conditions, which is generally not the case for microgrids [59]. In order to estimate the system eigenvalues, a modal estimation strategy is used in this thesis, namely the Prony technique [60]. As a result, the generator speed signal is sampled in discrete form (k), extracted in continuous form (t), and represented as the sum of n damped complex sinusoids as follows:

$$\omega(t) = \sum_{i=1}^{n} \bar{R}_i e^{\lambda_i t} = \sum_{i=1}^{n/2} A_i e^{\alpha_i t} \cos(\beta_i t + \Phi_i)$$

**E.Results Diesel-based Test System**

A test system based on the CIGRE benchmark for medium voltage distribution network [13] is implemented in PSCAD/EMTDC [62] with two diesel-based synchronous machines and three DERs to show the efficacy of the proposed VFC. Figure 4 depicts the test system's overall architecture, and the Appendix contains the pertinent data. The system's overall load, which is divided among the buses in an uneven fashion, is around 7 MVA. The model for feeders is connected sections. Be aware that the loop configuration in the CIGRE benchmark test system used in this thesis increases the complexity of controls. Since the performance of the VFC mostly depends on the load voltage sensitivity and voltage regulators' time constant, the findings from the test Outlines provided in this chapter are anticipated to be equivalent for a radial configuration of the CIGRE benchmark test system.

The bi-directional VSCs, which include PWM, $abd \leftrightarrow dq$ transformations, PLLs, and control blocks, are used to connect the DERs. These are simulated as perfect DC sources, and Figure 4.5 illustrates how the active power output of a real, lowvoltage 300 kW wind turbine was measured over 185s with a resolution of 0.1s. For the purposes of this study, the nominal ratings of the DERs are 1.5 MW, 600 kW, and 1.2 MW, respectively. DER#1 has five sub-units, DER#2 has two, and DER#3 has four. Each sub-unit's output is the same as the power.

The combined nominal rating of the synchronous machines is 5.4 MVA. The two synchronous machines are typically in charge of controlling the voltage in the instances covered here, while the DERs operate according to the CCM paradigm with unity power factor and no involvement in voltage regulation. Since the synchronous machine voltage regulation systems dominantly govern the voltage in isolated microgrids, the VFC is implanted on the exciters of these machines. The conventional IEEE AC1A excitation systems are utilised in this work [63]. As a result, the DERs are the slave controls delivering active power to the system, while the synchronous machines are the master controls controlling the voltage and frequency. The Ziegler-Nichols Tuning approach was used to acquire the parameters of the VFC, [64]. It should be noted that two lead-lag filters were utilised to get the highest controller performance; as a result, in Table 4.1, and represent the first filter's parameters, ⍰1and ⍰2 ⍰´1 and⍰´2 represent the second filter's values.

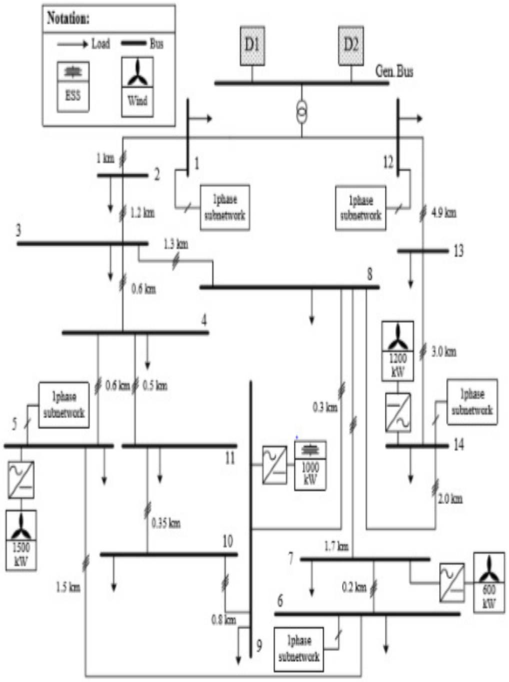

Figure 4: Test microgrid based on a medium voltage distribution network benchmark.

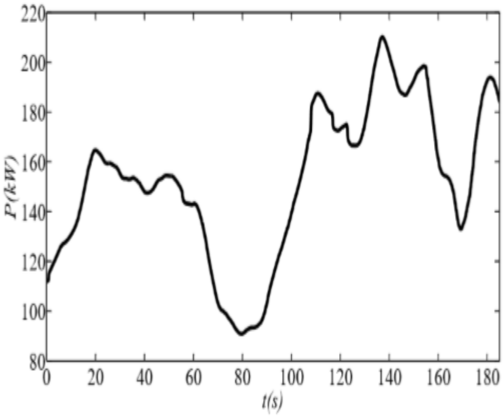

Figure 5: Low-voltage 300 kW wind turbine measured output power.

## V.RESULTS AND SIMULATION

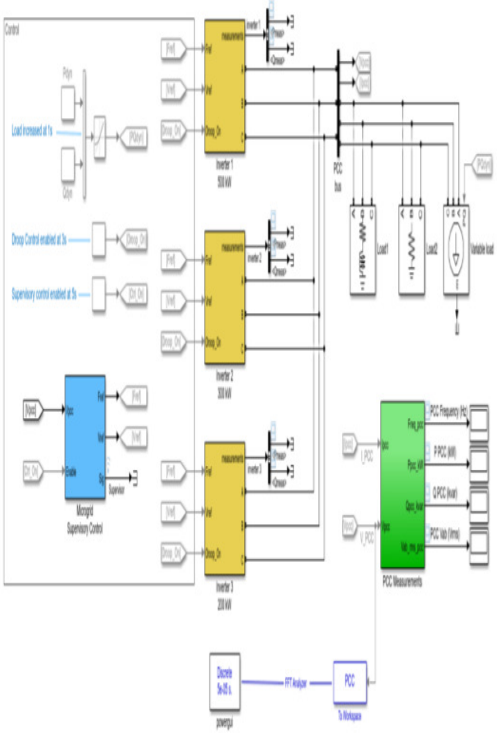

Figure 6: Matlab Simulation

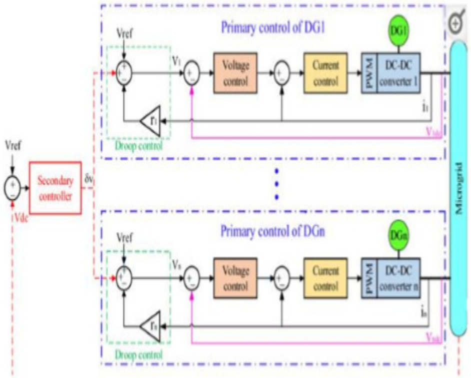

Figure 7: Primaryand Secindery Control Techniques

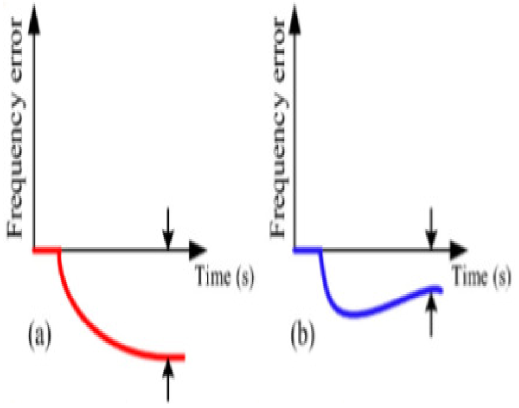

Figure 8: System Frequency (a)without primary control (b)with primary control

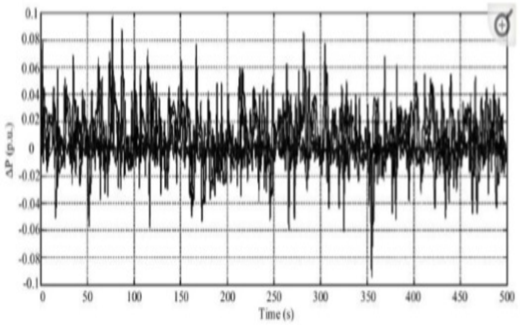

Figure 9: White noise

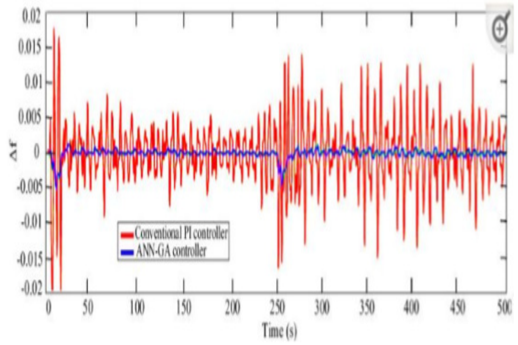

Figure 10: Microgrid frequency response to White noise

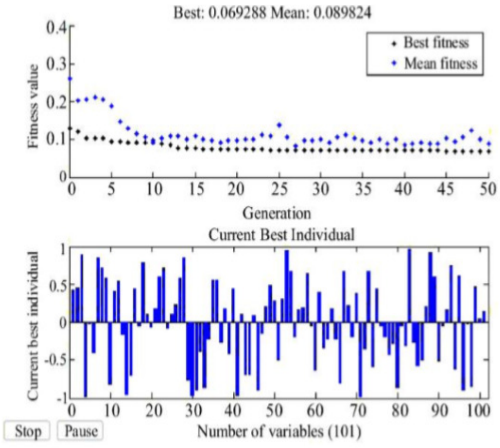

Figure 11: ANN training process by GA algorithm.

## VII. CONCLUSION

A fast voltage-based frequency controller has been proposed in this paper for isolated/islanded microgrids, acting as an additional control to conventional frequency controllers to improve frequency response of the system. Based on realistic analysis and results presented in this paper, the proposed controller is simple, has a straightforward implementation, and is easily applicable to a variety of different systems and voltage regulation devices (e.g. synchronous machines, DERs with voltage regulation capacity). The proposed controller offers several advantages, reducing the dependency of a microgrid with high renewable energy sources penetration on ESS, which makes these types of microgrids more viable. Hence, the VFC can play the role of a virtual storage, with capacity depending on the operating voltage levels and type of loads. In addition, the controller can be very effective in minimizing the impact of large disturbances on the system such as loss of a generation, enhancing small-perturbation stability by providing more damping for the system. The controller also provides zero steady-state error with respect to existing frequency control techniques, and requiresnoadditionalinvestmentorcommunicationinfrastructure. Finally, its response is almost instantaneous, and since the voltage can be kept within acceptable limits, it has no significant impact on customer quality of service. However, its performance is dependent on the load mix and overall voltage ranges.

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