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SCA Optimised 2-DOF-FOPID Controller for Coordinated Control in a Hybrid AC/DC Microgrid

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Abstract

Frequency regulation has gotten more difficult as the use of renewable energy sources (RES) has grown. The load frequency control (LFC) mechanism is a critical function in an electrical power network for maintaining a balance between power generation and load in order to avoid frequency deviation (FD). The goal of this work is to develop a practical LFC scheme for a hybrid AC/DC microgrid (MG) system that includes a wind turbine generator (WTG) and a battery energy storage system (BESS). The LFC system is implemented using two degree of freedom fractional order proportional integral derivative controllers (2-DOF-FOPID). A sine cosine algorithm (SCA) approach is used to calculate the controller parameters. The results of 2-DOF-FOPID controllers are compared to those of proportional integral double derivative (PIDD) and proportional integral derivative (PID) controllers. When compared to the PIDD and PID controllers, the 2-DOF-FOPID controller exhibits better dynamic responses in terms of settling time and magnitude of oscillations. Furthermore, the suggested 2-DOF-FOPID -based LFC scheme's robustness is tested under various system loading conditions.

Keywords: *LFC, MG system, SCA, 2-DOF-FOPID controller, hybrid AC/DC MG.*

I. Introduction

Microgrid (MG) integration with traditional power systems aims to address economic and environmental concerns while also increasing the reliability of traditional power systems. MG is a hybrid power or storage system that combines a number of distributed generating units (DGUs) such as wind, solar PV, and other RES. RES are increasing popularity in light of the present fossil fuel crisis and environmental concerns. Traditional fossil-fuel-based generating, on the other hand, remains a viable option due to its high reliability. Combining renewable and conventional energy sources is a notion that strikes a compromise between generation reliability, cost, and environmental considerations. However, there are numerous obstacles associated with RES based distributed generation (DGs), such as controllability, islanding operation, system stability, and so on [1]. The grid controls the voltage and frequency at the DG interconnection points in the grid-connected mode. Nonetheless, the fundamental problem in operating a renewable energy-based DG in islanded mode is its stability. In non-islanded mode, the power storage system in an MG can support the power balancing [2], however, a competent LFC scheme is required to maintain the system frequency.

The purpose of LFC is to reduce the frequency excursions in the system by minimizing the area control error (ACE) which is due to variations in load and intermittent output of distributed energy resources (DER) units. The LFC system monitors system frequency and tie-line power flows, adjusting generation within the region to keep the temporal average of the ACE constant. In LFC, ACE is commonly used as a metric of regulation. To lower the ACE, both frequency and tie-line power errors should be near zero. Fluctuations in power generation, as a result of the high penetration of unpredictable RESs, produce frequent mismatches in demand and supply, resulting in frequency variation in the microgrid. For AC systems, frequency stability is crucial. Earlier, the study focus was mostly on AC microgrids [3], in line with traditional AC consumption.

The growing availability of DC power sources such as fuel cells, PV, and BESS, as well as a growing choice of power electronics and DC loads, has generated interest in hybrid AC/DC MGs. Instead of purely DC or AC MGs, hybrid DC/AC MGs provide additional benefits such as improved power quality, localized energy supply, fewer conversion steps, and cheaper power processing costs. Bidirectional power converters (BPCs) link with hybrid AC/DC MGs to connect the AC and DC sectors [4]. Despite the fact that various LFC solutions for AC and DC MGs have been published, these techniques are not immediately applicable to hybrid AC/DC MGs systems due to the coexistence of AC and DC sections, which needs complex control and optimization methodologies.

Many researchers are now concentrating on power management for AC/DC hybrid MGs. A state-dynamic feedback linearization theory-based nonlinear control approach for parallel BPC in grid linked mode was proposed in ref. [5]. In reference [6], an effective hybrid MG control solution for sharing the power and voltage support from DC for BPCs was given, which may reduce the circulating current in parallel BPC working technique. Ge et al. [7] proposed a hybrid AC/DC MG control system that takes into account decentralized load management and distributed control mechanisms for local distributed generation units. Due to the variability in both DC and AC inputs and demands, hybrid MGs have more energy management issues than AC or DC MGs. Long-term power support is often provided via an MG's battery storage system. No previous research has considered the types of load and capacities of both AC and DC subgrids (SGs), which could result in power imbalance. Controlling power in a hybrid AC/DC MG is particularly difficult because to the aforementioned limits. An effective control technique is necessary to set the balance of power-load in both SGs, as well as to maintain the bus voltage in the DC SGs and the operational frequency in the AC SGs in a consistent manner.

According to the literature [8], most classical controllers have been widely used in automated generation and control (AGC) of multi-area power systems due to their ease of construction and execution. The dynamic features of these traditional controllers, on the other hand, exhibit much longer settling times and amplitude oscillations. The integral-double-derivative (IDD)[9] controller and the PIDD controller [10] are two new classical controllers that have recently been presented in AGC. The double derivative function facilitates faster dynamic responses, resulting in a shorter settling period and increased system stability. But traditional integral order (IO) controllers are insufficient for power system set point tracking and disturbance removal. The advent of fractional order (FO) calculus has resulted in a significant improvement in the domain of control system design. Computational processes are required for tuning the controller settings in AGC [11]. Furthermore, the majority of recent research depends on evolutionary approaches due to the nonlinear nature of constraints optimization difficulties and the difficulty of identifying the best solution. [12].

In recent decades, researchers have employed a number of optimization algorithms to deal with the computing of control parameters. In an LFC, designing controllers with optimal parameters is a difficult task. The firefly algorithm (FA), bacterial foraging (BFO) optimization, fruit fly algorithm (FFA), cuckoo search algorithm (CSA), and artificial bees' colony (ABC) algorithm are only a few of the optimization methods that have been suggested [13].

This work employs a distributed synchronized power control technique for a hybrid AC/DC MG, in which the two SGs are coupled via a BPC for power interaction. The suggested control method provides for a power interaction between the two SGs in the opposite direction, allowing them to coordinate their support. The primary contributions of this study are as follows: (a) While implementing a CFVC droop control system, the load sizes in both AC and DC SGs are taken into account, allowing for power exchange between them. (2) As controllers, 2-DOF-FOPID controllers are used, and the system's response is compared to that of traditional PIDD and PID controllers. To estimate controller design parameters, an integral-of-time-multiplied-absolute-error (ITAE) minimized SCA is used. The suggested implementation's robustness is demonstrated in both DC and AC SGs utilizing a load variation of 20%.

System description

This study describes a hybrid MG system which combines wind turbines and battery technologies. The MG features two types of SGs: AC and DC. For power service reliability interaction, the BPC connects the two SGs. The system under consideration is depicted in Figure 1. Wind turbines and batteries constitute the DC SG, whereas exclusively wind-based systems make up the AC SG. The energy storage element is only accessible in the DC SG and is used to provide cost-effective power support for the SG. A hybrid AC/DC MG is modelled and simulated to test the performance of the proposed CFVC method.

Wind Turbine System:

WTG's power output is determined by wind speed (V_w), pitch angle (β), blade radius (R), air density (ρ), and power co-efficient (C_P). The power generated by a wind turbine is calculated as follows [12]:

$$P_m = \frac{1}{2}\pi\rho C_p(\lambda,\beta)R^2V_w^3$$

(1)

The coefficient of power wind turbine unit is represented in [13]. The first order mathematical model of a WTG (G_p) can be expressed as [14]

$$G_p(s) = \frac{\Delta F_w}{\Delta P_{WP}} = \frac{K_{Ww}}{1+sT_w}$$

(2)

Where, ΔF_w is the change in speed of WTG and ΔP_{WG} is the variation in output power from the WTG Furthermore, the speed change of a WTG can be expressed in terms of power control. [15]

The hydraulic pitch actuator's TFs and data fit pitch response can be represented as [13]

$$G_{hpa}(s) = \frac{K_{w1}K_{w2}(1+sT_{w1})}{(1+s)(1+sT_{w2})} \tag{3}$$

$$G_{dfr}(s) = \frac{K_{w3}}{sT_{w3}+1}$$

(4)

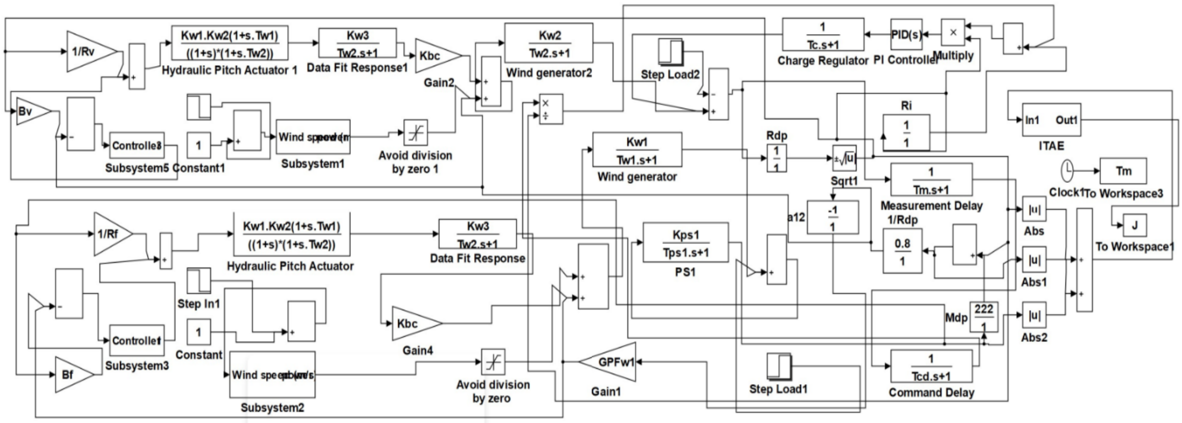


Fig. 1. Transfer Function model of the System [13]

BESS :

In MGs, BESS is frequently used to stabilize power supply in the face of intermittent renewable energy. A BESS system can be thought of as a black box with an output that can be determined analytically based on inputs and set points. Although the output voltage remains constant, the current varies depending on the load. A comprehensive charge control strategy (CRS) is required to provide steady operation and protect the system from harmful scenarios such as overcharging, deep-discharging, and so on. The command delay, measurement delay, and charge management factors are all taken into consideration in the system model, as illustrated in Fig. 1. A typical PID controller (K_p = 0.222, K_i = 0.513, K_d = 0.513) is also used to manage the BESS model under uncertain conditions in this study.

The TFs of different components are denoted by G_{md}, G_{cd}, and G_{cc} as [9]:

$$G_{md}(s) = \frac{1}{1+sT_m} \tag{5}$$

$$G_{cd}(s) = \frac{1}{1+sT_{cd}} \tag{6}$$

$$G_{cc}(s) = \frac{1}{1+sT_c}$$

(7)

Control model and strategy:

The CFVC system achieves power balance in each of the SGs by controlling RES generation and regulating power exchange via BPC. A power imbalance in the relevant area is shown by the FD in AC SGs and the change in voltage in DC SGs. [14]. When the AC SG's power is too much (or too little), *f* tends to be higher (or lower). Because the DC droop technique manages energy storage, the DC bus voltage (V_{dc}) tends to be higher when the DC SG's power is in excess (or deficit) (or lower). As a result, we analyse power in DC SG $P_{dc} - V_{dc}^2$ droop in DC SG power regulation. The relationship between voltage and power is defined as

$$\Delta V_{dc}^2 = R_{dp}\Delta P_{dc} \tag{8}$$

R_{dp} is the droop coefficient, and VDC and P_{dc} are the voltage and power variations in the DC SGs, respectively. The DC SG supports frequency in the AC SG, while the AC SG supports voltage in the DC SG. As a result, changes in DC voltage or AC frequency occur even if the power in any of the SGs varies. In this situation, the power interaction is assumed to be related to a droop control method.

$$\Delta V_{dc} = M_{dp}\,(f^{*} - f) \tag{9}$$

where f^{*} and f are the rated and normal frequencies of the system, respectively. According to Eqn. (9) the DC voltage and AC frequency rise or fall at the same time to evenly distribute the power fluctuation. The droop coefficient M_{dp} has a substantial impact on the power interaction since power must be altered in both SGs during synchronisation. As a result, the types of load and capabilities of the two SGs must be considered while choosing M_{dp} value. M_{dp}'s equations are represented in [16].

The ITAE is used to create the objective function of a heuristic optimization method. [9] is the derivation of the objective function.

$$J = ITAE = \int_0^{t_{sim}} (|\Delta F_{AC}| + |\Delta V_{DC}| + |\Delta P_{ic}|)\,.\,t\,.\,dt \tag{10}$$

Proposed algorithm

For optimising 2-DOF-FOPID controller parameters, a novel population-based optimization approach called SCA was utilised in this research. After SCA generates numerous initial candidate solutions at random, the algorithm demands them to fluctuate outwards or towards the optimal answer using a mathematical model based on sine and cosine functions [17].

As an optimization process for the algorithm, the following steps can be used:

Step 1: Create a collection of search agents

Step 2: Apply the objective function to each of the search agents.

Step 3: Revise the best solution found.

Step 4: Update the values

Step 5: Update the search agents' positions.

Step 6: return to step 2 if the termination criteria are not met, else return the best solution found so far as the global optimum.

2-DOF-FOPID Controller

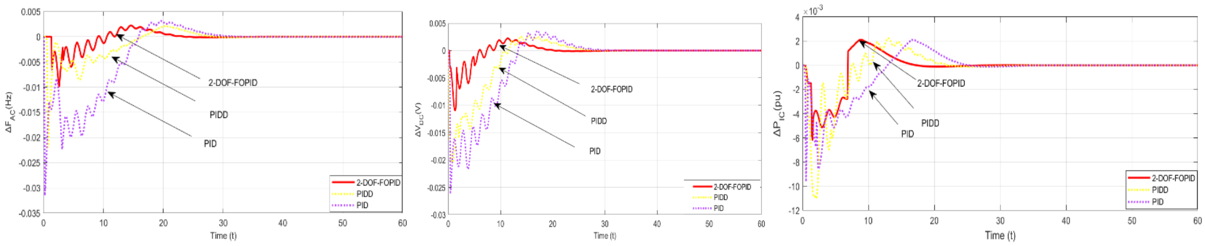
The degree of freedom controls the command input response and the independent disturbance rejection features of a closed-loop control system. A closed-loop control system's DOF is governed by the transfer functions that can be tuned independently. Control engineers must consider smooth set-point variable tracking and disturbance suppression when selecting a 2-DOF-FOPID controller. Control engineers must consider smooth set-point variable tracking and disturbance suppression when selecting a 2-DOF-FOPID controller. The 2-DOF-FOPID controller differs from the single DOF FOPID controller in that it produces an output signal after comparing the measured signal to the reference signal [18]. The total of proportional, derivative, and integral actions of the respective difference signals is the controller's output, and the actions are determined by the weight of the gain parameters. In comparison to traditional PIDD and PID controllers, the utilised controller enhances stability and provides quick response. For PID, the derivative operator dramatically increases turbulence, causing the system to become unstable.

II. Results and Analysis:

As shown in Fig. 1, the tested MG model is simulated in Matlab/SIMULINK with step load perturbations (SLPs) in all generating units. The responses of different controllers, such as PI, PID, and PIDD, are examined separately, while frequency bias (B_i) is kept constant at area frequency response attributes. The SCA method is used to determine the best values for the controllers' settings. According to Eq.(1), the optimization procedure is carried out by minimising the performance index. The optimum values of numerous controllers are shown in Table 1 under nominal loading conditions. The dynamic responses of the system are explored using the best controller parameter settings. The time responses of ΔF_{AC}, ΔV_{DC}, and ΔP_{IC} in both DC and AC SGs owing to SLP of 0.1 p.u and wind power change are shown in Fig. 3. Figure 4 shows the time responses of ΔF_{AC}, ΔV_{DC}, and ΔP_{IC} in both DC and AC SGs with a 0.1 p.u load disturbance. According to the results, 2-DOF-FOPID controllers provide fewer changes in area frequencies and tie-line powers. The SCA technique used can achieve optimal results with fewer iterations. The DC and AC SG loading is adjusted from nominal to 20% to verify the resilience of the implemented controller. As demonstrated in Fig. 6 (A), (B) the dynamic responses obtained with the loading fluctuations are almost equivalent to the results obtained with the nominal loading.

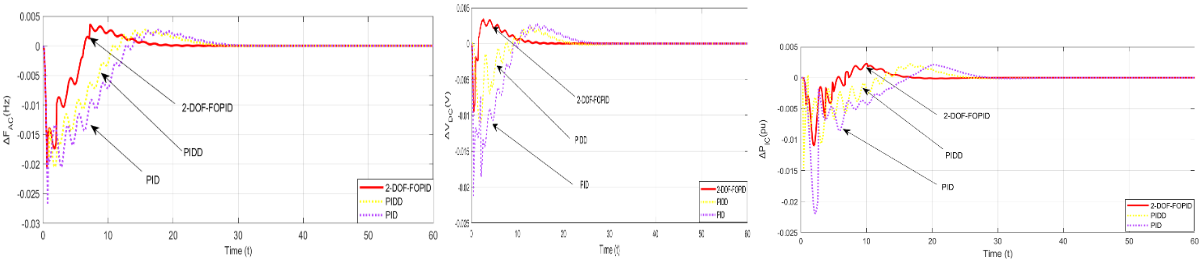
Area	**Generating source**	**PIDD**			**PID**			**2-DOF-FOPID**				
		ITAE=1140			**ITAE=892**			**ITAE=525**				
		K_p	K_i	K_{dd}	K_p	K_i	K_d	K_p	K_i	K_{dd}	λ_i	μ_i
AC SG	Wind	2.30	0.35	0.13	3.61	0.42	0.13	1.62	0.33	0.12	0.90	0.94
	Battery	2.12	0.01	0.35	1.12	0.03	0.44	1.11	0.002	0.43	0.93	0.76
DC SG	Wind	4.36	2.34	0.45	5.34	2.14	0.031	1.34	0.35	0.02	0.92	0.14

Table1: optimal data obtained with the ITAE optimized SCA technique



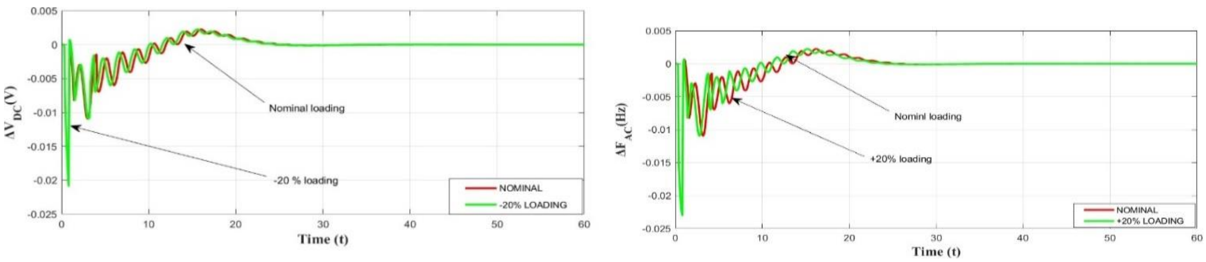
(A) (B) (C)

Fig. 3. Time responses of (A) ΔF_{AC}, (B) $\Delta V_{DC,}$ and (C) ΔP_{IC} with SLP of 0.1 p.u, and output power fluctuations of wind turbine concurrently in both DC and SC subgrids.



(A) (B) (C)

Fig. 4. Time responses of (A) ΔF_{AC}, (B) $\Delta V_{DC,}$ and (C) ΔP_{IC} with 0.1 pu load power perturbation simultaneously in both AC and DC SGs.



(B) (C)

Fig. 5. Sensitivity analysis with ±20% nominal loading in both AC and DC SGs.

III. Conclusion

In this study, a 2-DOF-FOPID controller is used to regulate the frequency of a hybrid AC/DC MG system. The SCA approach is used to tune the parameters of all the controllers, including PIDD, PID, and the associated dynamic responses are compared. Furthermore, the 2-DOF-FOPID controller's performance is evaluated under a variety of load circumstances to ensure its reliability. The results show that in renewable energy-based MG systems, the suggested SCA tuned 2-DOF-FOPID controller is exceptionally dependable and has a faster dynamic response.

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