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Model Predictive Approach to Improve Stability of Resistive Droop Control in Isolated AC Microgrids

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***Abstract*—** This study explores the application of Finite Control Set Model Predictive Control (FCS-MPC) in the primary control layer of a microgrid utilizing the resistive droop control technique. Given its compatibility with microgrid line impedances, predictive control effectively replaces the voltage and current loops found in conventional linear controllers. This approach enhances system responsiveness, stabilizes voltage and frequency, and ensures efficient power distribution among parallel inverters. Simulation results highlight the proposed control method's strong ability to maintain voltage and frequency deviations within acceptable limits while achieving precise power sharing and high voltage quality.

***Keywords*:** Isolated Microgrid, Resistive Droop Control, Finite Control Set Model Predictive , Power Sharing.

1. Introduction

The microgrid system serves as a link connecting various forms of distributed energy resources (DERs), including but not limited to fuel cells, micro turbines, photovoltaics (PV), and wind turbines, with the primary grid. The microgrid can be described as a versatile electrical network composed of diverse DERs, power electronic converters, energy storage systems, and various load types. These components operate cohesively alongside an energy management system, control mechanisms, and protective measures. Microgrids (MG) provide a myriad of benefits, including reduced carbon emissions, effective solutions for addressing power quality concerns, enhanced grid reliability, improved market strategies, optimized energy scheduling, and more efficient power delivery to rural communities[1].

The microgrid (MG) is typically linked to the primary grid through a point of common coupling (PCC). It functions in either grid-connected mode, where the frequency and voltage levels are dictated by the primary grid, or in islanded mode. Islanded mode can occur intentionally or unintentionally due to network faults. In islanded mode, precise control of frequency and voltage becomes crucial to ensure the system operates effectively[2]. All with a guarantee of accurate power sharing among the parallel-connected inverters that interface with the distributed generators (DGs).

Islanded microgrids are particularly susceptible to disturbances, leading to increased challenges in controlling the MG. To address these challenges, a hierarchical control structure has been introduced[3, 4], consisting of three control levels: primary, secondary, and tertiary control. The primary control focuses on power sharing, voltage and frequency regulation within the MG[5]. Parallel connections in isolated microgrids enhance reliability by allowing multiple power sources to work together. This configuration improves power sharing, increases overall system capacity, and ensures a stable and resilient energy supply[6]. Various control structures are implemented to operate parallel-connected inverters, which can be categorized as centralized, such as master-slave control[7], and decentralized, like droop control techniques[8]. The latter is widely used in the scientific community due to its ability to operate without the need for communication among the parallel-connected inverters.

A droop control strategy is implemented by adjusting the output frequency and voltage of inverters in response to the active and reactive power they deliver. This adjustment is based solely on local measurements, which enhances its reliability, flexibility, and eliminates issues related to the physical location of units[9]. In contrast to the conventional droop approach, the resistive droop method (P-E/Q-F) adjusts the voltage based on active power and the frequency based on reactive power, aligning with the resistive characteristics commonly found in

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microgrid line distributions.[10]. Nonetheless, the droop approach does suffer from several drawbacks that limit its application, including slow transient response, deviations in voltage and frequency, and dependence on the output inverter's impedance.

The finite control set model predictive control (FCS-MPC) is a promising option for primary microgrid control. It offers improved dynamic response, a discrete nature similar to electronic device converters, and straightforward implementation[11]. This makes it highly effective in enhancing transient response and ensuring the stability of both voltage and frequency. It employs a filter in conjunction with a discrete-time converter model to predict the system's output behavior for all possible input combinations through predefined cost function [12].

The rest of the paper is organized as follows: Section 2: Description of the microgrid system in isolated mode under study, along with the resistive droop approach. Section 3: Provide the FCS-MPC model predictive concept with a comprehensive mathematical model of VSI converter and LC output filter. Section 4:The simulation result and discussion. The conclusion of paper in Section 5.

2. The Island Microgid System and Resistive Droop Approach

A. The Island Microgrid

Figure 1 presents two distributed generators (DGs) connected in parallel to the point of common coupling (PCC). For feeding a common load .Each DG is interfaced with a voltage source converter (VSI) consisting of a two-level, three-phase inverter. The output of each VSI is connected to an LC filter designed to eliminate high-frequency components[13]. The Z-line impedances are assumed to be similar and exhibit resistive behavior.

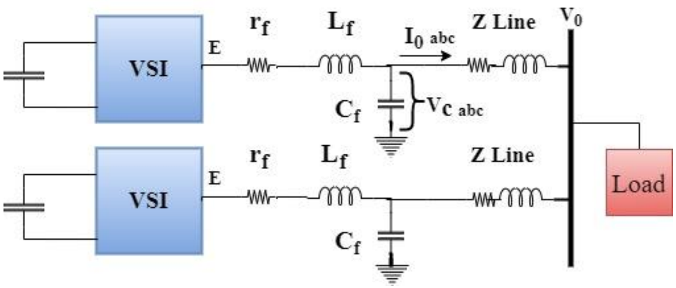


Fig 1.The island microgrid under study.

B. The Resistive Droop Approach

The droop control method is widely embraced within power systems and serves as a vital element in the primary control systems of microgrids. It plays a significant role in ensuring the efficient and stable operation of inverters operating in parallel. This is achieved by maintaining voltage and frequency deviations within acceptable limits while also guaranteeing precise power distribution among the parallel-connected distributed generators (DGs). The resistive droop control method, denoted as (P-E/Q-F), represents one among various types of droop control strategies. This approach takes into account the predominantly resistive characteristics of the impedance lines within the system. It determines the flow of power based on these considerations[2, 14].

The mathematical model of the isolated microgrid system under investigation can be developed using the following equations:

$$Q = \frac{-EV_0}{R}\sin\delta \approx \frac{-EV_0}{R}\,\delta \tag{1}$$

$$P = \left(\frac{EV_0}{R}\cos\delta - \frac{V_0^2}{R}\right) \approx \frac{V_0}{R}(E - V_0) \tag{2}$$

where, E represents the output voltage of the inverter, while V_0denotes the voltage at the Point of Common Coupling (PCC). R signifies the output resistance of the inverter, and δ represents the phase voltage difference between E and V_0, often called the power angle. From equations (1) and (2), it clear that active power is primarily influenced by the inverter voltage amplitude E, while the power angle δ regulates reactive power. Hence, the voltage reference for the inverter can be expressed in the following manner.

$$F = F_n^* + m_p(Q - Q^*) \quad (3)$$

$$E = E_n^* - n_q(P - P^*) \quad (4)$$

Where, $P^*$and Q^*denote the nominal active and reactive power reference. F and E signify the nominal frequency and the output voltage amplitude, respectively. While P and Q represent the actual real and reactive power output power. E_n^* and F_n^* are the magnitude and frequency references. m_p and n_q denote the proportional drooping frequency and voltage ,respectively. These parameters are subsequently designed as functions of the nominal power rating of the inverter.

3. Finite Control Set Model Predictive

The Model Predictive FCS-MPC approach is based on the minimization of a designed cost function, aiming to provide an optimal output. This approach involves anticipating future values within a predefined time horizon by utilizing the mathematical model of the system[15, 16].

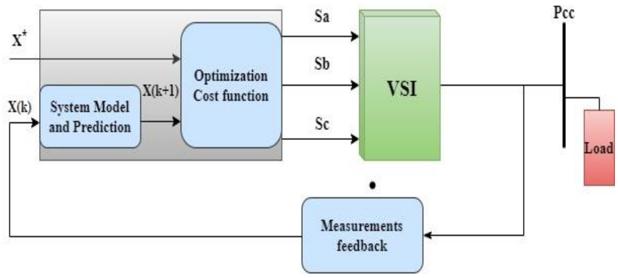


Fig 2. The FCS-MPC model predictive structure.

The model predictive use the feedback measurement x(k) and the model of system to predict the future value x(k+1) and through the cost function .where x^* is the reference value.

$$J = (x^* - x(k+1))^2 \quad (5)$$

A. ***Predictive Voltage Control***

The control performed in αβ frame, and the x* is the voltage reference generated by the resistive droop, while x(k) is the voltage measured across the filter capacitor. Also the switching signals of the Voltage Source Inverter (VSI), which are discussed in Section Two, are provided as follows:

$$V_i = \frac{2}{3} V_{dc} e^{i(j-1)\frac{\pi}{3}}, \quad j = 0; \ldots \ldots; 7 \quad (6)$$

$$C \frac{dV_c}{dt} = I_f - I_0 \quad (7)$$

$$V_i = V_c + V_f + R_f I_f \quad (8)$$

Where, I_f and V_f denote the current and the voltage inductor, respectively. I_0 represent the load current .while V_c and V_i signify the capacitor voltage and the output voltage inverter terminal. According to that the system state space model represented as:

$$\frac{dx}{dt} = Ax + B_1 V_i + B_2 I_0 \qquad (9)$$

$$x = \begin{bmatrix} I_f \\ V_c \end{bmatrix}, A = \begin{bmatrix} \frac{-R_f}{L_f} & \frac{-1}{L_f} \\ \frac{1}{C_f} & 0 \end{bmatrix}, B_1 = \begin{bmatrix} \frac{1}{L_f} \\ 0 \end{bmatrix} B_2 = \begin{bmatrix} 0 \\ \frac{-1}{C_f} \end{bmatrix} \quad (10)$$

The system model in discrete time expressed as:

$$\mathrm{X}(K+1) = A_d \mathrm{X}(K) + B_{1d} V_i(k) + B_{2d} I_0(K) \qquad (11)$$

Where

$$A_d = e^{A\,T_s},\ B_{2d} = \int_0^{T_s} e^{A\tau} B_1 d\tau, B_{2d} = \int_0^{T_s} e^{A\tau} B_2 d\tau$$

By approximating the exponential term and manipulating the previous equations, we can express the predicted capacitor voltage as follows:

$$V_c(k+1) = V_c(k) + \frac{T_s}{C_f}\left(I_f(K) - I_0(K)\right) \qquad (12)$$

And the cost function in αβ frame expressed as:

$$j = \left(V^*_{c\alpha\beta} - V_{c\alpha\beta}(k+1)\right)^2 \qquad (13)$$

Where $V^*_{c\alpha\beta}$ and $V_{c\alpha\beta}(k+1)$ are the resistive droop voltage reference and the anticipated future capacitor voltage, respectively .the result of cost function determine the voltage inverter vector that must applied on the output inverter.

4. Simulation Result

To evaluate the proposed control approach, the islanded microgrid, as described in section two, was simulated using MATLAB Simulink software. Multiple scenarios were executed to showcase the control scheme's stability, robustness, and effectiveness in both transient and steady-state conditions across linear load conditions. Also the load step change test to validate the resistive droop control capability. the simulations parameters of system depicted in Table.1 .

Table.1. simulation parameters

Simulation parameters		
Power stage	***value***	***unit***
Nominal RMS voltage	220	(V)
Nominal Frequency	50	(Hz)
DC Voltage	700	(V)
Filter Inverter Side	2.10^{-3} , 0.5	L_f (H) , R(Ω)
Filter Capacitor	60	C (uf)
Load1 Equal Load 2	10 , 6	P (Kw), Q (Kvar)

Simulation parameters		
Power stage	***value***	***unit***
Line Impedance VSI1 R , L	0.2 , $0.1.10^{-3}$	(Ω), (H)
LineIimpedance VSI2 R , L	0.2 , $0.1.10^{-3}$	(Ω), (H)
Droop Coeffetion m_p ,n_q	3.10^{-4} ,-5.10^{-4}	
Sampling time	$25.\ 10^{-6}$	(S)

To assess the performance of the isolated microgrid, the simulation was divided into three phases. In the first phase, at time zero (0) seconds, a 10 kW and 6 kVAR RL load was connected to the microgrid system. The voltage at the output of each inverter and on the load side, as shown in Figure 3 and Figure 4, remained stable, maintaining a fixed value of 311V. These voltage waveforms also exhibited sinusoidal characteristics with a Total Harmonic Distortion (THD) of 0.13%, as depicted in Figure 5. Additionally, it is worth noting that the total load current was equally distributed between the two inverters.

At 0.2 seconds, the load was doubled by connecting the second RL load, and it was disconnected at 0.4 seconds. Consequently, the current doubled in both DGs and on the load side while maintaining the voltage and frequency at their nominal values. This demonstration highlights the exceptional performance of the FCS-MPC (Model Predictive Control) model in stabilizing the voltage at the Point of Common Coupling (PCC) .

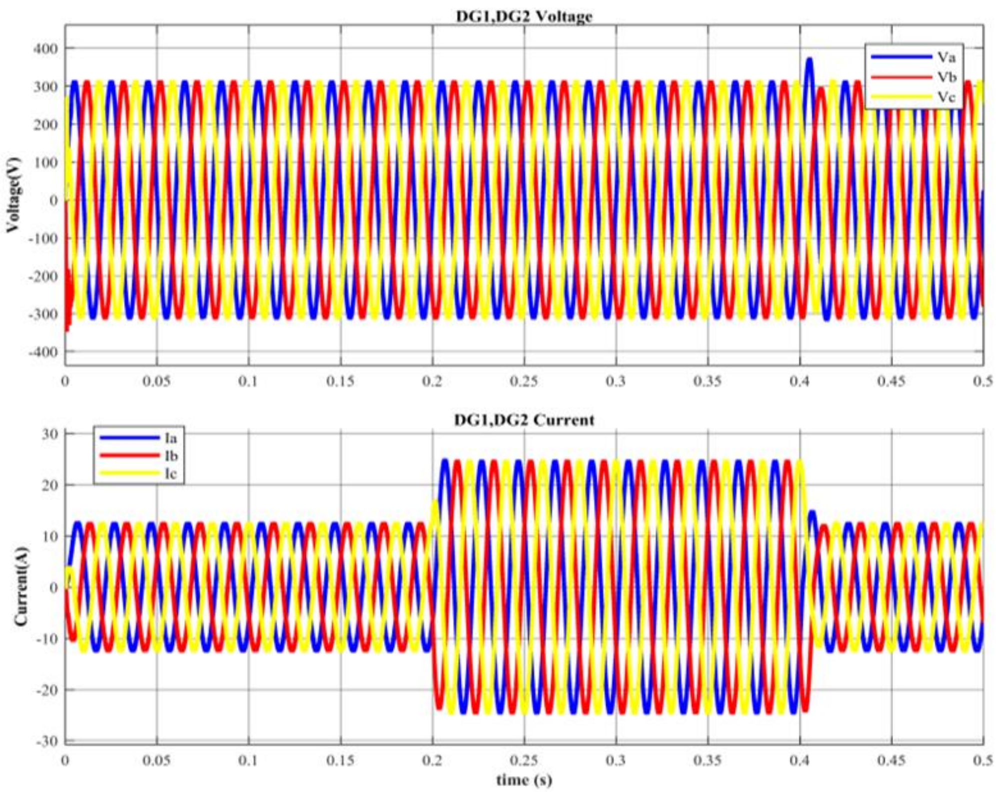


Fig 3. DG1,DG2 voltage and current .

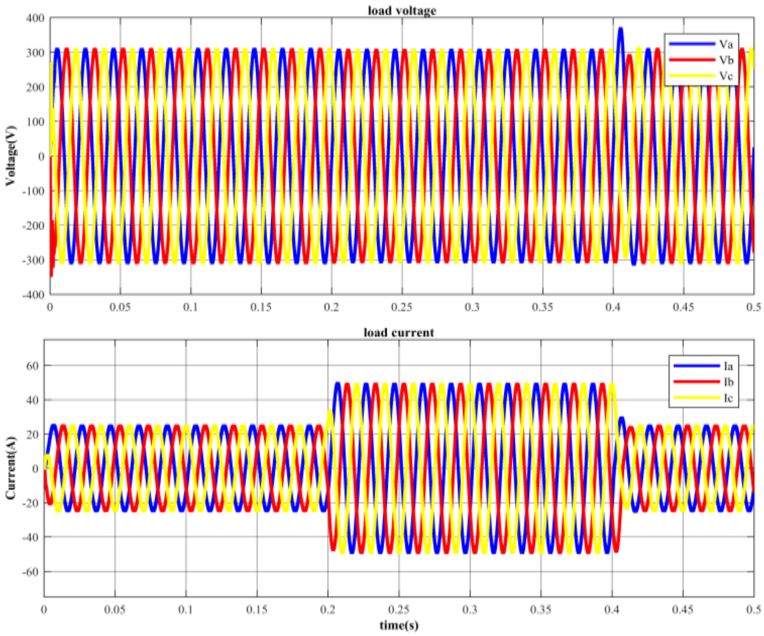


Fig 4.load voltage and current.

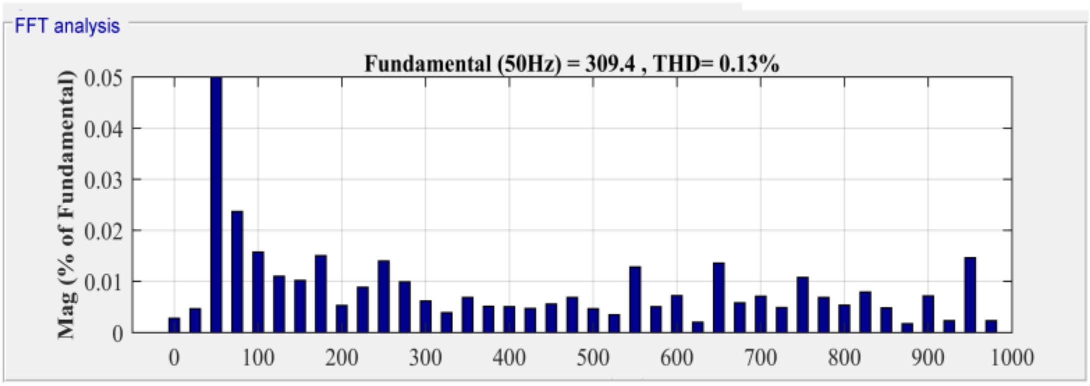
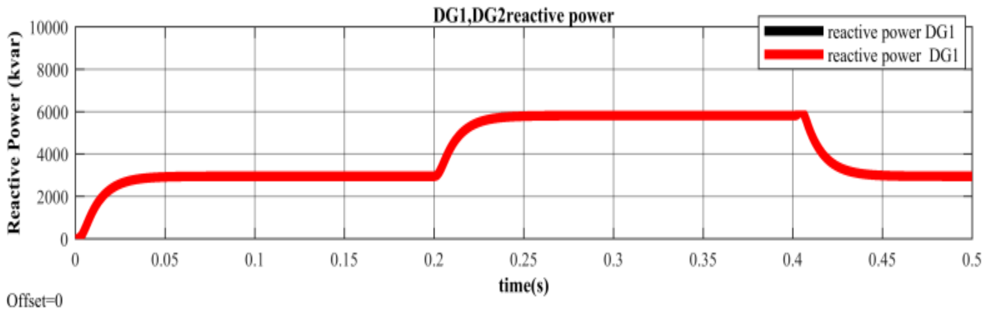
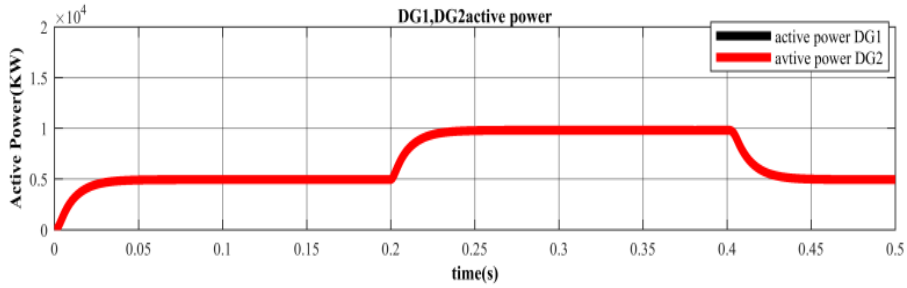


Fig 5.Total Voltage Harmonic Distortion (THD) .

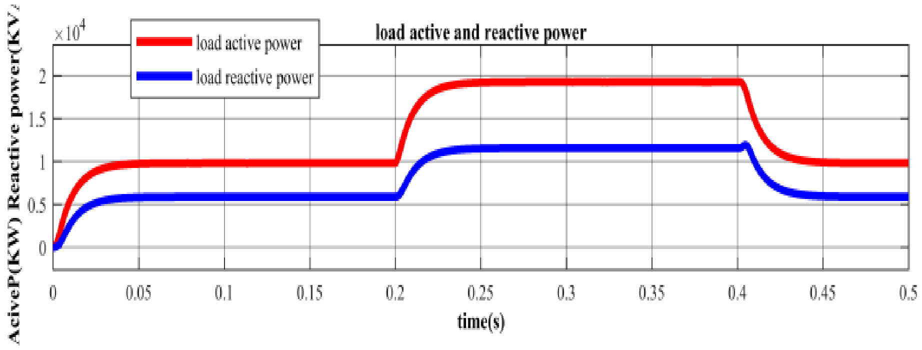
Figure 6(a) illustrates the active power in both DG1 and DG2, showcasing precise power sharing between them. Additionally, Figure 6(b) displays the reactive power, further demonstrating the balanced operation of the system. In Figure 6(c), the active and reactive load throughout the simulation phases are depicted, with the load power equalling the sum of the two DG powers. These results collectively underscore the effectiveness and robust capabilities of the resistive droop control method under varying load conditions. Also figure 7. Shown the small frequency deviation under load step change which proven the resistive droop concept.



(a)



(b)



(c)

Fig 6. The output DGs and the load active and reactive power.

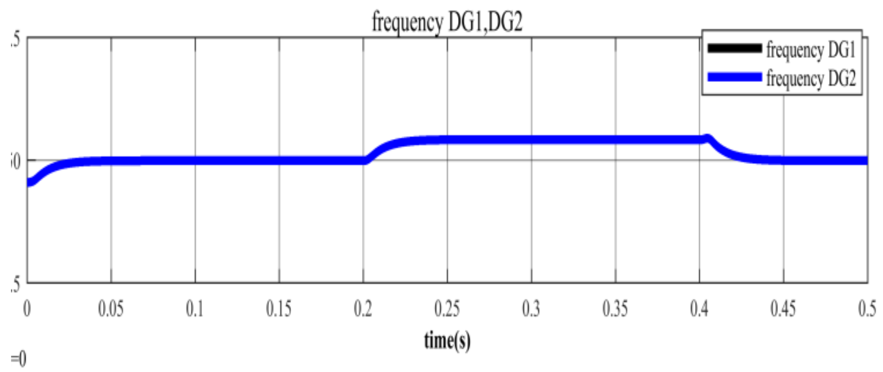


Fig 7. DG 1,DG2 frequency deviation.

5. Conclusion

This research examines the application of Finite Control Set Model Predictive Control (FCS-MPC) as a voltage controller in the primary layer of an islanded microgrid. The main goals are to improve the system's transient response and ensure stable voltage and frequency, while achieving accurate power distribution among distributed generators (DGs). This control strategy employs resistive droop control as a key component to attain these objectives.Simulation results highlight the proposed control strategy's outstanding performance in terms of system stability, robustness, and power quality. Additionally, the findings demonstrate the excellent compatibility of resistive droop control with microgrid systems.

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