

Stability Enhancement of AC Microgrid Using Discrete Mode Controllers with Optimum Sampling Frequency



Amit Arora, Mahendra Bhadu, and Arvind Kumar

Abstract This paper examines the influence of discrete mode controllers with optimum sampling frequency to enhance the stability of the grid-integrated AC microgrid. The damping of low-frequency electromechanical oscillation performance of distributed generators of AC microgrid is analyzed. The AC microgrid is comprised of two renewable energy resources a photovoltaic (PV) farm, a variable wind speed type DFIG wind farm, and another two distributed generators hydro and diesel are based on synchronous generators. The diesel generator is used as a backup source to provide the load demand when the grid is subjected to disturbance and the generation of renewable power is not as per demand. This research investigates the effect of the execution of different discrete type's power system stabilizers with an optimum sampling frequency to enhance the stability of the AC microgrid. The discrete type time domain mode PSSs such as conventional PSS ($\Delta\omega$ -PSS and ΔPa -PSS), MBPSS-4B, and LQG-based PSS controllers are executed on DGs of the AC microgrid for the damping of low-frequency electromechanical oscillation. The MATLAB/Simulink software gives a comparative analysis of the discrete mode controller's response to distributed generators of AC microgrid. The simulation result verified the system performance with an effective operational sampling frequency of discrete time domain mode controllers such as conventional PSSs, MBPSS-4B, and LQG controllers under fault conditions.

Keywords AC microgrid · Discrete mode controller · Power oscillation damping · Small signal stability · Distributed generators · Solar photovoltaic · Wind energy

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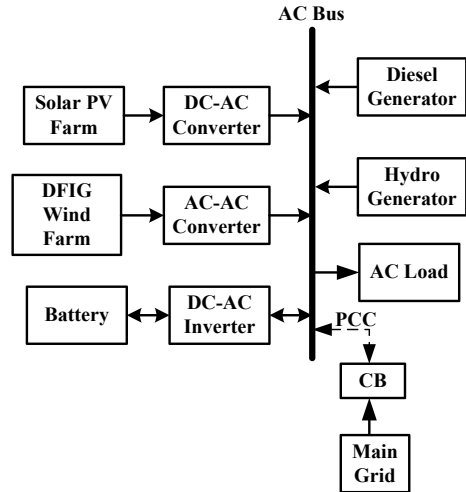
1 Introduction

In the present scenario, renewable energy sources-based microgrids are becoming increasingly in demand to generate clean energy. The generation of electricity from renewable energy sources (RESs) is only the key to decline the global warming. Interconnecting renewable energy generation sources with electrical power generation storage devices can be establishing a stable microgrid. The microgrid is an emerging field that offers to deliver reliable responses to the increase in stress on the main grid and transmission lines. The most effective general form for generation is, a microgrid integrated with both renewable energy sources (RESs) like wind, solar PV cells, and fuel cells also together with traditional energy sources like diesel generators, micro turbines, and micro or small hydro [1]. The integration of microgrid with renewable and traditional energy sources is controlled by the robust design controller, and it provides operational stability to the systems. In the interface of power electronics controller with RESs, there are many obstacles that are shown, such as continuing the power supply without any interruptions, integration of RESs with conventional grid, issues of power quality, stability, security, reliability, protection, and energy storage system, concerning the frequency and voltage deviation [2]. Therefore, researchers applied the technological advancement that is moving in the direction of implementation of renewable energy sources achieving maximum electricity generation to match the energy need. The major challenges with renewable energy sources are weather dependent so the generation of energy is variable in nature and utilization of these resources imposes a reduction in the inertia of the grid. Because of this, the problem of stability arises in power systems. Solar photovoltaic (SPV) energy and wind power are two main sources of renewable energy utilized in the generation of electricity, and they are free of pollution or carbon-free [3].

The voltage fluctuations, frequency oscillations, variance in generation and demand, etc., are a few main issues in the main power grid. The main focus of the researcher is to protect and maintain the stability of the main grid from the above discussed issues to construct a confined power generated grid that is known as a microgrid [4]. A microgrid provides electricity to rural, urban, and hilly areas if the failure or unavailability of the external grid. The advantages of a microgrid (MG) are provided energy at the time of peak load, environmentally friendly, and give an economical energy solution. The major problems for microgrids during the integration of intermittent renewable-based DGs are low inertia, change in voltage and frequency, stability, and protection [5].

The modes of operation in the microgrid are the following: the grid-connected, autonomous, or transited, and the reconnection operating modes. A microgrid in grid-connected mode can manage and interchange the generation of electricity with the conventional grid and maintain the power supply from renewable energy-based distributed generators of the microgrid, although the energy flows through a microgrid is bidirectional [6]. In the autonomous or stand-alone mode, the microgrid can sustain the balance in reactive power in the self-base without the existence of an infinite bus. So this mode has major challenges considering a proper voltage and frequency

Fig. 1 Typical diagram of AC microgrid



magnitude, and another is proper power balance. The microgrid is classified into three major types as per power bus and load that is AC power, DC power, and hybrid (AC/DC) power microgrids [7].

Traditionally, a hierarchical architecture with primary, secondary, and tertiary supervisory control levels has been accomplished for the control of distributed generators (DGs), BESSs, the transition of operating modes, and the stability of the main grid and microgrid [8]. Figure 1 shows the diagrammatic block diagram of the AC microgrid with different distributed generators.

In the microgrid, the distributed generation resources are associated with the utility grid with an interface of a power electronics converter to operate as per their requirements and also to maintain the stability and quality of modern power systems [9].

The dynamic stability of the microgrid is the main issue because of the disturbances due to the fault, changes in load, and changes in voltage and frequency. For this reason, the research is focused on the stability of microgrids in terms of analysis of small signal stability. To measure, the dynamic stability of the microgrid, a small signal stability analysis gives an adjustment to the control variable of the microgrid [10].

The small signal stability in terms of low-frequency electromechanical oscillation of the distributed generators of the systems should be enhanced the system stability. The execution of power system stabilizers (PSSs) in the power generating distributed generator units dampens the electromechanical oscillations, which improves the system stability [11]. The different types of robust design oscillation damping controllers are executed in distributed generators of the systems to achieve better performance of the systems against low-frequency oscillations, and they are represented as traditional or local PSSs based on input speed and power, multi-band

PSS (MBPSS), PID-PSS, fuzzy logic-based PSS (FLPSS), H infinity ($H \infty$), etc. [12–14].

However, type-1 fuzzy logic-based PSS controller techniques provide improve performance compared with conventional PID-based PSSs in terms of damping performance low-frequency oscillations of distributed generators of the systems; these standard type-1 fuzzy logic PSSs have shortcomings when it comes to handling significant levels of uncertainty and unpredictable disturbances in modern power systems. Have robustness in type-2 fuzzy logic-based PSS (FLPSS-II) to eliminate the uncertainties and unpredictable disturbance [15].

One of the best choices to get over these restrictions is a robust LQG controller. Its function's specificity makes it easier to manage uncertainty. According to a LQG-PSS with a distinctive estimation algorithm is successful at damping oscillations in the modern power system [16]. Continuous time domain LQG is a robust controller for damping the low-frequency oscillation (LFO) of distributed generators, and it also provides small signal stability to the system. This technique allows you to deal with regulation performance and provide the control signal to disturbances and measurement or random noise [17, 18].

The continuous time domain mode power system stabilizers are tuned by different tuning methods such as PV_r , GEP, and residue methods for selecting the optimal control values of gain and proper pole placements. Further, this tuned continuous time domain mode $H(S)$ PSS transfers in the discrete time domain mode $H(Z)$ PSS. The discrete transfer function of PSSs is used to easily dampen the low-frequency oscillations to achieve the small signal stability of the power system [19, 20].

The research gap is identified from the conclusion drawn from the literature survey on various aspects of the AC microgrid. Some domains need further attention such as comparative analysis of conventional lead-lag controllers in AC microgrid. The corresponding discrete mode controllers are also not armed systematically in any AC microgrid. There is also a need of investigating the performance of the AC microgrid at the optimal sampling frequency of discrete mode controllers.

The organization of the remaining article represents the following: Section 2 represents the proposed approach of the paper. Section 3 represents the modeling of the AC microgrid test system with the mathematical modeling of distributed generators, and Sect. 4 gives a brief discussion of discrete mode damping controllers and the mathematical modeling of robust discrete LQG controller. Section 5 represents the result section with the comparative analysis of the controller's validation. The paper ends with a conclusion in Sect. 6, followed by the references.

2 Proposed Approach

This paper proposed the design of damping robust discrete controllers to enhance the dynamic stability of the AC microgrid. The execution of discrete controllers in distributed generators of grid-integrated AC microgrid gives better performance against the disturbance of low-frequency electromechanical oscillations in a shorter

settling time. Overall the proposed approach of this research work is to raise the small signal stability of the AC microgrid using different types of discrete mode controllers with optimal sampling frequency.

The main objectives of the research paper are

- The robust design of discrete mode PSSs controllers is the main motive for a grid-connected AC microgrid to increase the system damping characteristics of low-frequency oscillation (LFO) mode for the stabilization of the microgrid.
- The performance of the different discrete mode PSSs such as CPSS (ΔPa -PSS and $\Delta\omega$ -PSS), MBPSS (MBPSS-4B), and LQG has been compared to analyze the effectiveness of these discrete PSSs for improving the stability of AC microgrid under different varying operating conditions such as a three-phase line to ground fault.
- The discrete mode controllers give better damping performance against the disturbance at the optimal control sampling frequency.
- The compared controller's performance gives discrete time domain mode LQG is the most robust power oscillations damping (POD) controller to improve the dynamic small signal stability and damp the low-frequency electromechanical oscillations of the system.
- Validation of the proposed controllers in MATLAB/Simulink platform.

3 Test System

In this modeling of the test system total, 24.5 MW capacity of the distributed generators of the microgrid is connected to the AC grid where 20 kV, 50 Hz with a base MVA is 1000 MVA construct a grid-integrated AC microgrid. The proposed AC microgrid comprises four different power generating units with their installed capacity, a photovoltaic (PV) farm is 8 MW, a DFIG wind turbine is 4.5 MW, hydro is 6 MW, and diesel is 6 MW as a backup. The test system represents in single line grid-integrated AC microgrid illustration under fault conditions shown in Fig. 2 to examine the impact on DGs of electromechanical low-frequency oscillation in power systems. The main research concentrates on oscillations in a low frequency on a scale of 0.1–1 Hz because the focus of this investigation is how to increase the damping performance of modern power systems [21].

The power system stabilizers (PSSs) allow an auxiliary stabilization signal to distributed generators of AC microgrid, which measures the low-frequency oscillations (LFO) of the system and also increases the system stability. To dampen out the power oscillation of DGs of AC microgrid PSSs are used, this is attained with a voltage regulator to generate a torque in phase with speed [22]. The distributed generators connected with different PSSs using a multi-input and single-output switch are represented in Fig. 3.

The equivalent solar photovoltaic (SPV) circuit diagram with a load R_L is represented in Fig. 4. The output current of the SPV is represented by Eq. (1). Its circuit diagram has a current source, diode, and resistor and is present in [23].

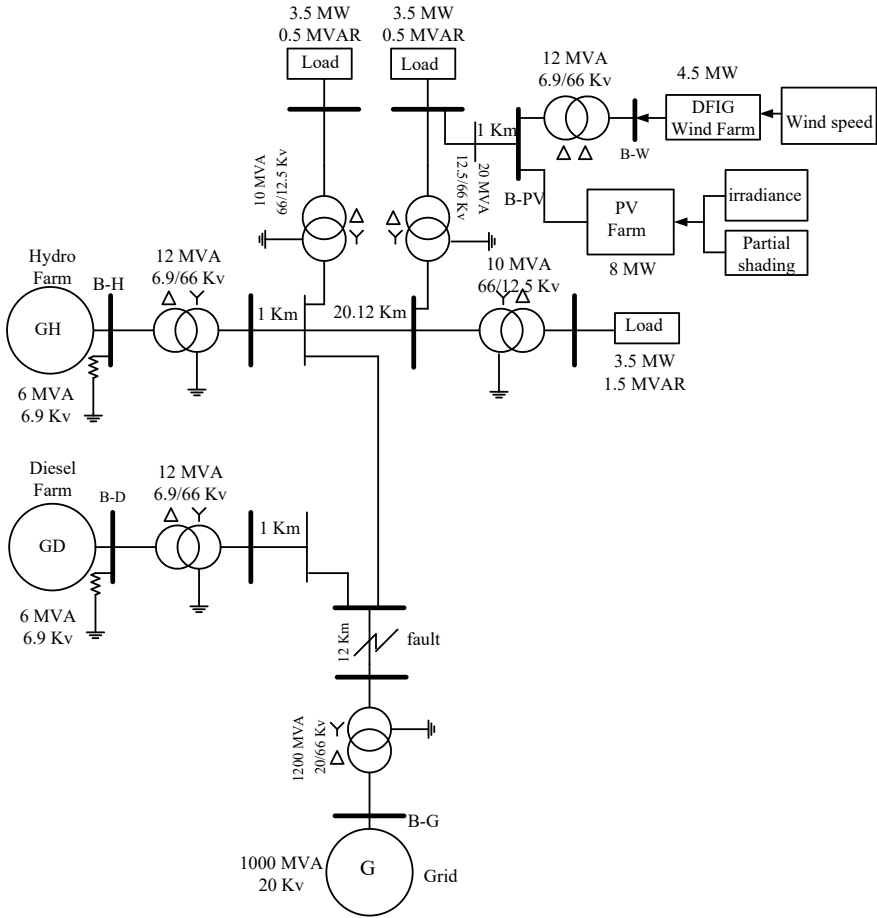


Fig. 2 AC microgrid single line diagram test system

$$I_{SPV} = I_{ph} - I_d - I_{Sh}, \tag{1}$$

where I_{SPV} is the total PV current, I_{ph} is photo current, and I_{sh} is the shunt current across shunt resistance.

The PN junction diode is used to get the unit exponential expression characteristics that represent a solar PV (SPV) system, and it is then expanded to obtain the solar PV total output current as shown below.

$$I_{SPV} = I_{SCA}(G) - N_P \times I_0 \left[\exp\left(\frac{V_A + I_{SPV}R_S}{\eta N_S k T}\right) q - 1 \right]. \tag{2}$$

Here, I_{SPV} is total solar PV current (Amp.), V_A is solar PV voltage (Volt.), η is identity factor, I_0 is reverse saturation current (Amp.), R_S is array series resistance

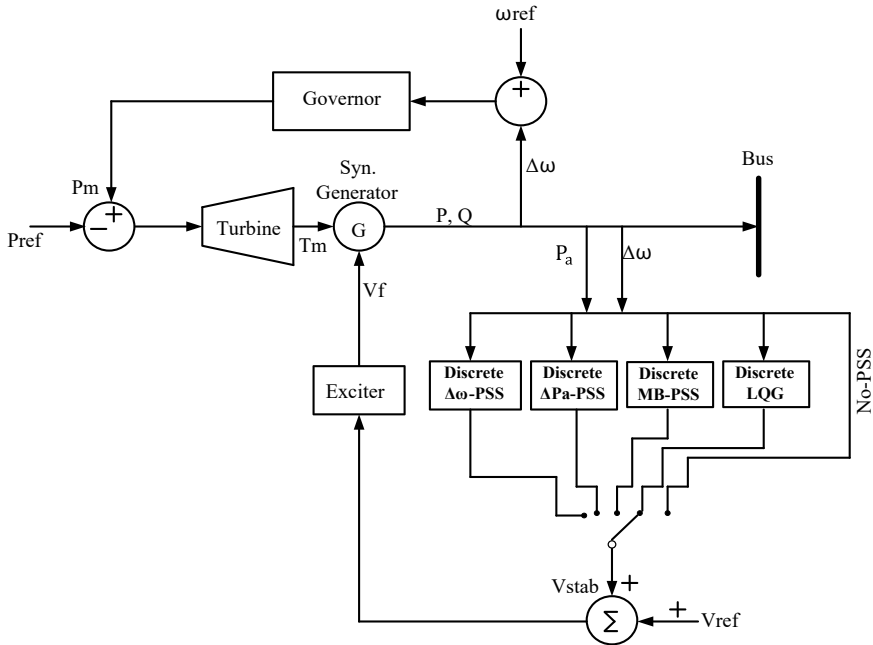


Fig. 3 Distributed generator arrangement with a discrete mode controller

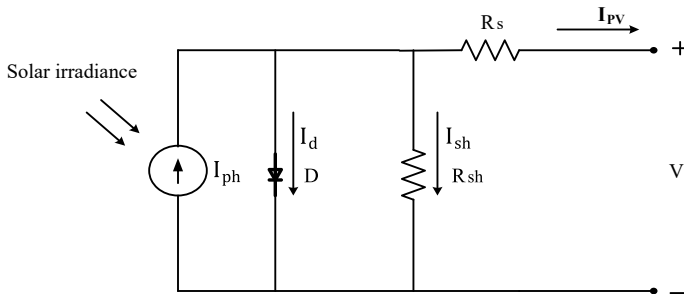


Fig. 4 Photovoltaic cell equivalent circuit

(Ω), $I_{SCA}(G) = N_P I_{SC}(G)$, I_{SC} is SPV short circuit current (Amp.), G is PV insolation (Wh/m^2), N_P is the No. of modules in parallel, N_S is the No. of modules in series, k is represented as the Boltzmann constant, and q is the electron charge (C).

The DFIG-based wind turbine (DFIG-WT) to generate electrical power is depicted in Fig. 5, which is used for variable speed wind turbines. Its output power can be represented as follows:

$$p_{mech.} = \frac{1}{2} C_p(\beta, \lambda) \pi R^2 \rho v_{wind}^3 \tag{3}$$

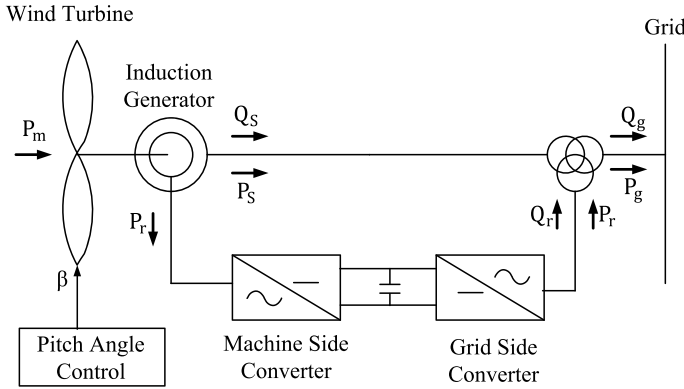


Fig. 5 DFIG configuration using wind energy conversion system

and generated torque due to the wind passing through the turbine blades is given as

$$T_m = 0.5 \frac{C_p(\beta, \lambda)}{\lambda} \rho \pi R^2 V_{wind}^3, \tag{4}$$

where $C_p(\beta, \lambda)$ known as the coefficient of power is related to the pitch angle (β) and tip velocity constant (λ) of the turbine blades, ρ denotes air density, v_{wind} denotes the velocity of wind, and R is the radius of the turbine blade [24].

Equation 5 shows the relationship between the DFIG parameters which is the power coefficient $C_p(\beta, \lambda)$ concerning relates with pitch angle (β) of turbine blades, wind velocity (ω_{wind}) m/s, and tip velocity constant λ , respectively.

$$C_p(\beta, \lambda) = 0.517 \left(\frac{116}{\lambda_i} - 0.4\beta - 5.0 \right) \exp\left(-\frac{21}{\lambda_i} \right) + 0.0068\lambda. \tag{5}$$

The tip speed ratio (λ_i) is given as in Eq. (6)

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}. \tag{6}$$

4 Modeling of Damping Controllers

The power oscillation of the AC microgrid is dampened by the different types of continuous and discrete types of damping controllers and by this improved the performance of the overall system. The small signal stability problem in the distributed generators of the AC microgrid system such as rotor speed deviation, rotor angle deviation, frequency deviation, and voltage deviation, etc. are the disturbances due

to fault. The execution of various types of discrete PSS in DGs of AC microgrid provides the oscillation damping and improves the system stability. The main role of PSSs dampens the electromechanical low-frequency oscillations (LFO) of the microgrid [25]. The AC microgrid distributed generators are used different types of power oscillation damping controllers which are described as

- (i) Speed-based stabilizer
- (ii) Frequency-based stabilizer
- (iii) Power-based stabilizer
- (iv) Discrete mode PSS
- (v) Multi-band stabilizer (MBPSS-4B)
- (vi) Discrete LQG controller.

4.1 Discrete Time Domain Controllers

This block diagram’s function is to transform the continuous time domain (t) signal to discrete time domain (z) response signal using contained blocks as shown in Fig. 6, corresponding to input signal block, sample and hold circuit, pulse generator, gain, discrete transfer function, and desired response blocks. In this, the continuous transfer function $H(s)$ converts into discrete transfer function $H(z)$ to develop a desired controller with the help of a sample and hold circuit at the desired sampling frequency. Sample and hold are used to implement a signal sample and hold in discrete mode at desired sampling frequency to achieve optimum control response of the system. With these blocks function design, a discrete time domain controllers and improved the performance of systems and achieved optimum control response against disturbance at a sampling frequency consider 25 Hz ($T = 0.04$ s) [26, 27].

While the estimation hold is zero-order hold (ZOH), at that time the discrete corresponding to $H(s)$ is represented by Eq. (7).

$$H_{ho}(z) = (1 - z^{-1}) \left\{ \frac{H(s)}{s} \right\}, \tag{7}$$

where $H(s)$ is known as the phase lead function shown in Eq. (8)

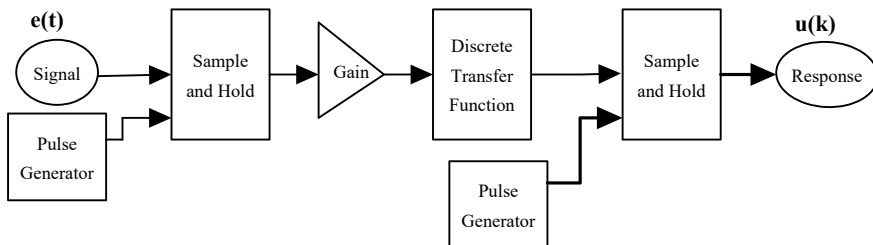


Fig. 6 Block diagram continuous to discrete mode controller conversion

$$H(s) = \frac{1 + sT_1}{1 + sT_2}. \tag{8}$$

So zero-order hold corresponding is represented by Eq. (9).

$$H_{ho}(z) = \frac{\frac{T_1}{T_2}z - \left(\frac{T_1 - T_2}{T_2} + e^{\frac{T}{T_2}}\right)}{z - e^{\frac{T}{T_2}}}. \tag{9}$$

4.2 Conventional Damping Controllers ($\Delta\omega$ -PSS and ΔPa -PSS)

The power oscillation damping controller is used to enhance the damping of the system. The basic functioning block model of the PSS damping controller is represented in Fig. 7. The deviation in rotor speed ($\Delta\omega$) or accelerating power (Pa) is selected as input to enhance the damping by adding the feedback signal (V_S) to excitation. The typical block diagram speed input-based PSS consists of different blocks considered as, a gain (K_{PSS}), a washout time filter (T_w) block, a phase angle compensation lead/lag with a time constant (T) block, and a limiter ($V_{max} - V_{min}$) [28–30].

The transfer function of the conventional power system stabilizer (CPSS) damping controller is given in Eq. (10) when the generator rotor speed ($\Delta\omega$) is selected as a feedback signal.

$$V_S = K_{PSS} \frac{(sT_w)}{(1 + sT_w)} \frac{(1 + sT_1)}{(1 + sT_2)} \frac{(1 + sT_3)}{(1 + sT_4)} y. \tag{10}$$

The above equation represents speed ($\Delta\omega$) or acceleration power (Pa) as the input signal as ‘y,’ T_w represents as washout time constant, $T_1, T_2, T_3,$ and T_4 are represented as the time constant, and K_{PSS} represents as the gain of PSS.

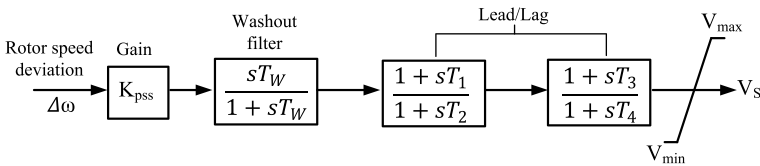


Fig. 7 Single input lead–lag power system stabilizer structure

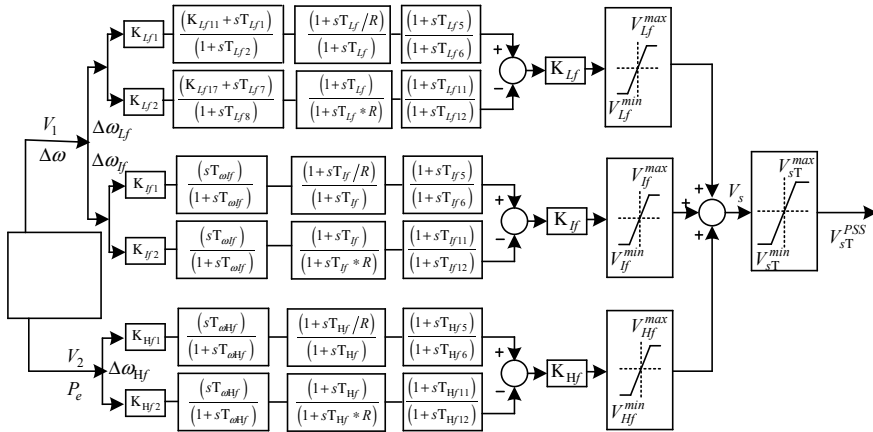


Fig. 8 Multi-input-based MBPSS-4B IEEE standard damping controller

4.3 Multi-band PSS (MBPSS-4B) Damping Controller

The MB-PSS damping controller structure is encountered by the IEEE St. 421.5 PSS-4B sort mode to achieve a wide range of electromechanical oscillation damping improvements. The structure of MBPSS-4B provides three adjustable tuning bands as the low-frequency band (F_L) with a range of 0.01–0.1 Hz, the intermediate frequency band (F_I) with a range of 0.1–1 Hz, and the high-frequency band (F_H) with a range of 1–4 Hz modes of the oscillation, which are shown in Fig. 8 [31, 32].

4.4 Mathematics Modeling of Discrete LQG Controller

The system implemented with the LQG controller is used to stabilize and regulate the system. The system is influenced by disturbances or uncertainties and also in addition to communication noise is considered a feedback measurement signal which is described by the state space equation of the system [33, 34]. The discrete time domain linear quadratic Gaussian controller equation in discrete time is described by Eqs. (11) and (12).

$$x_{i+1} = A_i x_i + B_i u_i + v_i, \tag{11}$$

$$y_i = C_i x_i + w_i. \tag{12}$$

In the mathematical modeling of discrete LQG controller denotes A_i , B_i , C_i as the state matrix and ' x_i ' is the state vector of ' n ' dimensional ' u_i ' is the vector of input of ' m ' dimensional, and ' y_i ' is the vector of the output of ' q ' dimensional, and

here, ‘ i ’ represents the discrete time index. The system needs to be, controllable, and observable, linear time-invariant. In input, ‘ v_i ’ is the disturbance noise, whereas ‘ w_i ’ is the measurement noise. Here, $E(w_i w_i^T) = W_i$ and $E(v_i v_i^T) = V_i$ are related to covariance matrices, respectively. The expectation operator of the system is denoted by E .

J is the cost function corresponding to obtain the optimal control ‘ u_i ’ on uncertainties in the system can be expressed by Eq. (13).

$$J = E \left[X_N^T F x_N + \sum_{i=0}^{N-1} (X_i^T Q_i X_i + u_i^T R_i u_i) \right], \tag{13}$$

$$F \geq 0, Q_i \geq 0, R_i > 0. \tag{14}$$

The discrete time mode LQG controller is represented by given equations as

$$\hat{X}_{i+1} = A_i \hat{X}_i + B_i u_i + L_{i+1} \left(y_{i+1} - C_{i+1} \{ A_i \hat{X}_i + B_i u_i \} \right), \tag{15}$$

$$\hat{X}_0 = E[X_0], \tag{16}$$

where \hat{X}_i is analogous to the predictive estimate.

$$\hat{X}_i = E[X_i | y^i, u^{i-1}]. \tag{17}$$

The gain of the Kalman estimator is

$$L_i = P_i C_i^T (C_i P_i C_i^T + W_i)^{-1}, \tag{18}$$

where P_i is calculated by the given Riccati difference equation that moved in forward time,

$$P_{i+1} = A_i \left(P_i - P_i C_i^T (C_i P_i C_i^T + W_i)^{-1} C_i P_i \right) A_i^T + V_i, \tag{19}$$

$$P_0 = E \left[(X_0 - \hat{X}_0)(X_0 - \hat{X}_0)^T \right]. \tag{20}$$

The feedback gain matrix is represented as

$$K_i = (B_i^T S_{i+1} B_i + R_i)^{-1} B_i^T S_{i+1} A_i, \tag{21}$$

where S_i is calculated by the given Riccati difference equation that moved in backward time,

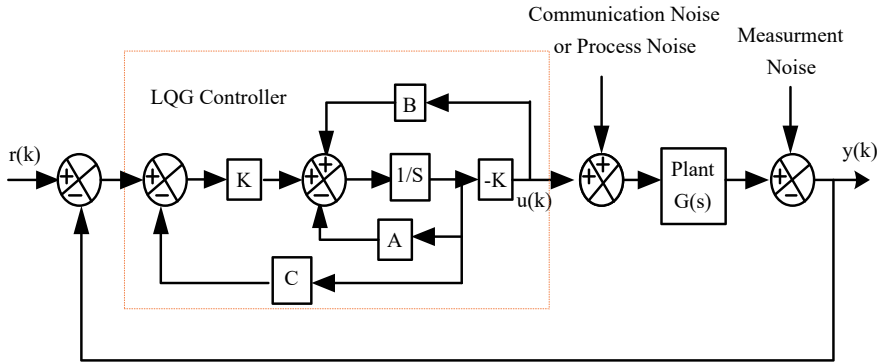


Fig. 9 Conventional model of LQG controller

$$S_i = A_i^T \left(S_{i+1} - S_{i+1} B_i (B_i^T S_{i+1} B_i + R_i)^{-1} B_i^T S_{i+1} \right) A_i + Q_i, \quad (22)$$

$$S_N = F. \quad (23)$$

The main functioning block diagram of the discrete mode LQG controller is represented in Fig. 9. The collective performance of Kalman estimator and linear regulator form the model of linear quadratic Gaussian controller which is used to provide effective performance against disturbances or uncertainties in the system [35]. In this work, the sampling time is 0.04 s. consider because controllers provide optimal control response against disturbances of low-frequency electromechanical oscillations, and discrete mode LQG controller gives better performance on this sampling frequency 25 Hz ($T = 0.04$ s).

5 Simulation Results

The simulation results present that the stability enhanced the AC microgrid with the effect of discrete controllers at the optimal control sampling frequency. A 3- ϕ L-G fault, on the transmission line at a $T = 1$ s. with spam of the fault is 0.15 s. in the AC microgrid test model. The implementation of the distinct types of discrete damping controllers at an optimum control sampling frequency of 25 Hz ($T = 0.04$ s) is analyzed for the improvement of the constraint of low-frequency electromechanical oscillations in distributed generators of the grid-integrated AC microgrid. The responses of the diesel and hydro distributed generators with the effect of different types of discrete controllers with considered optimal sampling frequency are represented in Figs. 10, 11, 12, 13, 14 and 15 respectively with the variable such as rotor speed deviation ($\Delta\omega$), rotor angle deviation ($\Delta\delta$), and output active power (P_e). Similarly, the responses of the DFIG-based wind farm and solar photovoltaic (SPV)

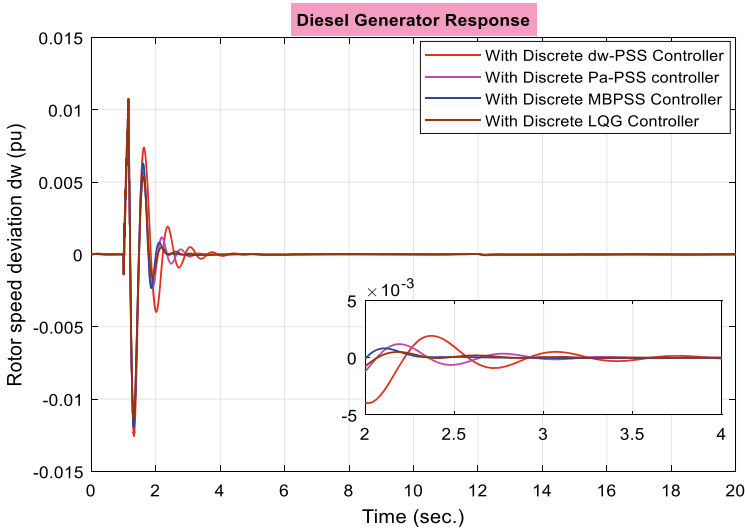


Fig. 10 Rotor speed deviation $\Delta\omega$ (pu) of diesel generator

farm distributed generators with the influence of discrete controllers are represented in Fig. 16 with the parameter of rotor speed deviation ($\Delta\omega$) of the DFIG-based wind farm distributed generator, and Fig. 17 PV bus voltage at PCC of photovoltaic (PV) farm distributed generator. The obtained response represents the enhanced stability in terms of damping the electromechanical low-frequency oscillation of AC microgrid distributed generators with the discrete controllers at the optimal sampling frequency. The robust design LQG controller is ideal and gives better results compared with conventional PSS ($\Delta\omega$ -PSS and ΔPa -PSS) and MBPSS-4B controllers in the discrete time domain mode with considered optimal sampling frequency.

The summarized results show that the different discrete mode controllers at optimum control sampling frequency, i.e., $F = 25$ Hz ($T = 0.04$ s), enhance the stability of the AC microgrid. The discrete LQG damping controller is more robust and improves the small signal stability of low-frequency electromechanical oscillations of the distributed generators of the AC microgrid.

6 Conclusion and Future Scope

This research work analyzed the enhancement of the stability of the AC microgrid with the design of the damping controller in a discrete time domain with optimum sampling frequency. In this, a microgrid integrated with four different distributed generators unit like a variable wind speed-based DFIG wind farm, photovoltaic (PV) farm, hydro, and one backup unit as a diesel generator. The execution of various types of damping discrete controllers such as conventional PSSs ($\Delta\omega$ -PSS and ΔPa -PSS),

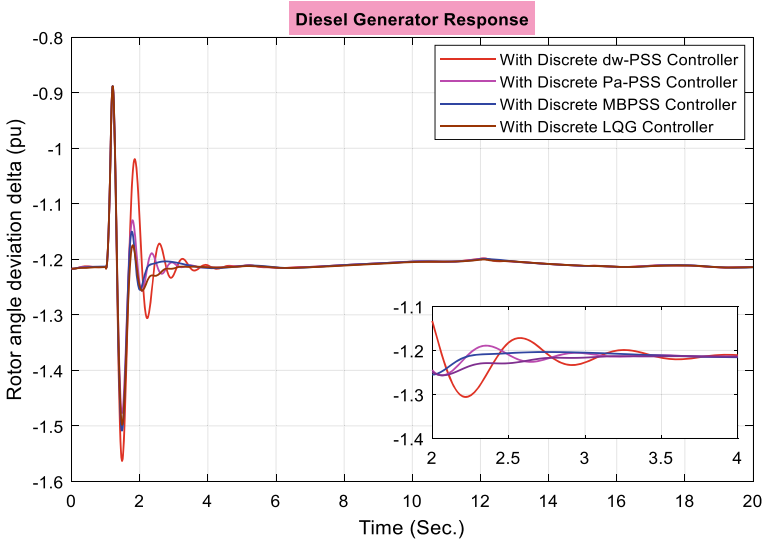


Fig. 11 Rotor angle deviation $\Delta\delta$ (rad) of diesel generator

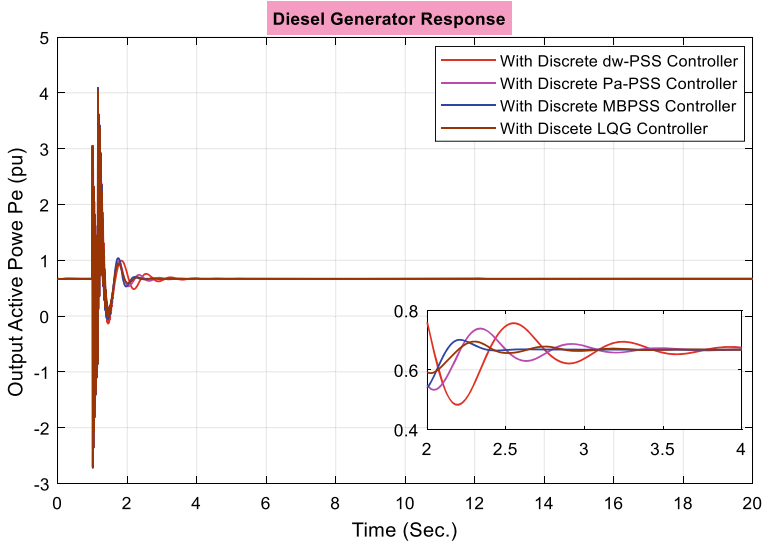


Fig. 12 Output active power (P_e) of diesel generator

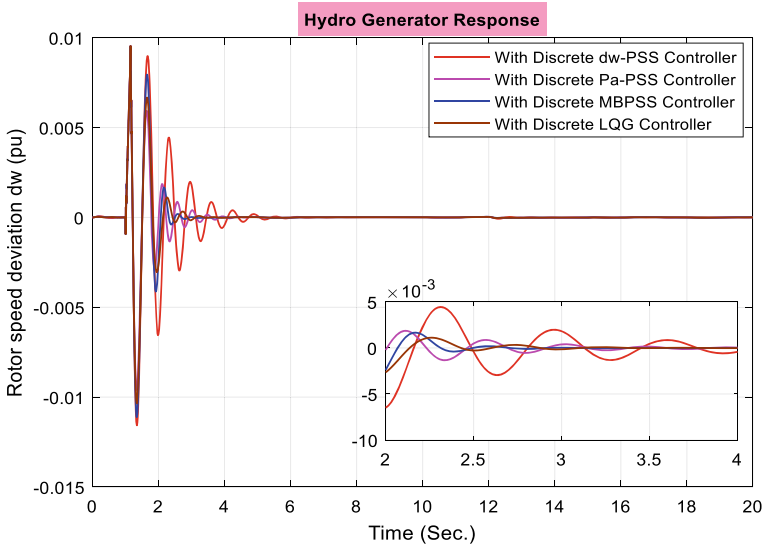


Fig. 13 Rotor speed deviation $\Delta\omega$ (pu) of hydro generator

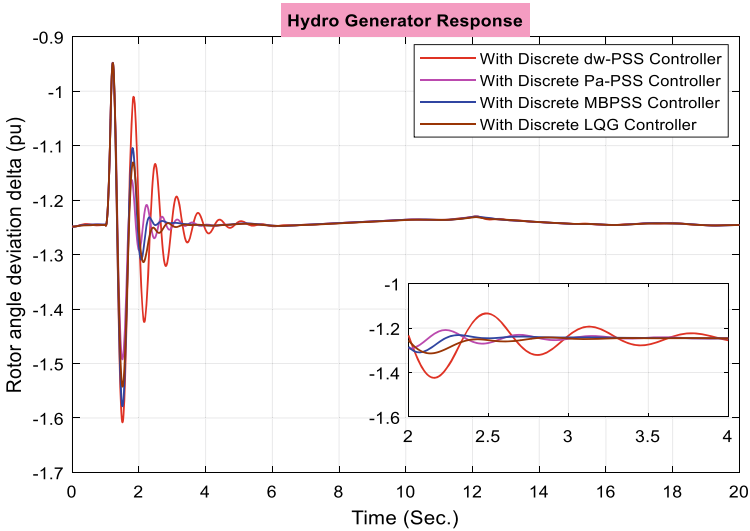


Fig. 14 Rotor angle deviation $\Delta\delta$ (rad) of hydro generator

multi-band PSS4B (MBPSS-4B), and robust LQG controller at an optimum sampling frequency ($T = 0.04$ s) executed on the distributed generators of the AC microgrid. Therefore examined and compared the performance of controllers with the disturbances and their effect to increase the dynamic small signal stability. The attained

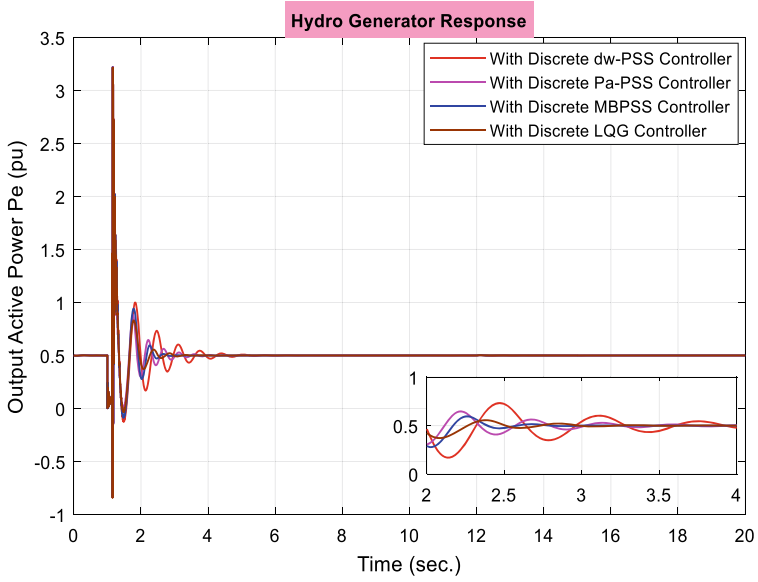


Fig. 15 Output active power (P_e) of hydro generator (pu)

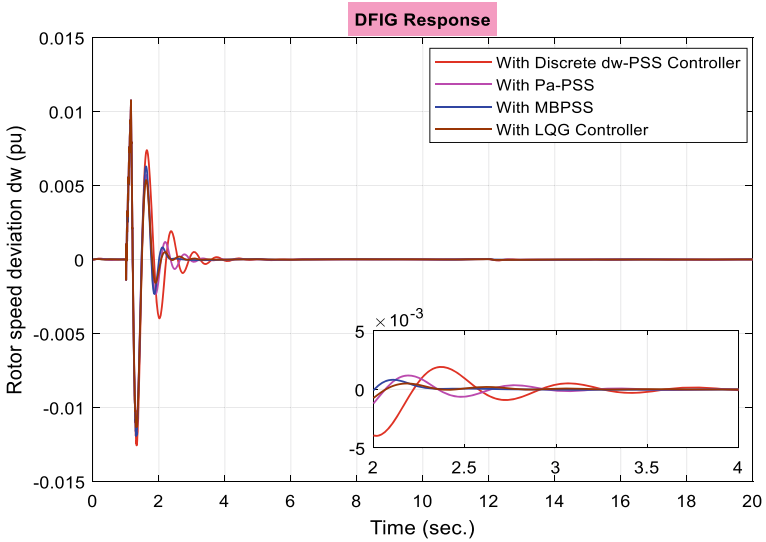


Fig. 16 Rotor speed deviation $\Delta\omega$ (pu) of DFIG-based wind farm

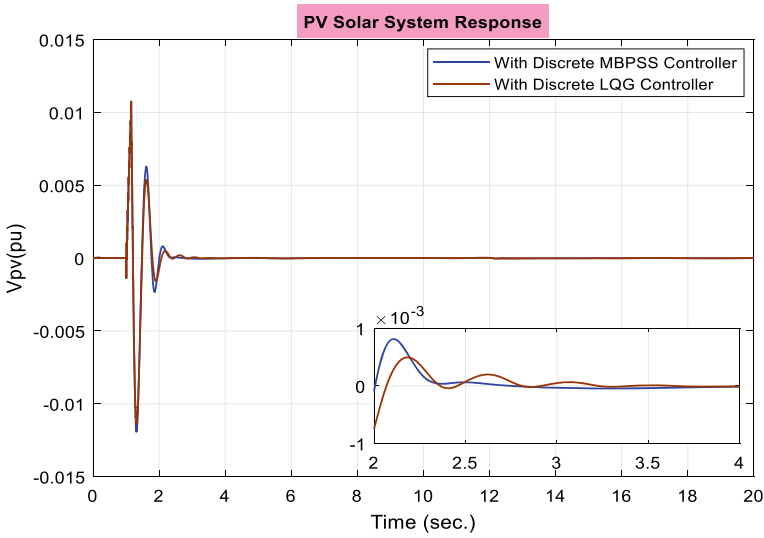


Fig. 17 PCC PV voltage (pu) of PV solar farm

responses of the DGs of the AC microgrid appear that the discrete time domain LQG controller is the more robust damping controller for dampening the low-frequency oscillations in a shorter settling time compared with the discrete conventional PSSs and discrete multi-band PSS4B (MBPSS-4B). Overall, we examined the performance of controllers in discrete time domain mode where the sampling frequency is considered 25 Hz ($T = 0.04$ s), the performance shows that discrete time domain LQG is the most robust power oscillations damping controller to improve the dynamic small signal stability and damp the low-frequency electromechanical oscillations of the system in shorter settling time. This research work can be extended further for the implementation of all considered discrete types of controllers that can be used to investigate the performance of islanded mode AC microgrid.

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