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Research Article

Power Quality and Stability Analysis of a Renewable Micro Grid Using Small-Signal Stability Analysis with PQ Based Artificial Neural Network Control Scheme

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ARTICLE INFO	ABSTRACT

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Micro grids (MGs), comprising diverse micro sources like solar PV, wind generating system, Battery energy storage system power electronics, and constant power loads (CPLs), faces stability challenges. Stability analysis is vital during both design and operation. This paper explores a modelling method for CPLs in AC systems. A small-signal state-space model (SSM) of a micro grid is developed, including sub-models for the power controller and network/loads. The model is simulated to investigate PID, artificial neural network (ANN) and P-Q ANN controllers. The study examines the impact of factors such as P-Q gains, CPLs, and line impedance on micro grid stability. A model of an islanded micro grid in MATLAB/SIMULINK is developed and simulated for different time spans. Different case studies like power quality issues, constant power load and irradiance variations are investigated. Finally the Eigen value analysis is done in this work.

Keywords: Power Quality Issues, Micro Grid (MGs), Renewable Energy Sources (RES) and P-Q control and PID

INTRODUCTION

Microgrids are self-contained power systems that combine various local generations, like solar PVs, wind turbines, with smart controls and loads. They can operate in two ways Connected to the main grid (Supplying power and receiving backup when needed) and Islanded mode (Operating independently, ideal for remote areas or during outages)[1]. The growth of renewable energy, leads to be used in Micro Grids as distributed generations (DGs). The MG is used in various parts of power system, which provides clean and zero emission energy[2] .In a micro grid, numerous power electronic converters are employed. Typically, PQ control is used to regulate the inverter voltage and frequency [3]. Small signal stability (SSS) is a key fact in both the design and operation and stability analysis of micro grids. Existing research has consistently highlighted the significant impact of system parameters, particularly constant power loads (CPLs), on the stability of micro grids [4]. Reference [5] presents that the PQ gains are key factors to damped out the micro Grid stability. However, the analysis does not explore the impact of loads on stability. The SSM for a micro grid is investigated the relation between micro grid stability and both controller parameters and loads [6]. A new control strategy is suggested to enhance the transient response of inverters and selection of P-Q gains for stability analysis. The optimal P-Q control problem for grid-connected inverters in a micro grid is framed as a constrained optimization task. Six parameters of three decoupled PI controllers are treated as decision variables. The objective function minimizes the integral time absolute error (ITAE) between the output and the reference active power, as well as the ITAE for reactive power [7]. The study [] concludes that the deep learning model, an Artificial Neural Network (ANN) optimized with the Adam optimizer, outperforms other models. The ANN achieves an accuracy of 97.27%, precision of 96.79%, recall of 95.67%, and an F1 score of 96.22% and provides superior stability to the Micro Grid. This study in [] employs an Artificial Neural Network (ANN) to train and predict the nodal voltage levels of the IEEE 4-bus system. Four distinct models were proposed to validate the effectiveness of the ANN approach and demonstrate that the ensemble of these models outperforms other models in predicting nodal voltage stability. The ensemble model achieved the highest accuracy rate of 98.73%, showing its superior performance in forecasting the stability of the electrical system. The above literatures have

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not discussed about the constraints in PID controllers like Complex tuning, often requiring trial-and-error or expertise. Improper tuning can cause instability or overshooting. The researchers have overcame these challenges by using artificial neural networks. However the Artificial Neural Networks (ANNs) can be computationally intensive, requiring significant processing power and time for training, especially with large datasets. They are also prone to over fitting if not properly regularized. Additionally, ANNs lack interpretability, making it difficult to understand how decisions or predictions are made, limiting their practical application. To overcome the above challenges, in this paper, P-Q based ANN has been investigated in a renewable source base Micro Grid as shown in figure-1. The proposed approach followed by SSS state-space model of the micro grid model which consists of a power controller sub-model, a CPL sub-model, and a network and loads sub-model. Finally, a MATLAB /Simulink model of a micro grid is developed to validate the performance of a proposed controller.

After a brief introduction the paper is organized as mentioned. The construction and operation of Micro Grid is discussed in second section. Section -3 presents small signal state space model of the renewable source based Micro Grid. Section-4 explains the various controllers used in this work. Simulation results are presented in section-4 and conclusions are drawn in section 6.

MICROGRID OPERATING IN PQ CONTROL MODE

The microgrid depicted in Figure 1 is considered for investigation for investigation of the proposed controllers. Both AC and DC buses are present in the considered MG. the AC bus is integrated with the renewable based DGs and three phase loads. Similarly the storage systems and DC loads are connected to the DC bus. An intelligent switches are present at the Point of Common Coupling (PCC), connecting the AC/DC bus to the power system. In islanding mode, two strategies are commonly used to control the inverters and PQ control mode. In the PQ mode, the inverters in the microgrid are divided into two groups, master and slave inverters. The master inverters works as voltage sources to maintain the AC voltage of the microgrid, while the slave inverters act as current sources to supply active power to the grid. In PQ control mode, no communication line is required between the inverters. Active and reactive power sharing is achieved by adjusting the magnitude and frequency of the output voltage, allowing for average power sharing. The micro grid is investigated using PQ control mode.

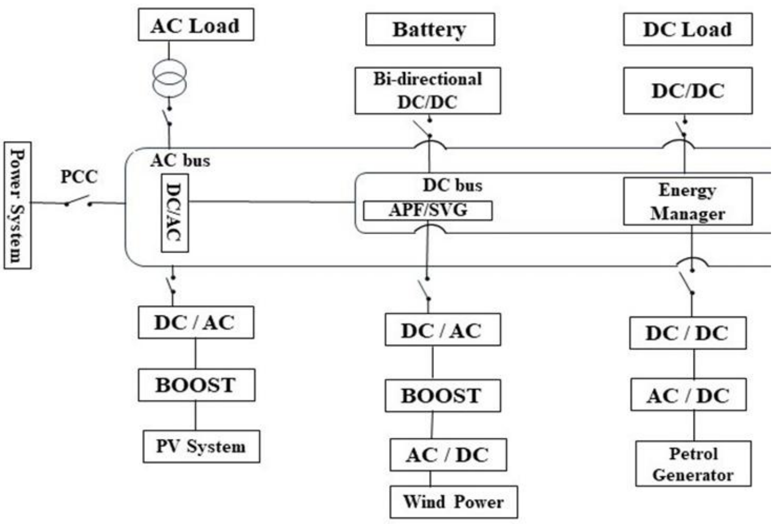

Figure 1. The structure of micro grid

PROPESED CONTROLLERS

Controllers are essential in micro grids to ensure stable and efficient operation. They regulate key parameters like voltage, frequency, and power flow, ensuring synchronization with the grid or smooth operation in island mode. Controllers help balance power supply and demand, particularly when integrating renewable energy sources, which can be intermittent. They also manage the dynamic response to load changes and disturbances, preventing system instability. Additionally, controllers optimize energy storage, improve power quality, and enhance the overall

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reliability and resilience of the micro grid, ensuring that it meets both local demand and regulatory requirements effectively. In this work three controllers like PID, artificial neural network (ANN) and P-Q based ANN are investigated for stability and power quality of a renewable based Micro Grid.

PID Controller

In micro grid inverters, PID control manages output voltage and frequency to maintain system stability. The proportional component addresses immediate errors, the integral component compensates for long-term steady-state errors, and the derivative component anticipates and corrects rapid fluctuations. This control mechanism helps regulate power during load variations, maximizes the use of renewable energy, and ensures synchronization with the grid. By continuously adjusting the inverter's output, the PID controller ensures voltage and frequency remain within optimal ranges, preventing disruptions and promoting efficient power flow. It improves the overall stability, performance, and reliability of the micro grid, especially during changes in load or renewable energy availability.

$$u(t) = k_p e(\tau) + k_i \int_0^t e(\tau) + k_d \frac{de(\tau)}{dt}$$

Where $e(\tau) = v_{invref} - v_{inv}$

k_p, k_i, k_d are the PID gains

ANN Controller

Artificial Neural Networks (ANNs) can be effectively applied for inverter control in a micro grid, where they learn and adapt to control the inverter's output voltage and current for optimal performance. In such systems, the ANN uses inverter voltage and current as inputs to predict the required control signals for adjusting the inverter's operation, ensuring stable power generation and distribution. The ANN typically consists of input layers, hidden layers, and an output layer. The inputs are the measured inverter voltage v_{inv} and current i_{inv}, while the output is the control signal $u(t)$ that adjusts the inverter's operation. The network learns the relationship between input variables and the control actions through training on real or simulated data.

The mathematical expression for an ANN-based controller is:

$$u(t) = f\left(\sum_{i=1}^{n} w_i . x_i + b\right)$$

Where $u(t)$ = controller output

$$x_i = \begin{bmatrix} v_{inv} \\ i_{inv} \end{bmatrix} = \text{Input to the neural network}$$

w_i, b are the weights and bias associated with each input.

The ANN adjusts the inverter's parameters based on the learned weights to minimize error, ensuring voltage and current stay within desired limits and adapting to changing load or renewable generation conditions.

The PQ Control for MG Inverter

In an islanded MG operation with PQ control, the inverter's control scheme mimics the that of a synchronous machine integrated with grid. This regulates active power by frequency adjustment and the reactive power and output voltage adjustment.

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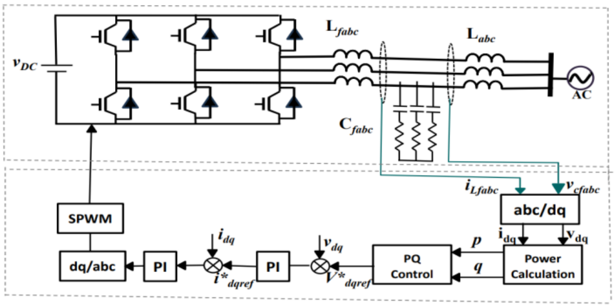

Figure 2. The schematic of PQ control

The P-Q control shame of the inverter is designed as following. The voltage regulation is set by PQ gain m, and n, which can be defined as:

$$\omega = \omega_n - mP \quad (1)$$

$$V = V_n - nQ \quad (2)$$

Where ω_n and v_n are the frequency and voltage. The power calculation block of the inverter can calculate the active power (P) and reactive power (Q), which are defined by (3) and (4):

$$p = V_d i_d + V_q i_q \quad (3)$$

$$q = V_d i_q + V_q i_d \quad (4)$$

$$v(t) = v_n - n\frac{1}{s}q(t) \quad (5)$$

THE SMALL-SIGNAL STATE SPACE MODEL OF MICROGRID

The MG stability is analyzed by developing a small signal state space model. The equivalent circuit model is presented in figure 3. The equivalent model contains three inverters with their internal components. Assuming that all inverters are stable and maintain their output rated voltage and current. The SSSS model of the islanded micro grid is established, comprising three sub-models that is a power controller sub-model, a coupling transformer sub-model, and a network and loads sub-model.

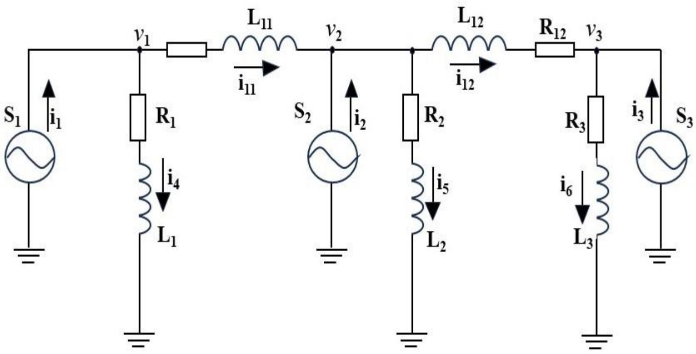

Figure 3. Equivalent model of MG

Power Controller Model

The power control is presented in figure-1. Here the magnitude of reference voltage and it's frequency can be expressed by the nonlinear equations (6) and (7). These equations can be expanded using a Taylor series, resulting in a linear equation in the time domain.

$$\Delta f(t) = -f_c - \frac{d}{dx}f_x \quad (6)$$

$$\Delta v(t) = -X_c\Delta v - nX_c\Delta q \quad (7)$$

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If f_{com} is compensated frequency., the power angle δ can be expressed in (8) and (9)

$$\delta = \int (f - f_{com}) dt \quad (8)$$

And then:

$$\delta = tan^{-1}(\frac{v_q}{v_d}) \quad (9)$$

The linear form of equation (8) can be expressed by:

$$\Delta\delta = k_d \Delta v_d + k_q \Delta v \quad (10)$$

Where, $k_d = \frac{\partial f}{\partial v_d} |V_{d0} = \frac{V_{q0}}{{V_{d0}}^2 + {V_{q0}}^2}$

$$kq = \frac{\partial f}{\partial v_q} |V_{q0} = \frac{V_{d0}}{{V_{d0}}^2 + {V_{q0}}^2}$$

It is known that $\Delta f(t) = s\Delta\, tan^{-1}(\frac{v_q}{v_d})(s)$, and then we can obtain that:

$$\Delta f = k_d \Delta v_d - k_q \Delta v_q \quad (11)$$

Considering that;

$$v = \sqrt{{v_d}^2 + {v_q}^2} \quad (12)$$

After the linearity, we can obtain that:

$$\Delta v = r_d \Delta v_d + r_q \Delta v_q \quad (13)$$

Considering the equation above, a matrix can be obtained:

$$\begin{bmatrix} \Delta i_{di} \\ \Delta i_{qi} \end{bmatrix} = [A_{INVi}] \begin{bmatrix} \Delta i_{di} \\ \Delta i_{qi} \end{bmatrix} + [A_{INVi}] \begin{bmatrix} \Delta p_i \\ \Delta q_i \end{bmatrix} \quad (14)$$

Where, $[A_{INVi}] = \begin{bmatrix} -1 & 0 & 0 \\ \frac{r_{qi}}{k_{di}r_{qi} - k_{qi}r_{di}} & \frac{k_{qi}r_{di}}{k_{di}r_{qi} - k_{qi}r_{di}} & \frac{k_{qi}r_{qi}}{k_{di}r_{qi} - k_{qi}r_{di}} \\ \frac{r_{di}}{k_{qi}r_{di} - k_{di}r_{qi}} & \frac{k_{di}r_{di}}{k_{qi}r_{di} - k_{di}r_{qi}} & \frac{k_{di}r_{di}}{k_{qi}r_{di} - k_{di}r_{qi}} \end{bmatrix}$

$$[B_{INVi}] = \begin{bmatrix} & 0 \\ -m & \frac{nk_{qi}}{k_{di}r_{qi} - k_{qi}r_{di}} \\ 0 & \\ 0 & \frac{nk_{di}}{k_{qi}r_{di} - k_{di}r_{qi}} \end{bmatrix}$$

The linear form of equation (3) & (4) can be written as:

$$\begin{bmatrix} \Delta p_i \\ \Delta q_i \end{bmatrix} = [I_{si}] \begin{bmatrix} \Delta v_{di} \\ \Delta v_{qi} \end{bmatrix} + [V_{si}] \begin{bmatrix} \Delta i_{di} \\ \Delta i_{qi} \end{bmatrix} \quad (15)$$

Where, $[I_{si}] = \begin{bmatrix} i_{di0} & i_{qi0} \\ i_{qi0} & -i_{di0} \end{bmatrix}$, $[V_{si}] = \begin{bmatrix} v_{di0} & v_{qi0} \\ -v_{qi0} & v_{di0} \end{bmatrix}$

Using equation (14) in (15), we can obtain that:

$$\begin{bmatrix} \Delta i_{di} \\ \Delta i_{qi} \end{bmatrix} = [A_{INVi}] \begin{bmatrix} \Delta i_{di} \\ \Delta i_{qi} \end{bmatrix} + [B_{INVi}][I_{si}] \begin{bmatrix} \Delta v_{di} \\ \Delta v_{qi} \end{bmatrix} + [B_{INVi}][V_{si}] \begin{bmatrix} \Delta i_{di} \\ \Delta i_{qi} \end{bmatrix} \quad (16)$$

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Constant Power Loads Model

DC loads are integrated to the MG through rectifiers. These rectifiers provides the negative impedance characteristics of the constant power loads (CPLs).

These can be treated as typical CPLs in the AC system. As discussed in literature small worries in voltage and current imply certain behaviours.

$$\frac{\tilde{V}}{\tilde{I}} = -\frac{V}{I} = -|Z_{CPL}| \quad (17)$$

Where V and I are the peak values.

$|Z_{CPL}|$ is expressed by (18)

$$|Z_{CPL}| = \frac{V}{I} = \frac{V_r}{I_r} = \frac{{V_r}^2}{P} \cos\alpha \quad (18)$$

Where Vr and Ir are RMS values, and α is the phase difference, which can be considered as zero for high rectifier pf. Nevertheless in case of low pf, cannot be ignored.

The equivalent model parameters are calculated by:

$$|R_{CPL}| = -|Z_{CPL}| \cos\alpha \quad (19)$$

$$|L_{CPL}| = \frac{|Z_{CPL}| \sin\alpha}{\omega} \quad (20)$$

A. Network and loads Model

The state space model can be developed using nodal admittance matrix as per figure-3.

$$Y_{ij} = G_{ij} + jB_{ij} \quad (21)$$

The SSSS model of network and can be written as:

$$[\Delta i_{dq}] = [Y_{ij}][\Delta v_{dq}] \quad (22)$$

$$\text{Where, } [Y_{ij}] = \begin{bmatrix} G_{11} & -B_{11} & G_{12} & -B_{12} & G_{13} & -B_{13} \\ B_{11} & G_{11} & B_{12} & G_{12} & B_{13} & G_{13} \\ G_{21} & -B_{21} & G_{22} & -B_{22} & G_{23} & -B_{23} \\ B_{21} & G_{21} & B_{22} & G_{22} & B_{23} & G_{23} \\ G_{31} & -B_{31} & G_{32} & -B_{32} & G_{33} & -B_{33} \\ B_{31} & G_{31} & B_{32} & G_{32} & B_{33} & G_{33} \end{bmatrix}$$

The Small-Signal State Space model of Microgrid

The micro Grid SSSS model is designed as following

$$\begin{bmatrix} \Delta v_{di} \\ \Delta v_{qi} \end{bmatrix} = [C] \begin{bmatrix} \Delta v_{di} \\ \Delta v_{qi} \end{bmatrix} \quad (23)$$

$$\text{Where, } [C] = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Using equation (23)

$$\begin{bmatrix} \Delta v_{di} \\ \Delta v_{qi} \end{bmatrix} = [A] \begin{bmatrix} \Delta v_{di} \\ \Delta v_{qi} \end{bmatrix} \quad (24)$$

$$\text{Where } [A] = [A_{INVi}] + [B_{INVi}]\left([I_{si}] + [V_{si}][Y_{ij}]\right)[C] \quad (25)$$

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SIMULATION VALIDATION

The result analysis of the renewable micro grid's power quality and stability using small-signal stability analysis and a PQ-based Artificial Neural Network (ANN) control scheme indicates significant improvements in both. The small-signal analysis reveals the system's stability margins, identifying potential resonance issues and damping requirements. By incorporating the ANN control scheme, the micro grid demonstrated enhanced dynamic response and optimal power flow, reducing voltage fluctuations and frequency deviations. The ANN-based control effectively stabilized the micro grid, ensuring reliable operation under varying load conditions and enhancing overall power quality, thus contributing to a robust and efficient renewable energy integration.

PQ Management using Artificial Neural Networks (ANNs)

In micro grids, maintaining (PQ) is critical, as disturbances such as voltage sags, harmonics, frequency deviations, and transients can degrade the performance of sensitive equipment. The integration of renewable energy sources and energy storage systems further complicates PQ management due to their intermittent and variable nature. Artificial Neural Networks (ANNs) have emerged as an effective tool for monitoring, predicting, and mitigating these disturbances in micro grid environments. ANNs are computational models inspired by biological neural networks, composed of layers of interconnected neurons: an input layer, one or more hidden layers, and an output layer. For PQ applications in micro grids, ANNs can process real-time voltage, current, and frequency data to classify disturbances or predict future PQ behaviour based on historical data. A common architecture used in power quality analysis is the Feed forward Neural Network (FNN), which is trained to map the input features to the desired output, such as the type of disturbance. Each neuron in the hidden layers computes a weighted sum of its inputs, followed by an activation function, and the final output is calculated from the last layer. The output yk of the k-th neuron in the output layer is given by:

$$y_k = f\left(\sum_{i=1}^{m} w_{ki}\, a_i + b_k\right)$$

where w_{ki} represents the weight connecting the i-th neuron in the hidden layer to the k-th output neuron, a_i is the output of the i-th hidden layer neuron, b_k is the bias term, and f (·) is the activation function (such as sigmoid, tanh, or ReLU). The training of the network involves adjusting the weights and biases using supervised learning techniques like backpropagation to minimize the error between predicted and actual outputs. Once trained, the ANN can detect, classify, and predict PQ disturbances in real-time. Additionally, ANNs can optimize control strategies in the microgrid, such as dynamic voltage regulation or harmonic compensation, ensuring stable and high-quality power delivery. The ability of ANNs to handle nonlinearities and learn from large datasets makes them an ideal solution for power quality monitoring and improvement in micro grid systems.

Case-1: Voltage Swell

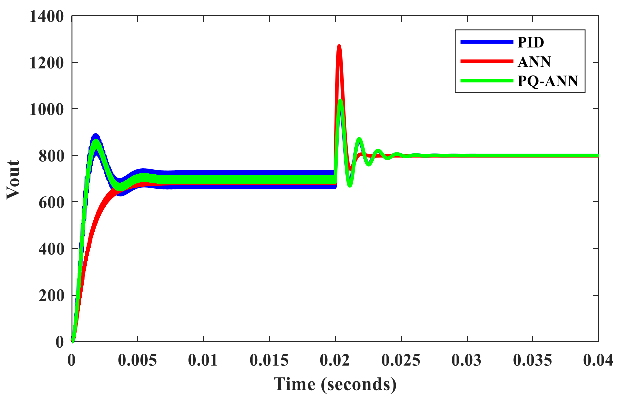

Figure 4. Output Voltage of DC/DC Converter

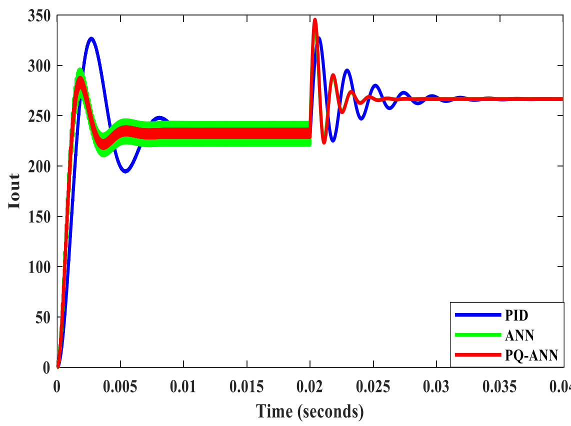

Figure 5. Output Current of DC/DC Converter

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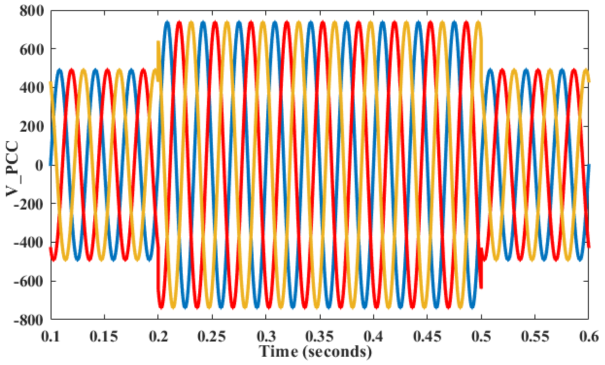

Figure 6. Inverter Voltage during Swell for PID Controller

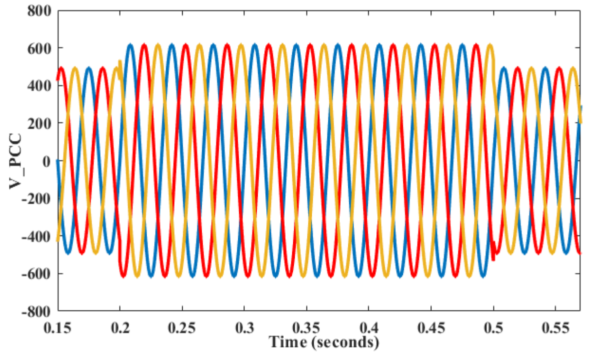

Figure 7. Inverter Voltage during Swell for ANN Controller

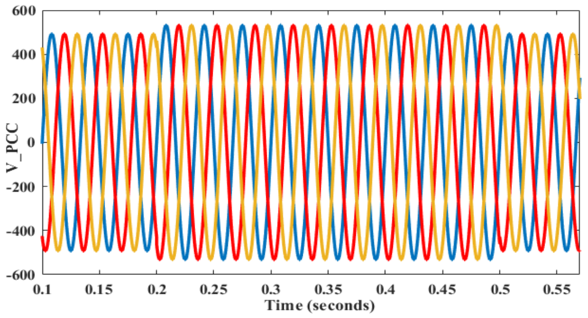

Figure 8. Inverter Voltage during swell for PQ-ANN Controller

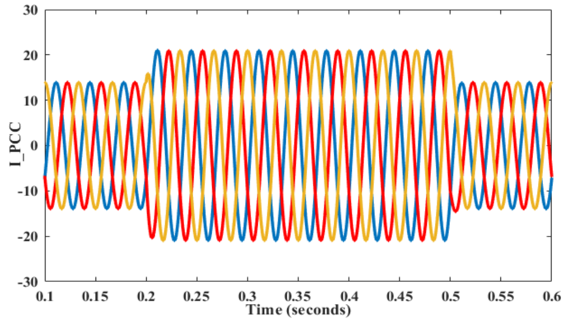

Figure 9. Inverter Current during Swell for PID Controller

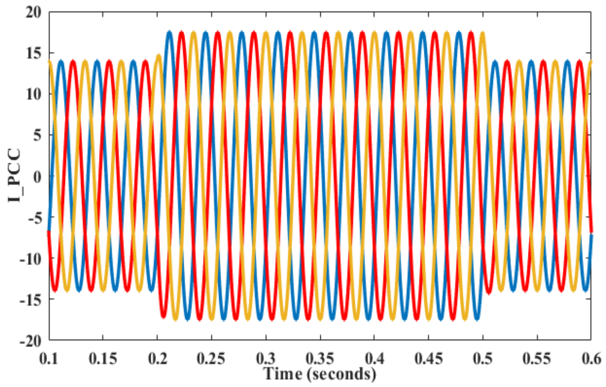

Figure 10. Inverter Current during Swell for ANN Controller

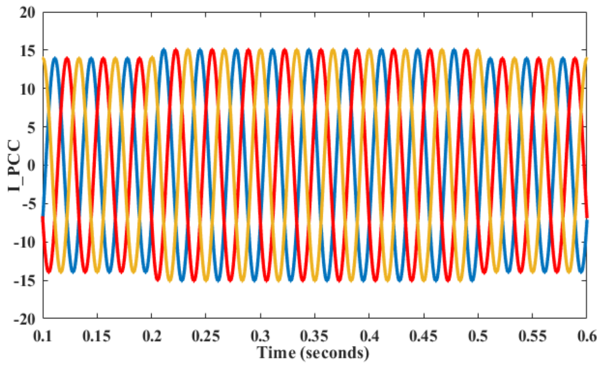

Figure 11. Inverter Current during Swell for PQ-ANN Controller

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Case-2 Voltage Sag

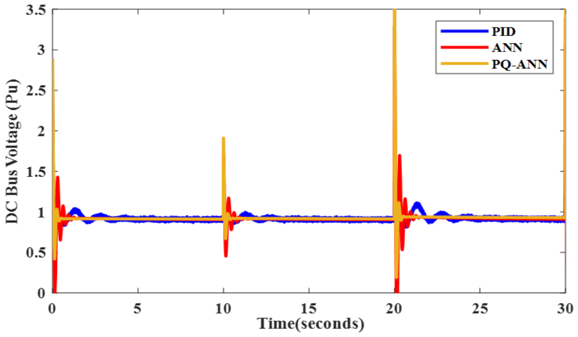

Figure 12. Output Voltage of DC/DC Converter

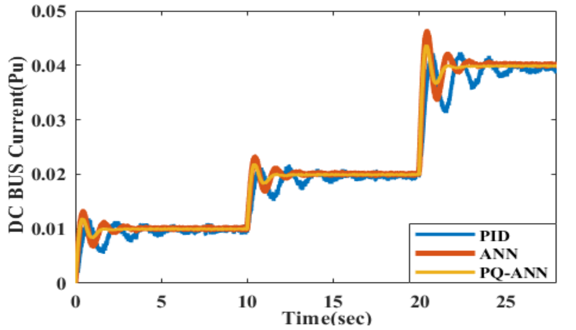

Figure 13. Output Current of DC/DC Converter

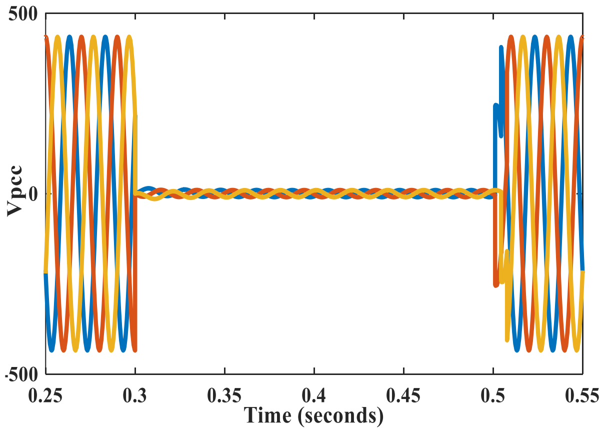

Figure 14. Inverter Voltage during Sag for PID Controller

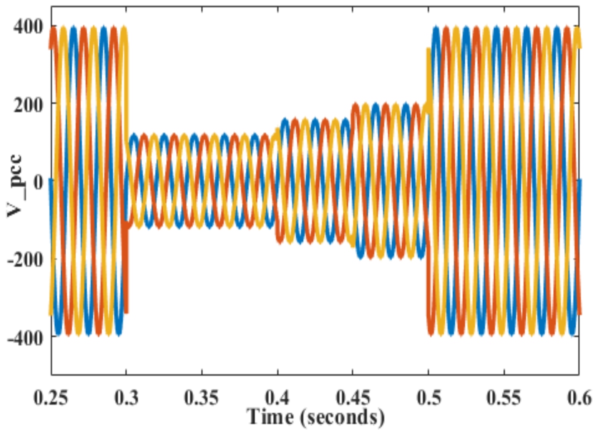

Figure 15. Inverter Voltage during Sag for ANN Controller

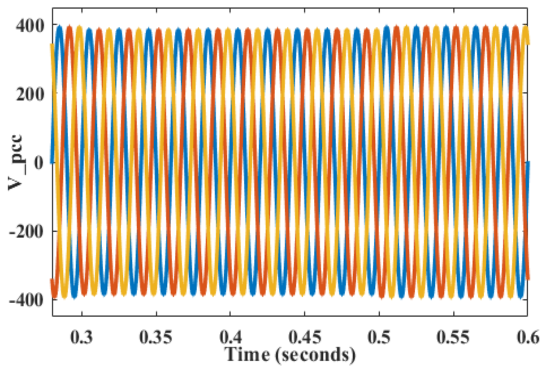

Figure 16. Inverter Voltage during sag for PQ-ANN Controller

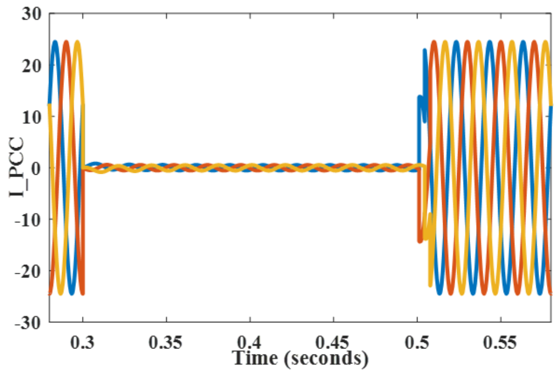

Figure 17. Inverter Current during Sag for PID Controller

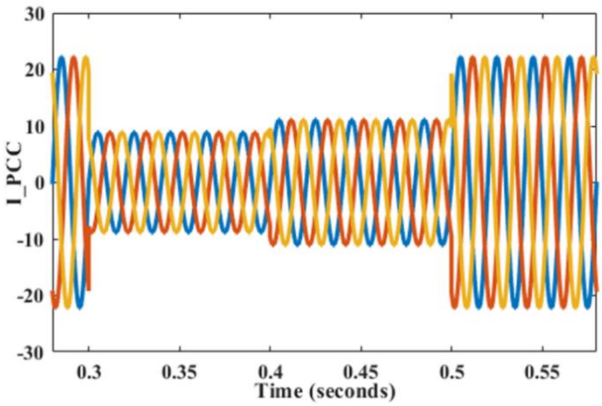

Figure 18. Inverter Current during Sag for ANN Controller

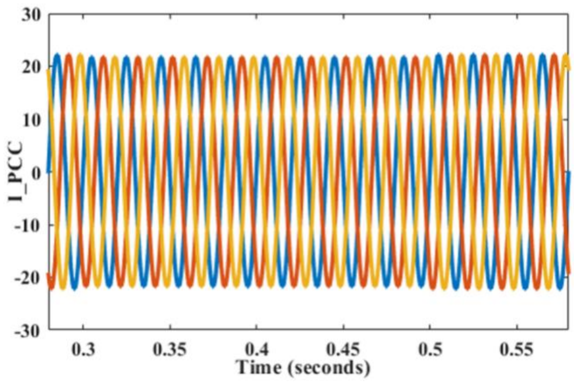

Figure 19. Inverter Current during Sag for PQ-ANN Controller

Case: 3 (Change in Constant Power Load)

In a DC micro grid, constant power load (CPL) represents a type of load where the power demand remains unchanged despite variations in voltage or current. CPLs introduce a negative incremental impedance characteristic, which can lead to system instability, particularly under fluctuating load conditions. The study highlights that the DC microgrid faces instability due to uncertainties in load variations, a challenge exacerbated by CPL dynamics. Figure 20 presents the DC bus voltage response over T=1s, T = 10s, T=20s with three variations at 10s intervals. Under CPL conditions, voltage stability is critical, as any deviation may result in system-wide disturbances. The Conventional PID exhibits six cycles of oscillations, while the ANN reduces this to three cycles. In contrast, the proposed controller demonstrates exceptional stability by mitigating voltage oscillations more efficiently. The simulation results confirm that the proposed controller offers superior stability, efficiency, and robustness compared to conventional control methods. Figure 21 depicts the DC bus current adapting to the load demand over a time frame of T=1s, T = 10s, T=20s with three variations at 10s intervals. In a system with CPLs, maintaining stability is crucial as abrupt load changes can lead to significant voltage oscillations. The results indicate that undammed oscillations persist for three cycles in the ANN controller and five cycles in the Conventional PID controller. However, the proposed controller effectively suppresses these oscillations within half a cycle, showcasing its robustness in CPL environments. Figure 22 illustrates the DC bus output power, reaffirming the proposed controller's superiority in ensuring a stable power supply despite CPL-induced fluctuations. Lastly, Figure 23 analyses power loss, a crucial factor for microgrid reliability. Even minor power losses in CPL scenarios can significantly impact system stability. The study investigates the proposed controller's effectiveness in counteracting disturbances caused by power losses, demonstrating its ability to enhance microgrid resilience.

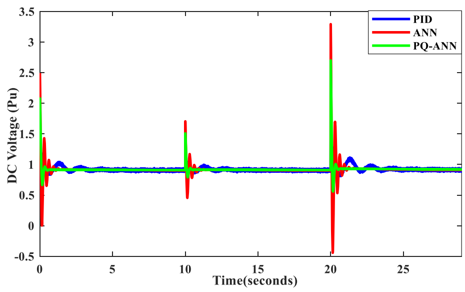

Figure 20. Output Voltage of DC/DC Converter during constant power Load

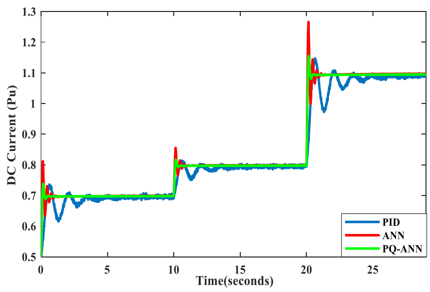

Figure 21. Output Current of DC/DC Converter during constant power Load

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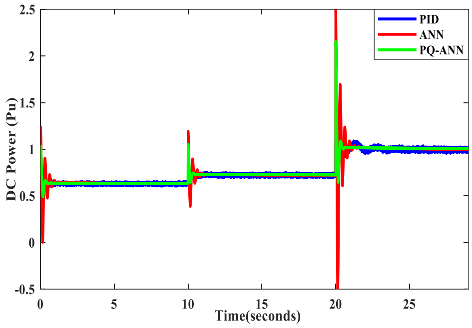

Figure 22. DC Power during constant power Load

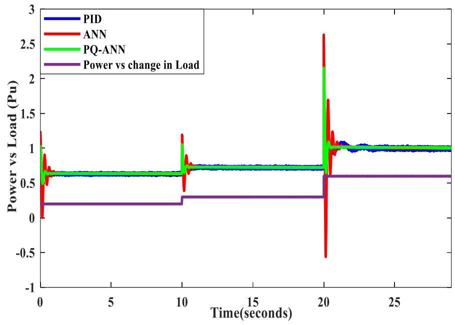

Figure 23. Change in Power with respect to Load

C. Total Harmonic Distortion (THD) for Proposed Controller during Sag & Swell

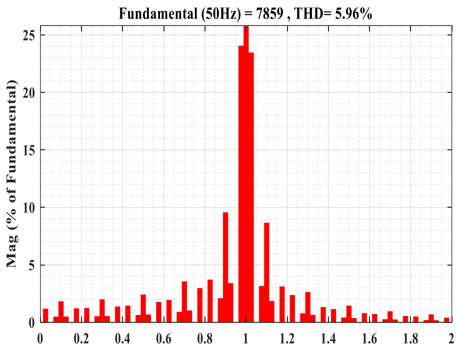

Figure 24. THD of PCC voltage during SAG for PID controller

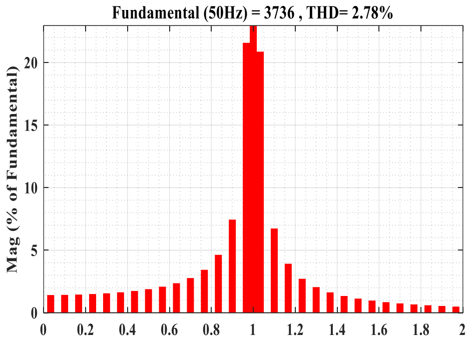

Figure 25. THD of PCC voltage during SAG for ANN controller

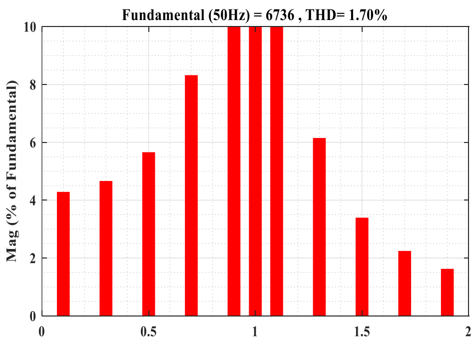

Figure 26. THD of PCC voltage during SAG for PQ-ANN controller

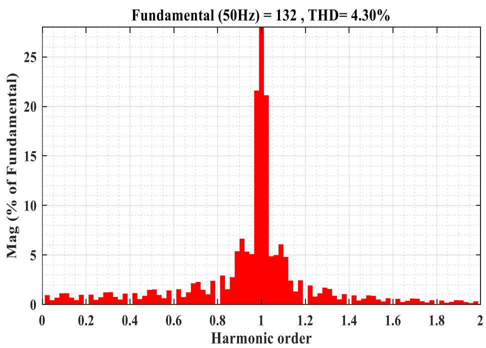

Figure 27. THD of PCC voltage during SWELL for PID controller

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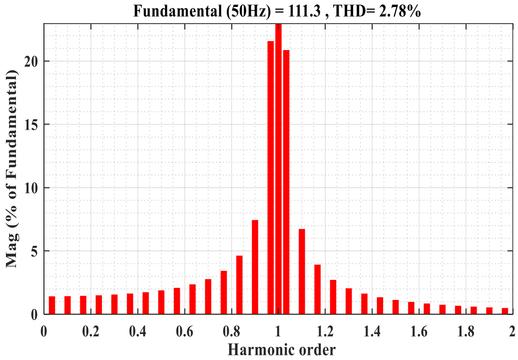

Figure 28 THD of PCC voltage during SWELL for ANN controller

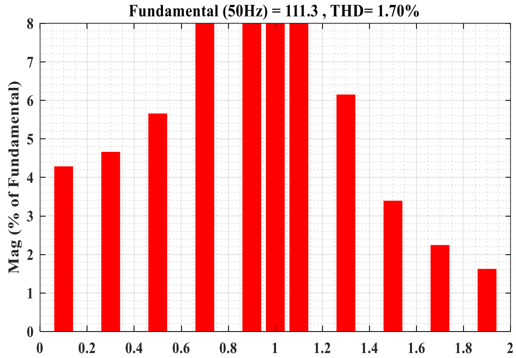

Figure 29. THD of PCC voltage during SWELL for PQ-ANN controller

CONCLUSION

This paper explores the small-signal stability analysis of a renewable micro grid, focusing on constant power loads (CPLs), power quality (PQ) issues, and improved stability. The integration of a PQ-based Artificial Neural Network (ANN) control scheme demonstrates its effectiveness in managing stability and enhancing power quality. The analysis reveals that micro grid stability is significantly influenced by factors such as PQ gain, CPL percentage, and line impedance. By controlling these parameters, stability issues, such as voltage fluctuations and frequency deviations, can be mitigated. Time-domain simulations in MATLAB further validate the proposed control scheme, showing superior performance in handling power quality disturbances compared to traditional methods, thus ensuring a reliable and efficient renewable energy integration into micro grids.

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APPENDIX

SYSTEM COMPONENTS	VALUES
PV	V_o=60, R_1+R_2=1.4Ω,R_3=1.06,C=1.25F
Boost	L= 0.5mH, C=100 µF, Fs=20KHz, V_o=500, V_{in}=60V
MLI	IGBTs=14, Gate Driver Circuit =11 V_{OUT}= 500 V
Transmission Line Parameters	Resistance= 0.01755Ω, Inductance= 0.8737e-3H,
Grid	V=600, X/R=9, F=50Hz

Controllers Parameters	PQ-ANN			ANN			PID		
	Kp	Ki	Kd	Kp	Ki	Kd	Kp	Ki	Kd
PV Voltage	0.23	0.17	0.58	1.14	1.112	1.43	2.13	2.58	2.75
GRID Voltage	0.34	0.19	0.68	1.6	1.9	1.50	2.32	3.9	3.56