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Research Article

Dg With Reduced Upfc In Micro Grids Using Lcl Plus Nonlinear Optimal Control For Stability Improvement

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Abstract—

This research presents a new method to improve the ability of small-scale microgrids to maintain stability during temporary disturbances. This is achieved by combining a simplified Unified Power Flow Controller (UPFC) configuration with a low-pass filter (LCL) in the Distributed Generation (DG) unit. The DG unit consists of a Photovoltaic (PV) system that is linked to the grid via a dc-dc buck converter and inverter. The dc-dc converter ensures a consistent output voltage that is linked to the inverter, which produces the necessary ac voltage to power the grid. The downsized Unified Power Flow Controller (UPFC) with a Low Capacitance-Inductance (LCL) filter utilizes the Direct Current (DC) connection of the Distributed Generation (DG) unit to generate an appropriate series voltage. This voltage is then injected into the power line to enhance transient stability. In order to get the highest level of system stability while minimizing expenses, a nonlinear discrete-time Hamilton-Jacobi-Bellman (HJB) optimal control approach is used. The control strategy is specifically developed to optimize the functioning of the microgrid, with the primary goal of decreasing the total cost associated with stability improvement. The cost function is estimated by using a Neural Network that utilizes the weighted residual approach. The simulation results confirm the efficacy of the suggested model and control method. The integration of the DG unit, LCL, and UPFC architecture exhibits exceptional efficacy in attenuating oscillations within the system. This study adds to the progress in comprehending and using decreased UPFC structures in microgrid setups, presenting a feasible approach to achieve improved stability and dependability in distributed power systems.

Keywords— microgrid stability, Unified Power Flow Controller, low-pass filter, Distributed Generation, Photovoltaic, dc-dc buck converter, inverter, Hamilton-Jacobi-Bellman optimal control, Neural Network, stability improvement.

I. INTRODUCTION

Microgrids have evolved as an innovative solution in the field of electrical power systems to tackle the issues presented by the growing energy demand and the need for a more robust and environmentally friendly power infrastructure [1]. The stability of microgrids, which are self-contained energy systems operating independently, is a crucial aspect in guaranteeing their efficient and dependable functioning. In recent years [2], scientists and engineers have explored many techniques to improve the stability of microgrids. One such way that has attracted interest is the use of a unique reduced UPFC design with nonlinear optimum control [3]. In order to grasp the importance of this innovative method, it is crucial to examine the historical backdrop of power systems and the development of microgrid technology.
Conventional power systems [4] functioned within a centralized framework, whereby large power plants produced energy that was then transferred across extensive distances to consumers. Although this paradigm was effective for a long time, it became evident that it had drawbacks in terms of efficiency, resilience, and environmental sustainability [5]. In response to these issues, the notion of

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microgrids arose as a significant change in the way energy production is organized, moving towards a decentralized and distributed approach [6].

The inception of microgrids may be attributed to the latter part of the 20th century, when there was a surge in progress in renewable energy technology, including solar and wind power [7]. These technologies enabled the production of energy on a smaller scale, often at the location where it is used, thereby decreasing the need on centralized power facilities. The use of energy storage technologies also enhanced the capacity of microgrids to function autonomously or in tandem with the main power grid. Nevertheless, with the increasing prevalence of microgrids, the issue of stability has arisen as a crucial problem [8]. Microgrids are inherently vulnerable to swings and disruptions caused by the unpredictability of renewable energy sources and the dynamic nature of localized energy demand. This led researchers to investigate novel strategies to improve the stability of microgrids and assure their smooth integration into the larger power system. The UPFC has emerged as a very promising technology for enhancing power system stability.

The historical progression of power systems and microgrid development demonstrates a persistent endeavor to surmount obstacles and enhance the effectiveness of energy production and delivery. The Reduced UPFC structure achieved by Nonlinear Optimal Control is the result of extensive study and technical progress over many decades [9]. The remarkable feature of this methodology is its use of nonlinear optimum control, which represents a break from conventional linear control techniques and instead adopts a more sophisticated and adaptable strategy.

II. LITERATURE SURVEY

The FLC was suggested by the authors in [10] for the MPPT control of solar PV in an AC-MG. The purpose of the research was to investigate ways to improve the performance of PV systems in a variety of partly shaded environments. To determine whether the newly designed controller is successful, the simulated as well as the experimental data were evaluated. Another noteworthy piece of research work relevant to FLC-based MPPT was carried out in [11], where the authors presented an adaptive FLC for the purpose of accomplishing MPPT of an AC-MG-tied solar PV system. According to the findings, the adaptive FLC-based MPPT controller can extract a bigger quantity of power. This is possible due to the controller's higher power factor. Here, the FLC was applied by the authors of [12] to optimize the parameters of a UPQC for the purpose of enhancing the voltage profile of an AC-MG system. When it came to reducing voltage sag and unbalancing, a comparison was made between the efficacy of the suggested controller and its performance and the performance of the standard PI controller.

In [13], the authors created an FLC-based dynamic voltage restorer (DVR) with the goal of removing the voltage sags and swells that occur in grid-connected wind farms because of overloading, underloading, and fault circumstances. To provide a different kind of power to the DVR, the control structure made use of solar photovoltaic panels. In the study work that was described, a DC voltage source was created using a DVR in conjunction with a PV module that had high and low boost power converters. This created an environment that was less susceptible to fluctuations in voltage. In [14], Modified FLC controller is developed, which is dependent on the control rules and membership functions that it has. It is quite difficult to calibrate these characteristics such that they work ideally for the process in which they are being used. Because of this, the controllers in question do not have a enough capacity for learning. As a result of this, the FLC is an awkward controller for the implementation of the MG PQI improvement since the characteristics of DGs and loads are wholly unexpected and dynamic. Utilizing a different CI method to modify the FLC parameters in accordance with the system dynamics is the answer to this issue, which can be found here. As an example, the authors in [15] employed GA, whereas [16] used online PSO, in [17] used BCO, and in [19] used chaotic PSO to adjust FLC in MG controls. In addition to this, the ANN system is also one of the most effective solutions to the difficulties described, as will be shown in the next portion of this article. The authors of [20] added a complementary control loop that was based on radial basis function neural networks (RBFNNs). Multiple renewable energy sources are integrated into one or more loads through non-isolated direct link connection or through time-sharing of devices concept. This was done in addition to the conventional droop control scheme. Because RBFNNs were included into droop control, power calculations were more precise and took less time, resulting in improved MG stability and a higher power-sharing ratio.

III. PROPOSED SYSTEM MODEL

The operational process for the proposed system contains a sequence of interdependent phases. These steps include the use of DG system with a decreased UPFC in microgrids. The system also incorporates an LCL filter and nonlinear optimum control techniques to enhance stability. Every individual element has a crucial function in preserving the stability of the microgrid, guaranteeing effective electricity production, and improving the transient stability via the UPFC. Figure 1 depicts the whole operating process of the proposed system.

First step: Distributed Generation using Photovoltaic Source: The process starts with the DG unit, wherein a PV source functions as the principal energy input. The photovoltaic device captures solar energy and transforms it into DC electricity. The first step is crucial as it signifies the production of environmentally friendly and sustainable energy, in line with the overarching objective of creating sustainable power systems.

Step 2: DC-DC Buck Converter: The DC power produced by the PV source is then sent to the DC-DC Buck Converter. This component is essential for controlling and ensuring a consistent DC voltage at the dc link capacitor. The converter maintains voltage stability, minimizing fluctuations that may occur due to the intermittent nature of solar energy. The regulated DC voltage provides a dependable basis for future activities inside the microgrid.

Step 3: LCL Filter: After the DC-DC conversion, the system includes an LCL filter. The inclusion of this filter is crucial to condition the power output from the DC-DC converter prior to its entry into the inverter. The purpose of the LCL filter is to attenuate harmonics and provide a filtered AC voltage, hence guaranteeing a more refined and sinusoidal waveform. This phase enhances the overall quality of electricity supplied to succeeding components and the grid.

Step 4: Inverter: The AC voltage, which has been filtered by the LCL filter, is thereafter routed to the inverter. The function of the inverter is to transform the filtered AC voltage into the appropriate AC voltage based on the specific needs of the system. The proper functioning of the inverter is essential to ensure that the power output meets the requirements of the grid, hence enhancing the overall stability and dependability of the microgrid.

Step 5: Implementation of Reduced UPFC: The reduced UPFC is strategically placed inside the system design. By using the dc link of the DG unit, the UPFC produces a certain series voltage and introduces it into the power lines of the grid. The introduction of additional voltage in a series configuration is a crucial characteristic of the UPFC and plays a significant role in improving the transient stability of the microgrid. The Reduced UPFC works in tandem with the DG unit, establishing a mutually beneficial association that actively mitigates oscillations and controls power transmission.

Step 6: Control Mechanism: The functioning of the whole system is regulated by sophisticated control methods that use Nonlinear Optimal Control techniques. The Inverter and the Reduced UPFC exchange control signals to provide a synchronized reaction to dynamic changes in the microgrid environment. Nonlinear Optimal Control enhances the system's capacity to effectively adapt to changing situations and improve stability while minimizing costs, thereby adding a level of complexity.

Step 7: Feedback Loops: The system utilizes feedback loops to improve control mechanisms. The Inverter exerts control on the UPFC, exerting influence over its operation. Furthermore, the UPFC receives data from both the LCL filter and the grid voltage, allowing it to adapt dynamically to changing circumstances. These feedback loops are essential for ensuring stability and responsiveness in the microgrid.

Step 8: Series Voltage Injection: The UPFC introduces the produced series voltage into the power lines of the grid. The injected voltage has an active role in improving transient stability. The UPFC enhances the stability of the microgrid by carefully adjusting the injected series voltage to mitigate power fluctuations.

Step 9: Establishing Grid Connection: The power, which has been stabilized and controlled, is smoothly incorporated into the wider power grid together with the injected series voltage. The link guarantees that the microgrid makes a beneficial contribution to the larger electrical network by fulfilling the grid's criteria for stability and dependability.

Step 10: Continuous Monitoring and Adaptation: The whole system is constantly monitored, and the control mechanisms adjust to changes in solar irradiation, grid conditions, and other dynamic variables. The Nonlinear Optimal Control technique enables the system to make immediate adaptations, guaranteeing the stability and responsiveness of the microgrid to dynamic conditions.

The operating method of the proposed system is a complex and interconnected series of phases. Each component, from the PV source generating power to the Reduced UPFC injecting series voltage, plays a crucial role in providing improved stability within the microgrid. The integration of sophisticated control mechanisms, feedback loops, and adaptive methods guarantees the efficient and dependable operation of the system under various and ever-changing settings. The suggested system's holistic approach makes it a potential option for enhancing the stability of microgrids. This contributes to the larger shift towards sustainable and resilient energy systems.

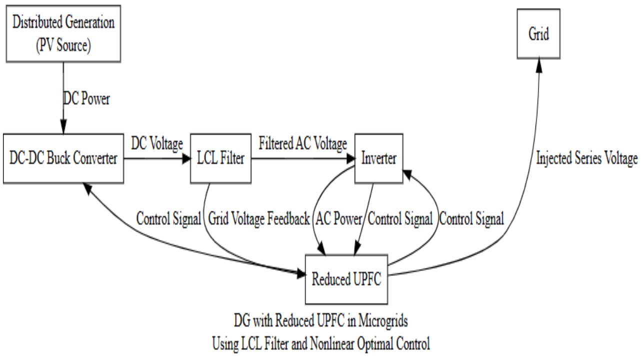

Fig. 1. Proposed System.

A. *DC-DC Buck Converter*

The DC-DC Buck Converter is an essential element in the proposed system, playing a vital role in the effective conversion of the DC power produced by the PV source. The functioning of the system entails an intricate interaction of electrical components to control and sustain a consistent DC voltage, guaranteeing stability in the microgrid. The mathematical equations that regulate the operation of the DC-DC Buck Converter provide valuable insights into the complexities of its functioning and its role in the overall functionality of the system.

The fundamental premise of the DC-DC Buck Converter is voltage reduction. The main goal is to reduce the input voltage from the PV source to a lower, controlled voltage that is appropriate for the next phases of the microgrid system. This procedure is crucial for adjusting the variable output from the PV source to meet the specific needs of the microgrid, hence guaranteeing a reliable and uninterrupted power supply. The behavior of the DC-DC Buck Converter may be described by a mathematical equation that determines the connection between the input and output voltages. Denote the input voltage as Vin, the output voltage as Vout, and the duty cycle of the converter as D. The duty cycle denotes the proportion of time in which the switch in the converter is activated. The correlation between these parameters may be mathematically represented by the equation:

$$Vout = D \cdot Vin$$

In this context, D functions as a control variable, dictating the proportion of time that the switch is turned on compared to the whole duration of the switching period. As the duty cycle rises, the output voltage reduces in direct proportion, and conversely. The equation serves as the basis for comprehending the voltage reduction mechanism of the DC-DC Buck Converter. The functioning of the converter consists of two primary phases: the on-state and the off-state. While the switch is closed in the on-state, the inductor accumulates energy, and the output voltage is dictated by the duty cycle. An inductor accumulates energy in the form of a magnetic field, which aids in the uninterrupted movement of electric current. The equation governing the relationship between the inductor current (iL), the input voltage, and the duty cycle is as follows:

$$Vin = L\frac{diL}{dt} + Vout$$

In this context, L denotes the inductance of the inductor, whereas diL/dt indicates the derivative of the inductor current with respect to time. This equation illustrates the equilibrium between the energy stored in the inductor and the input and output voltages when the circuit is in the on-state. In contrast, when the switch is open and in the off state, the energy stored in the inductor is discharged. The inductor undergoes discharge, resulting in the transfer of energy to the output capacitor. The equation that governs this discharge phase is provided by:

$$Vout = -L.\frac{diL}{dt}$$

The equation demonstrates the energy transfer process from the inductor to the output capacitor while the system is in the off-state. The negative sign denotes the direction of the energy transfer. The duty cycle (D) is a crucial factor in determining the level of output voltage control. The duty cycle is the quotient of the duration during which the switch is in the "on" state divided by the overall duration of the switching period. The duty cycle is mathematically expressed as:

$$D = \frac{Ton}{Toff + Ton}$$

In this context, Ton refers to the length of time during which the system is in the on-state, whereas Toff refers to the length of time during which the system is in the off-state. Precise regulation of the duty cycle is crucial for maintaining stability and efficiency in the DC-DC Buck Converter, since it directly affects the output voltage. The efficiency (η) of the converter may be measured as the ratio of the output power (Pout) to the input power (Pin), providing a quantification of the total energy transfer efficiency. In mathematical terms, efficiency is quantified as:

$$\eta = \frac{Pout}{Pin}$$

Efficiency is a crucial metric as it offers valuable information about the converter's ability to transform input power into the appropriate output with effectiveness. The total efficiency of the DC-DC buck converter is influenced by many parameters, including as switching losses, conduction losses, and component characteristics. Furthermore, the actual execution of the DC-DC Buck Converter encompasses factors such as the selection of suitable components, the handling of transient reactions, and the reduction of losses. The careful choice of components, such as the values of the inductor and capacitor, is crucial for getting the required performance. To effectively manage transient responses, it is necessary to carefully handle the dynamics that occur when a system is switched on or off, to avoid voltage spikes or overshoots. To optimize the total efficiency of the converter, it is crucial to minimize both conduction and switching losses.

B. *LCL Filter*

The LCL filter is an essential element in power electronic systems, serving a critical function in regulating the output voltage and mitigating harmonics. The functioning of this system relies on complex interactions between inductors and capacitors to generate the intended filtering effect. To understand the operation of the LCL filter, it is crucial to examine its mathematical equations, which provide the basis for its dynamic behavior and its importance in improving the quality of AC power output. Essentially, the LCL filter is placed between the output of a power converter, such a DC-DC converter, and the following load, usually an inverter. The main objective of this device is to reduce high-frequency harmonics and modify the output voltage waveform, guaranteeing adherence to grid regulations and enhancing the quality of power supplied to the load. The functioning of the LCL filter may be comprehended by analyzing the following set of mathematical equations:

The voltage across the inductor (L1) in the filter. The voltage across the first inductor (L1) in the LCL filter, represented as vL1(t), may be calculated using the formula for an inductor in a circuit: vL1(t) = L1 * d/dt(iL1(t)), where L1 is the inductance of the first inductor and iL1(t) is the current passing through it.

Capacitor voltage in the filter: The voltage across the capacitor (C) in the LCL filter, represented as vC(t), is dictated by the equation governing the behavior of a capacitor in an electrical circuit: The equation vC(t) = C1∫iC(t)dt represents the relationship between the voltage across a capacitor, denoted as vC(t), and the integral of the current flowing through it, denoted as iC(t). The variable C represents the capacitance of the capacitor.

The voltage across the inductor (L2) in the filter. The voltage across the second inductor (L2) in the LCL filter, represented as vL2(t), may be expressed as vL2(t) = L2 * d/dt(iL2(t)), where L2 is the inductance of the second inductor and iL2(t) is the current flowing through it.

Capacitor (C) current in the filter: The current passing through the capacitor (C), represented as iC(t), is equal to the total of the currents passing through the two inductors: iC(t) = iL1(t) + iL2(t).

Resonant frequency of the LCL circuit: The resonant frequency (fr) of the LCL filter, which describes its reaction to harmonic frequencies, may be calculated using the formula: fr=2πL1(C+2Cm)1, where Cm represents any extra capacitance connected in parallel with the capacitor.

The equations demonstrate the dynamic interaction between the inductors and capacitor in the LCL filter. Inductors restrict the rate of current change, so aiding in the filtering process. Capacitors, on the other hand, assist in smoothing voltage waveforms by integrating the current. The resonant frequency indicates the LCL filter's capacity to reduce certain frequencies and highlights the need of accurate design for achieving the best possible performance.

The LCL filter is successful in its operation due to its capacity to reduce high-frequency harmonics, avoid resonance at undesired frequencies, and guarantee a smooth and sinusoidal AC output. To do this, one must carefully analyze the values of the components and how they interact with each other, finding a balance between the need for efficient filtering and the possible difficulties caused by resonance and damping. The LCL filter is a crucial component in power electronic systems, playing a vital role in ensuring the high quality and dependability of AC power transmission.

C. *Reduced UPFC*

The reduced UPFC plays a crucial role in the proposed microgrid system, making a substantial contribution to the improvement of stability and control. The UPFC is a highly adaptable and sophisticated device used in power systems to enhance power flow, voltage stability, and transient stability. The reduced UPFC is a simplified iteration that provides the necessary functionality while minimizing complexity and ensuring cost-effectiveness. The functioning of this system requires complex mathematical equations that control the creation and injection of a series voltage. This plays a vital role in enhancing the stability of microgrids. The primary function of the Reduced UPFC is to make use of the direct current connection of the DG unit. This distinctive characteristic sets it apart from its full-sized equivalent and presents an innovative method for improving stability. The dc link of the DG unit serves as a crucial interface, allowing the Reduced UPFC to produce and introduce series voltage into the power lines of the grid. The mathematical description of this process entails the use of ideas derived from power electronics, control theory, and circuit analysis. The mathematical representation of the series voltage injection may be expressed by the equation:

$$Vseries = Vdc \cdot \sqrt[2]{2} \cdot sin(\omega t)$$

Here, Vdc represents the direct current voltage generated by the DG unit, ω represents the angular frequency, and wt represents the duration. The equation represents the sinusoidal characteristics of the injected series voltage, where the amplitude is dictated by the level of the direct current voltage. The coordination of this injection with the voltage of the grid is a crucial factor that impacts the efficacy of the stability enhancement. The functioning of the Reduced UPFC is governed by a control mechanism that utilizes advanced mathematical models, often relying on optimum control procedures. An strategy that may be used is the use of Hamiltonian dynamics and the Hamilton-Jacobi-Bellman (HJB) equation. The Hamilton-Jacobi-Bellman equation (HJB equation) is a kind of partial differential equation that emerges within the realm of control theory and optimization. The Reduced Unified Power Flow Controller (UPFC) plays a crucial role in achieving microgrid stability at minimal expense. The Hamilton-Jacobi-Bellman equation may be formulated as:

$$H(x, u, \nabla V) = 0$$

The Hamiltonian, denoted by H, represents the system's energy. The system state is represented by x, the control input by u, and the gradient of the value function V is denoted by ∇V. The value function V represents the combined cost of the system's operation and stability, and its optimization is crucial for the efficacy of the Reduced UPFC. Nonlinear Optimal Control approaches are used to enhance the mathematical framework that governs the functioning of the Reduced UPFC. Nonlinear Optimal Control entails the optimization of a performance index, which often quantifies the behavior or efficiency of the system. The performance index of the Reduced UPFC is closely associated with the goals of improving stability and minimizing costs. A possible expression for the performance index J in nonlinear optimal control is:

$$J = \int L(x, u, t)dt + M(x(tf), tf)$$

The variables in the equation are as follows: L represents the cost function at a certain moment, x represents the state of the system, u represents the control input, and t represents the time. The expression M(x(tf),tf) denotes the terminal cost, which takes into consideration the condition of the system at the final time tf. The optimization procedure entails identifying the control input that minimizes the performance index. The reduced UPFC employs sophisticated optimization methods to address the nonlinear optimal control issue. A strategy may be used that utilizes the Pontryagin's Minimum notion, which is a key notion in the field of optimal control theory. The Pontryagin's minimum principle asserts that in an optimum control trajectory, the Hamiltonian is minimized in relation to the control input. The control input u of the Reduced UPFC is determined by maximizing the Hamiltonian function:

$$u = argmin\left(u * \ H(x, u, \nabla V)\right)$$

The optimization procedure guarantees that the reduced UPFC functions in a way that reduces the expenses linked to stability improvement while complying with system limitations. The functioning of the reduced UPFC is further improved by including a Neural Network. The neural network functions as a tool to estimate the cost function using the weighted residual technique. By using a neural network, the system can acquire knowledge and adjust itself to the intricate dynamics of the microgrid. This allows for a data-driven method of enhancing stability. The functionality of the Reduced UPFC, as dictated by these mathematical equations and optimization approaches, highlights the advanced nature and flexibility of the system. The complex interaction among the dc link of the DG unit, the series voltage injection, and the nonlinear optimal control methods jointly enhances the stability of microgrids. The reduced UPFC, characterized by its simplified structure and sophisticated mathematical principles, plays a crucial role in achieving durable, efficient, and cost-effective microgrid operations.

IV. RESULTS AND DISCUSSION

Figure 2 illustrates the suggested situation by showing the injected series voltage of the UPFC and the grid voltage at Bus 1 for a length of 5 seconds. Both waveforms are represented as sinusoidal waves with a voltage amplitude of 200 volts. This diagram provides a graphical depiction of the expected outcomes that would occur because of suggested modifications or improvements to the UPFC operation. The synchronized sinusoidal waves of the injected series voltage and grid voltage at Bus 1 demonstrate the capacity of the UPFC to control and affect the electrical characteristics of the grid. An in-depth examination of this image enables the discovery of possible enhancements in phase alignment, amplitude control, or transient responsiveness. The suggested modifications to the injected series voltage seek to maximize voltage stability and control inside the microgrid, demonstrating a more sophisticated and improved performance compared to the current situation.

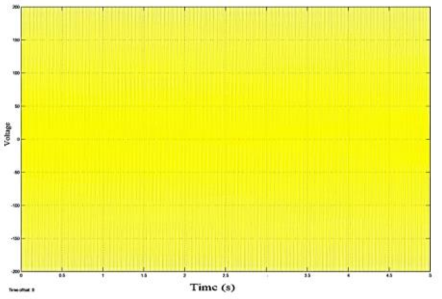

Fig. 2. Proposed injected series voltage of UPFC & grid voltage at bus 1.

Figure 3 illustrates the contrasting behaviors of active power in the transmission line and the injected power from the UPFC. Both power factors are quantified in watts throughout a 5-second time frame. This diagram illustrates the expected alterations in power transmission caused by planned modifications to the Unified Power Flow Controller's functioning. The power waveforms demonstrate a greater amplitude of 0.01 watts, indicating an increased impact of the UPFC on the dynamics of the transmission line. This heightened power level indicates a situation in which the suggested modifications to the UPFC's functioning lead to a more significant influence on power flow inside the microgrid. The temporal progression of these power variables enables the identification of distinct time periods in which the suggested UPFC changes actively enhance the optimization of power flow and stability.

Figure 4 illustrates the contrasting behaviors of active power inside the transmission line and the injected power from the UPFC. Both power variables are quantified in watts within a 5-second interval, with an augmented magnitude of 0.55 watts. This diagram offers a glimpse into the expected alterations in power transmission caused by suggested modifications to the UPFC's functioning. A greater power magnitude indicates a stronger influence of the UPFC on the dynamics of the transmission line. This heightened power level indicates a situation in which suggested modifications to the UPFC's functioning lead to a significant impact on power distribution within the microgrid. The temporal progression of these power variables enables the identification of the time periods in which the suggested UPFC alterations actively boost power flow and stability, demonstrating superior performance relative to current settings.

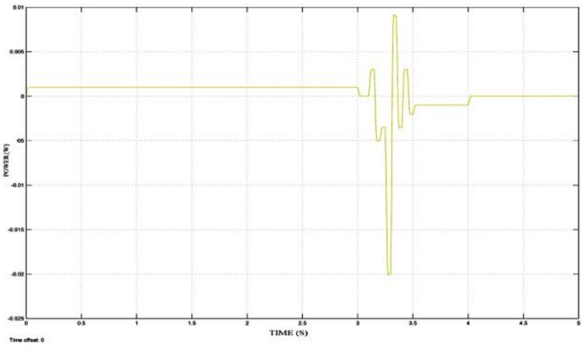

Fig. 3. Proposed active power of transmission line & injected power of UPFC.

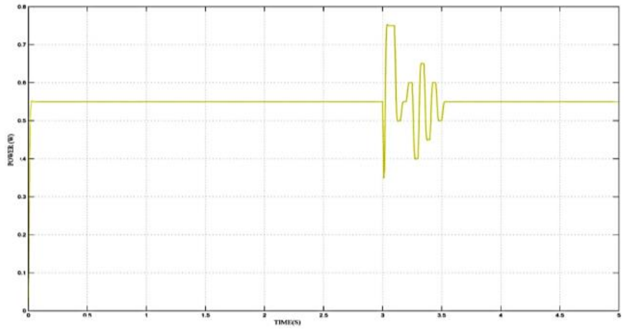

Fig. 4. Proposed active power of transmission line & injected power of UPFC.

Figure 5 illustrates the suggested scenario for the injected series voltage of the UPFC for a length of 5 seconds. The voltage is represented by an amplitude of either +0.1 volts or -0.1 volts. This diagram illustrates the expected fluctuations in the injected series voltage of the UPFC, displaying a dynamic waveform that oscillates around zero voltage. The suggested variations in the injected series voltage indicate a situation in which the UPFC may actively regulate and oscillate the voltage levels. The capacity to adapt is essential for maintaining voltage management and stability in the microgrid. The oscillating characteristics of the voltage waveform emphasize the suggested improvements that seek to provide a more adaptable and reactive functioning of the UPFC, hence enhancing grid stability.

Figure 6 depicts the suggested scenario for the voltage of the DC connection that supplies power to both inverters of the DG and UPFC unit. The DC link demonstrates its stability and control by maintaining a consistent voltage level of 90 volts. The constant DC link voltage of 90 volts implies that changes to the UPFC operation are made to provide a steady and dependable energy supply to the inverters of the DG unit. Maintaining a stable DC link voltage is crucial to ensure the dependable functioning of the inverters, which provide the necessary AC power for the microgrid. The diagram illustrates the stable circumstances of the suggested DC link voltage, highlighting the UPFC's function in ensuring a dependable power supply to the microgrid.

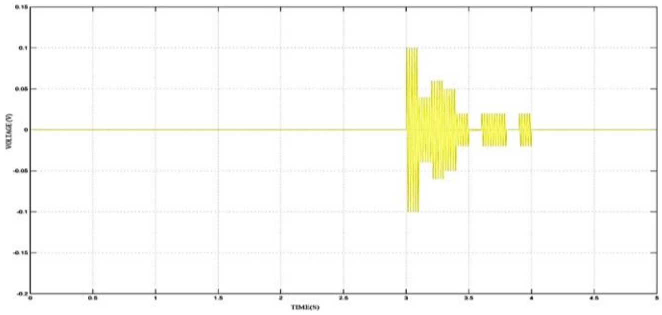

Fig. 5. Proposed injected series voltage of UPFC.

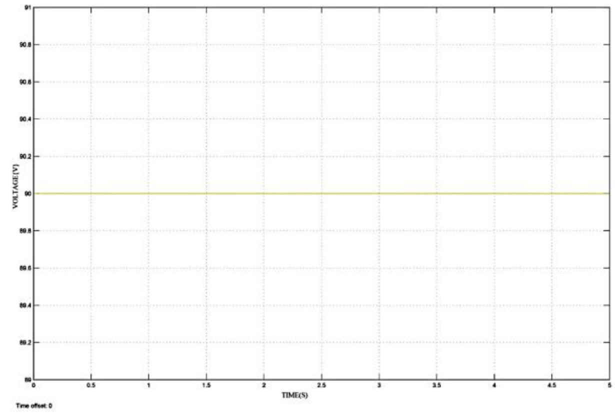

Fig. 6. Proposed DC link voltage that feeds both inverters of DG + UPFC unit.

V. CONCLUSION

The suggested system combines DG with a reduced UPFC in microgrids. It utilizes an LCL filter and Nonlinear Optimal Control. This system provides many benefits, including improved efficiency, dependability, and sustainability of the microgrid. By using PV source, the system aids in the worldwide transition to sustainable energy, coinciding with environmental objectives. The reduced UPFC significantly enhances transient stability by deliberately injecting a series voltage into the power lines of the grid. This action effectively dampens oscillations and improves the overall resilience of the system. The system guarantees effective DC-DC conversion, maintains a superior AC power output via an LCL filter, and utilizes sophisticated control mechanisms to coordinate responses and adapt to changing situations. The DG unit and the reduced UPFC have a symbiotic connection that establishes a collaborative framework to enhance stability. Furthermore, the system integrates feedback loops, which enhance its ability to respond and adapt effectively. The Nonlinear Optimal Control technique emphasizes the potential for reducing costs, while the system's improved grid integration facilitates seamless interactions with the wider power grid. Additionally, the incorporation of cutting-edge control techniques and the implementation of a streamlined UPFC structure place the system at the forefront of research and development in microgrid stability.

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