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Fuzzy Based Quick Acting DC Link Voltage Controller for Three Phases of D-Statcom Connected to the Microgrid

Abstract: - The microgrid systems are the combinations of solar photovoltaic, wind energy, fuel cell and battery systems, as well as conventional generators for backup. The micro grid system barriers that are encountered for their integration to the network. In power systems, voltage stability and power quality are major problems. Due to fluctuations in dc link voltage, changes in load may have an effect on the compensation. This work offers a fuzzy logic-based supervisory approach to enhance the performance of the dc link transient. The controllers employ proportional and integral gain changes with fuzzy logic PI controllers integrated with distribution static synchronous compensator (D-STATCOM). These changes occur in the transient response phase right after a load fluctuation. In order to verify the suggested controller, mathematical equations are given to compute the gains of the traditional controller using fuzzy-logic PI fast-acting dc-link voltage controllers for obtaining similar quick transient reaction. Fuzzy logic PI controller enhancements that employ greater sampling during the transient period and expert knowledge of system behavior enhance the controller's performance. Compared to a standard PI controller, a dc link error reduces the capacitor voltage during a load shift. Utilizing the suggested method and the outcomes of MATLAB simulations, it will be demonstrated that efficiency and the voltage's quick settling time.

Keywords: Fuzzy logic, PI Controllers, D-STATCOM, Microgrid, Power Quality and Voltage Stability.

I. INTRODUCTION

The need for stable, high-quality energy has greatly increased as a result of the electrical power networks' fast expansion. Power quality concerns and the necessity for voltage stability plague the electrical power distribution networks in the majority of the world (Frolov et al., 2019) (Abdalla et al., n.d.). The distribution system's main concern with the electricity system is its quality because consumers receive voltage and current signals from it. Low power quality has a detrimental impact on the power system, reducing load efficiency, shortening the life of electrical equipment, and eventually leading to power quality issues such as voltage instability & current harmonics (Nascimento & Gouvêa, 2017).

Concerns about power quality (PQ) in the power distribution network have grown as a result of the increased use of power electronics-based machinery, as well as nonlinear and unbalanced loads. They cause electrical equipment to overheat, have a low power factor, voltage distortion, and interfere with communication systems, as well as a high neutral-to-ground voltage and excessive neutral currents (Bollen et al., 2000; Mishra & Karthikeyan, 2009). By introducing additional voltages, currents, or both to the system, the literature recounts the development of a variety of specialized power devices to solve the aforementioned power-quality issues (Mishral et al., 2000). A shunt-connected specialized power device called the distribution static compensator (DSTATCOM), injects current at the point of common coupling (PCC) to offer harmonic filtering, power factor correction, and load balancing. The DSTATCOM is composed of a voltage-source inverter (VSI) with current control, which injects current into the PCC via the interface inductor. To enable VSI operation, an adequate dc voltage is placed across a dc storage capacitor. Some of the electrical power users, notably the telecommunications industry, use power-electronics driving applications, etc.

Microgrids (MGs) are networks of distributed generating units that function in concert with a dependable control system. With the help of this controller, the power system's efficiency can be raised while voltage stability and system power quality are guaranteed. A number of advantages for maximizing the utilization of electric networks are provided by micro-grids. The static synchronous compensator (STATCOM), one of many methods used to address power quality problems, is one such technology. The STATCOM belongs to the category of flexible AC transmission system (FACTS) devices inside power systems (Rohani et al., 2019). A distributed STATCOM (D-STATCOM) successfully helps distributed networks address power quality issues, producing positive results.

In order to get the correct variations in the reference load voltage, a control strategy that modulates the needed source current has been put forth. Over a significant source voltage range, this voltage indirectly affects the source current drawn. Therefore, during normal operation, the control algorithm makes sure that the source currents are balanced, sinusoidal, and in accordance with the required source voltages (Valluri & Kumar, 2015a). Even with voltage variations present, the load terminal keeps a constant voltage. The compensator is adaptable, rapid to

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adjust the voltage at the load terminal, and may benefit from continuous conduction mode (CCM) when utilized in voltage control mode (VCM) with the proposed design and control algorithm.

A Literature Survey

The dc power is essential for the compensator's transient reaction since it is similar to the average load power when the dc load is likewise powered by the DSTATCOM's dc connection. As a result, there are two critical problems that need to be resolved: giving the dc-link voltage controller a quick settling time, and keeping the dc-link voltage within predetermined bounds for transient load scenarios. The difference between the capacitor voltage and its reference value is typically utilized as an input when a proportional-integral (PI) controller is used to maintain the dc-link voltage. Conventional dc-link voltage controllers, on the other hand, have sluggish transient reactions, especially in situations when the load is changing quickly. In prior investigations, the stability of dc-link voltage controllers was investigated. However, the majority of the earlier research in this field focused on rectifier units with easily analyzed switching patterns. The dc-link capacitor's energy is used in this research to introduce a brand-new, effective dc-link voltage controller that reacts swiftly(Mishra & Karthikeyan, 2009). Extensive simulation, experimental verification, and modelling are used to show this controller's efficacy. This paper provides mathematical equations for designing the gains of the conventional controller based on the fast-acting dc-link voltage controllers, which is in contrast to the conventional proportional-integral (PI) controller used to control the dc-link voltage of the DSTATCOM, which lacks a systematic design procedure for figuring out its gains (Dinavahi et al., 2004; Valluri & Kumar, 2015b). This strategy seeks to produce a comparable quick transient reaction.

The three-phase three-wire distribution system uses the control approach of naive back propagation based icos, which was first presented by Mrutyunjaya Mangaraj and Anup Kumar Panda [13] The PI controller received the reference current extraction. To track the power in low frequency, a grid-connected PV system with high frequency and ripple-free MPPT is needed (Mangaraj & Panda, 2017). By synchronising the dc-link voltage and employing film capacitors, the system's dependability was increased. In a dc-link capacitor, a 5-kW PV converter module was put up for experimentation. Chandan Kumar and Mahesh Mishra (C. Kumar & Mishra, 2014) a shunt active filter was developed as a component to correct power factor and reduce load imbalances for distribution networks. They designed an external inductor to better voltage regulation and constructed a hierarchical controller for optimised on-line energy management in freestanding hybrid power systems.

Emad Maher Natsheh et al.(Natsheh et al., 2013) proposed a topology for compensating for neutral current that does not require a four-leg inverter or a dynamic hybrid structure model. According to Ghosh and Joshi (2000), To lower the DC link voltage and manage non-stiff power sources, they employed an inverter powered by a voltage source. Srinivas Bhaskar Karanki et al.(Karanki et al., 2012) presented a DSTATCOM architecture for non-stiff power source load adjustment. They demonstrated how to generate a reference current compensation under equal and distorted voltages while also lowering the DC-link voltage rating. Rabinovici et al. (Rabinovici et al., 2010) created a multilayer cascaded H-bridge inverter using a series space vector modulation approach. When compared to standard SVPWM, our technique provided a workable solution with less complexity. The researchers effectively reduced harmonics in the system using MATLAB simulation. Roshan Kumar et al., (P. R. Kumar et al., 2014) created a unique three-phase space vector structure for a hybrid multilevel inverter. Their invention included a system that used a single DC source to reduce common mode voltage. The researchers used IGBT-supported inverters to operate an induction motor's steady-state and transient operations. Aleenejad et al. (Aleenejad et al., 2015) Changes that might be made to the space vector modulation strategy to enable multilayer cascaded H-bridge inverters to operate fault-tolerantly. They enhanced the current topology by reconfiguring their modulation approach and implementing a DC offset for fault scenarios. This change enabled the inverter to operate at a greater level. A rapid space vector modulation technique was developed by Roodsari and Nowicki (Roodsari & Nowicki, 2013) for multilayer inverters, especially the cascaded H-bridge inverter with changing DC sources. To efficiently compute switching states, they used a sub-triangle algorithm using reference frame vector coordinates.

II. MODELLING OF D-STATCOM CONFIGURATIONS

As illustrated in Fig. 1, A wind turbine serves as the AC grid component of the planned DC hybrid micro-grid, which also includes DC renewable energy sources including solar panels, fuel cells, & energy storage systems (batteries). These resources' capabilities are shown in Table 1. A DC-DC boost chopper and a three-phase, three-level Voltage Source Converter (VSC) link the DC producing units to the utility grid.

An external control loop is used to keep the DC voltage within the 260 V range. On the other hand, internal control loops are in charge of altering the active current component (i_d) in accordance with the results of the external DC voltage controller. For a power factor of one, they also maintain the reactive current component (i_q) at zero. Three modulating signals (V_{abc} ref) are created from the voltage outputs (V_d and V_q) of the current controller and are then utilised by the PWM generator. These signals are routed through a 100 kVA three-phase coupling transformer with a voltage ratio of 260 V/25 kV. The output is then connected to a 120 kV equivalent transmission system after being routed through a 25 kV distribution feeder. The proposed micro-grid is connected to a D-STATCOM installed on bus (B7) before being connected to the 25 kV distribution system. Figure 2 illustrates how this D-STATCOM is utilized to control voltage at bus (B7).

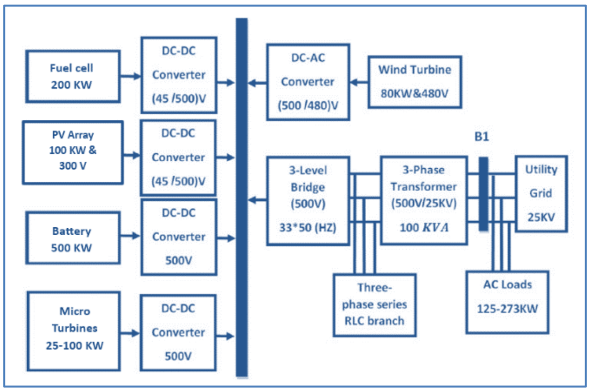


Fig.1 Proposed DC Microgrid system.

An array of photovoltaic (PV) cells are connected in series and parallel to form a photovoltaic (PV) module, which provides the output voltage and current needed by the PV array. Since the PV array runs at a constant DC voltage, the output voltage needs to be adjusted for the system to perform as efficiently as possible. This is accomplished by using a maximum power point tracking (MPPT) approach. The main goal of MPPT is to maximize electricity generation from PV modules while taking changing weather conditions into consideration. Shows a PV module configuration with 66 parallel strings, each string consisting of 5 modules linked in series.

Mechanical energy is converted to electrical energy by the wind turbine module. These turbines are made to run at a specified speed in order to maximize energy production and reach the necessary power output capacity. To create the most output power, the turbines must continuously adapt to changing wind speed conditions. In the imagined micro-grid, the wind turbine module serves as a distributed generator. It utilizes a double fed induction generator (DFIG) that rotates at 3000 rpm and a 50–85 kW AC/DC converter.

Depending on the electrolytes used in the module, fuel cells are divided into several categories. A proton exchange membrane (PEM) fuel cell is recommended in this situation. It is made up of an electrolyte membrane, an anode, and a cathode. Due to its high efficiency and adaptable design, the PEMFC can generate output voltages up to 45 V and output powers up to 200 kW.

When demand exceeds supply, it is vital to investigate alternate possibilities for preserving a balance between demand and supply. To alleviate this issue, a battery is used to store surplus produced power, allowing it to be used when needed. A voltage source converter (VSC) is attached to the battery in the proposed microgrid to regulate the adjustment of reactive and active power. To do this, two control loops utilizing control algorithms are designed to maintain the battery's state of charge (SOC).

Given the current situation, where demand outnumbers supply, it is critical to investigate alternate strategies to achieve a balance between them. To overcome this, using a battery to store surplus produced electricity for future use is a potential alternative. In the intended microgrid, the battery is coupled to a voltage source converter (VSC) to effectively control both active & reactive power compensation using two control loops. The battery's state of charge (SOC) is intended to be stable through the use of control systems.

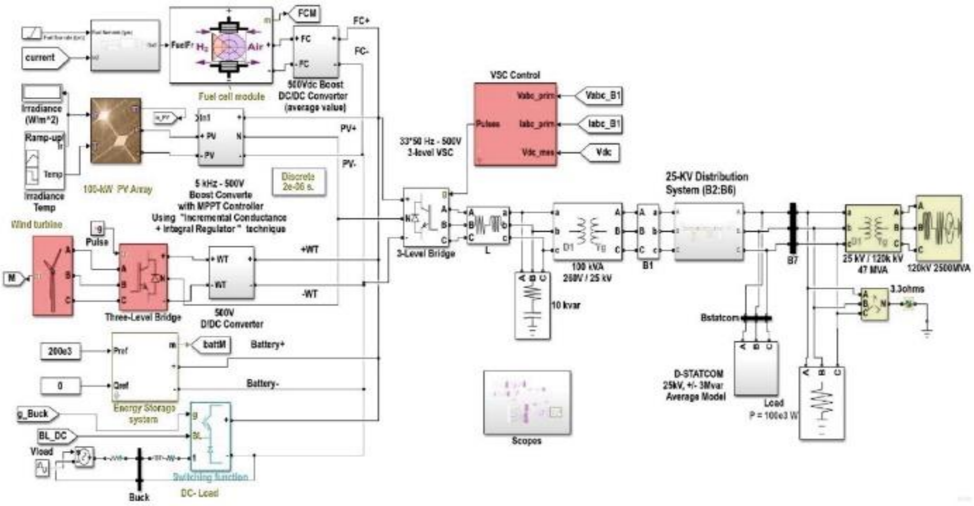


Fig.2 proposed Simulink DC Microgrid system.

2.1 Voltage controller - DC Link

According to the diagram, the power supply uses the DC connection on the D-STATCOM to directly power both a DC load and an unbalanced nonlinear AC load. Transients on the load side have a considerable influence on the DC bus voltage. Closed-loop controllers are used to maintain stability and control over the DC-link voltage. The proportional-integral (PI) control provides a versatile and effective solution for a variety of control problems. Using its mathematical formula, the PI controller generates a control signal that modifies the DC-link voltage.

$$V_C = K_p\left(V_{dcref} - V_{dc}\right) + K_i \int\left(V_{dcref} - V_{dc}\right)dt + K_d \frac{d(V_{dcref} - V_{dc})}{dt}$$

A PI controller's proportional, derivative, and integral gains are denoted, respectively, by Kp, Kd, and Ki. By triggering a control response proportionate to the misleading signal, the proportional term contributes. When the gain of the proportional controller is increased, the rising time & the steady-state error are decreased, Kp, is increased, but the rate at which the system deviates from the target state and the total time needed to settle are also increased. Ki increases, yet overshoot and settling time grow while the steady-state error is kept to a minimum. As opposed to this, raising Kd, the derivative gain, improves stability. However, the derivative term could operate against predicative actions in circumstances of transit delays.

2.2 DC-Link voltage fast acting controllers.

Introduced a dc-link voltage controller that is energy-based. From the actual voltage, Vdc, to the intended reference value, Vdcref, which is represented as Wdc, the controller calculates the amount of energy needed to charge the dc-link capacitor. The voltage of the dc-link capacitor commonly exhibits voltage ripples at double the supply frequency. The dc power, P'dc, required by the dc-link capacitor is also calculated while taking the ripple period of the voltage into consideration. These systems, however, have a steady-state error when adjusting for mixed AC and DC loads because they lack an integral term. To address this problem, an essential phrase is utilized. The error in squares of the real and standard capacitor voltages are sent to this controller. Figure shows how the controller uses the following equations to calculate the total amount of DC power needed by the dc-link capacitor.

$$P_{\mathrm{dc}} = K_{\mathrm{pe}}\left(V_{\mathrm{dc\,ref}}^2 - v_{\mathrm{dc}}^2\right) + K_{\mathrm{ie}} \int \left(V_{\mathrm{dc\,ref}}^2 - v_{\mathrm{dc}}^2\right) \mathrm{dt}.$$

The coefficients and display the recommended energy-based dc-link voltage controller's proportional and integral gains. The term "fast-acting dc-link voltage controller" refers to how quickly it reacts compared to a typical PI controller since it is an energy-based controller. Another advantage is the simplicity with which the proportional and integral profits may be computed.

III. D-STATCOM CURRENT CONTROLLED FUZZY-PI

The PI controller has limits and is useless when the error signal (e) suddenly changes. It can only capture the current value of the error and cannot be adjusted for changes in error levels, whether they increase or decrease. This shortcoming is quantitatively described as the error derivative (De). Furthermore, the PI controller cannot function properly across several testing sites.

Similarly, the PI controller is ineffective in large nonlinear power systems and has a shorter reaction time, both of which might complicate power system correction. Fuzzy Logic Control is presented as a solution to these problems. Fuzzy logic control includes a fuzzification procedure that translates crisp data into appropriate rule base representations, allowing for greater flexibility.

Based on the knowledge base, which includes the system database, the fuzzy interference mechanism calculates the suitable fuzzification technique. The rule base represents the system's core control method and is often stated as a set of If-Then rules. Because of its applicability for systems with slow-change dynamics, the Mamdani approach is used in this work to handle Fuzzy-PI.

A fuzzy logic controller (FLC) can be set up to work as a current regulator, an AC voltage regulator, or a DC voltage regulator. The DC and AC voltage regulators are examined in the outside regulation loop of a DSTATCOM (Distribution Static Compensator), while the current regulator is evaluated in the inner regulation loop. The AC voltage regulator generates a reference value ($i_q$ref) for the current regulator, where (i_q) stands for the out-of-phase current that regulates the reactive power flow. The output of the DC voltage regulator is determined by the reference value ($i_d$ref) of the current regulator, whose current (id) regulates the active power flow and is in phase with the voltage. The current regulatory body developed V_{2d} and V_{2q} as a result of the phrases ($i_d$ref-i_d) and ($i_q$ref-i_q). To create synchronization with the PLL output, the PWM modulator emits pulses that regulate IGBTs in the VSC based on V2d and V_{2q}. The fuzzy-PI (FPI) current-regulated D-STATCOM is shown fully configured in Fig. 3b (Fig. 3a). The Fuzzy-PI current controller is configured with two inputs and two outputs.

Two inputs and two outputs are present on the D-STATCOM system's Fuzzy-PI (FPI) controller. Figure 3c shows the error signal and rate of change of the d-axis current error, which are the identical inputs utilized to regulate the d-axis and q-axis currents. The FPI controller's outputs, represented by Vd and Vq, are defuzzied to achieve the needed voltage values. These voltages are then transformed to per unit (pu) to create per unit modulation signals, which are then sent into an inverter. An external integrator is used to reduce any steady-state inaccuracy in the Fuzzy Logic Controller (FLC) output.

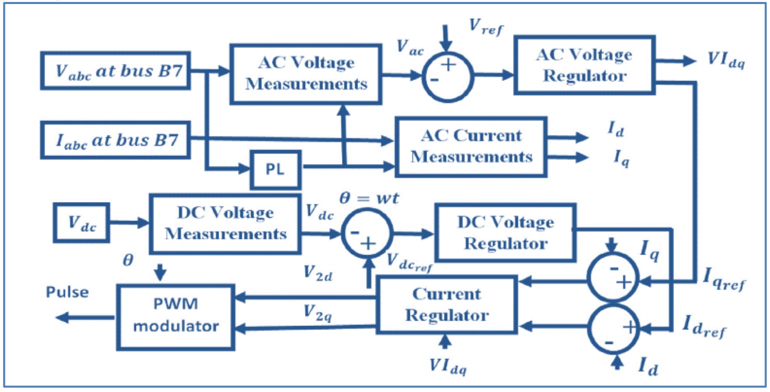


Fig. 3a Fully configured Fuzzy-PI current-controlled D-STATCOM.

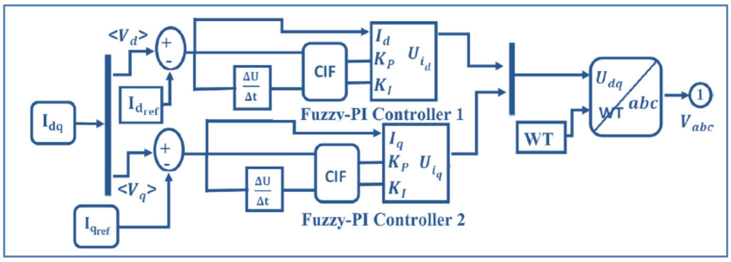


Fig. 3b D-STATCOM with Fuzzy-PI current control Configuration of a Simulink system for current control.

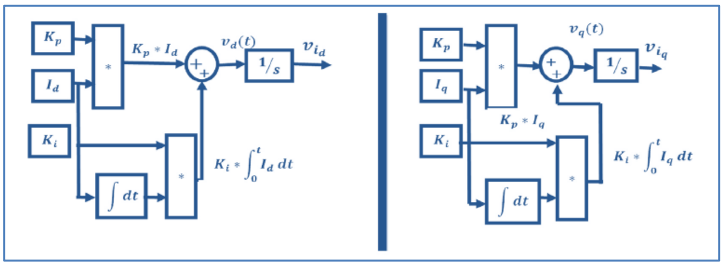


Fig. 3c Comprehensive instructions for obtaining the Fuzzy-PI controller's outputs.

IV. RESULT AND DISCUSSION

A model of the system depicted in Figure 4 was constructed to evaluate the microgrid system's ability to regulate voltage. The controllers were simulated in real-time using the MATLAB platform. The simulation was designed to give results that were comparable to those predicted from the actual hardware system. The voltage controllers' performance was evaluated throughout the course of a normal day, taking into account various load circumstances.

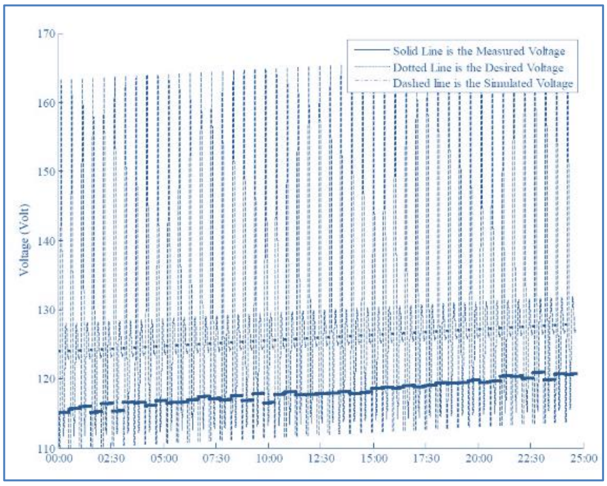


Fig.4 voltage response of a microgrid using a PI controller.

The output from the PI & FL-PI controllers is shown in the analysis. Figure 5 demonstrates how a DC microgrid's voltage is managed by the PI controller in response to shifting demand & photovoltaic (PV) electricity. The regulated voltage gradually approaches the target value of 124 volts (shown by a dotted line in the figure), closely matching the measured value (represented by a continuous line). The PI controller, depicted by a dashed line, contributes significantly to producing this response. This study' data was collected at 30-minute intervals during a normal day. Figure 6 shows the FL-PI controller's reaction for controlling a DC microgrid's voltage with variations in the microgrid's real power as a result of shifting demand and PV production. The FL-PI controller helps the regulated voltage move closer to both its measured value (shown by a continuous line in the plot) and its goal value of 124 volt.

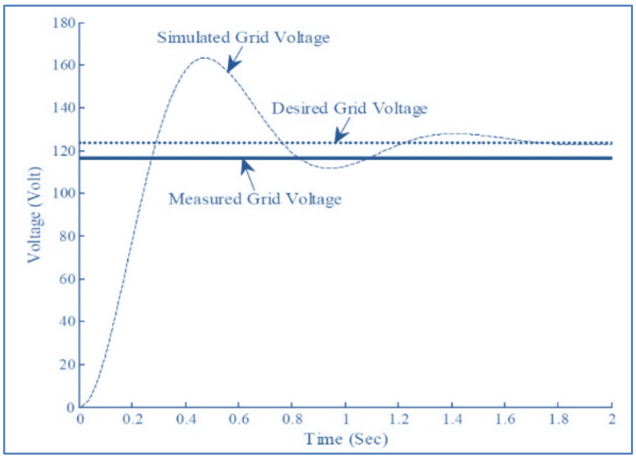


Fig.5 PI microgrid voltage control controller response.

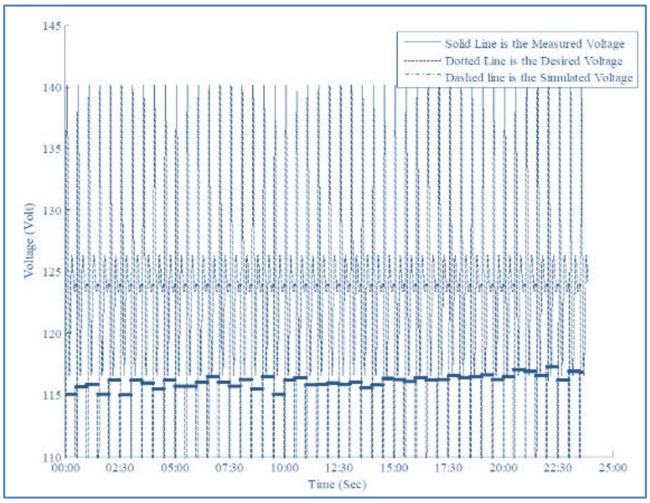


Fig.6 Voltage response of the microgrid using the FL-PI controller

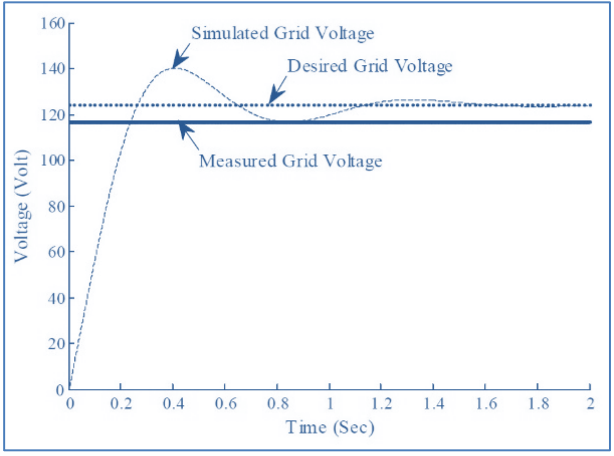
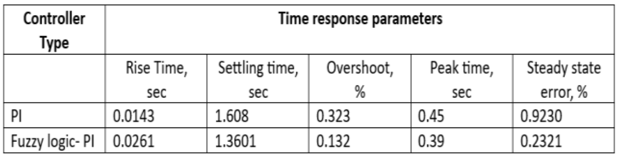


Fig.7 FL-PI controller response to microgrid voltage regulation.

Table I presents the PI and FL-PI controllers' time response parameters. The FL-PI controller's rise time is longer than that of the PI controllers. On the other hand, the FL-PI controller performs better than the PI controller since its steady-state error is smaller. Comparing the FL-PI controller to the PI controller, the overrun is substantially lower. The peak voltage of the PI controller is roughly 162 volts, which is approximately 38 volts more than the target level. The FL-PI controller, on the other hand, achieves a peak voltage of approximately 140 volts, which is just 16 volts more than the target level. When compared to the PI controller, this corresponds to a smaller percentage overrun for the FL-PI controller. The FL-PI controller's decreased overshoot illustrates its greater stability and reduced voltage fluctuations on the microgrid. Furthermore, the FL-PI controller has a lower settling time than the PI controller, making it quicker. Additionally, as seen in figure 7, the FL-PI controller reaches its peak response more quickly than the PI controller due to its shorter peak time.

Table 1 The voltage controllers for DC Microgrid have a time response that is developed.



Controller Type	Time response parameters				
	Rise Time, sec	Settling time, sec	Overshoot, %	Peak time, sec	Steady state error, %
PI	0.0143	1.608	0.323	0.45	0.9230
Fuzzy logic- PI	0.0261	1.3601	0.132	0.39	0.2321

V. CONCLUSION

Providing electricity to isolated locations that are far from the main power system is made possible by DC microgrids. The correct operation of these Microgrid is hampered significantly by the need to maintain consistent DC bus voltage. Designing PI and the fuzzy logic PI controllers to manage the DC bus voltage is the main goal of this study. An extensive examination revealed that the Fuzzy logic-PI controller outperforms the typical PI controller at regulating the voltage for the DC microgrid under investigation.

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[20] TY - JOUR AU - Ahmed, Hassan AU - Abdel-Rahim, Omar AU - Ali, Ziad PY - 2022/02/26 SP - 734 T1 - New High-Gain Transformerless DC/DC Boost Converter System VL - 11 DO - 10.3390/electronics11050734 JO - Electronics ER.