# Power Quality Improvement using Dual Multilevel Converter for Micro Grid-Connected PV Energy Systems using ANFIS

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**ABSTRAC-** This paper presents the implementation of dual voltage source inverter (DVSI) approach to improve the microgrid performance by enhancing the power quality. This paper also improves the power quality in photovoltaic (PV) generation interactive microgrids, respectively. The power generated from PV based distributive energy resources (DER) is perfectly applied to the microgrid through the two inverters, thus the nonlinear and unbalance load related problems are compensated. Thus, the power quality problems such as voltage sag, current drops, and power factor, active, and reactive powers are reduced by dual multilevel converter (DMLC). This converter also used for cooperative controlling to minimize the unbalances and voltage harmonics in microgrid by using adaptive neuro fuzzy interface system (ANFIS) based controller, which is applied in the shunt and series manner between the two VSIs. The total load current is mutually shared among the series and shunt VSI, if one VSI fails, then the other VSI continues its operation. Thus, the DMLC components failure rate is reduced, and the system lost energy is also reduced, which leads to improved reliability by maintain the reduction of down time price at environmental free conditions. The proposed control model is implemented in MATLAB/Simulink environment, and the obtained results shows that the superiority of total harmonic distortion (THD) reduction by the proposed ANFIS controller as compared to the conventional artificial neural network (ANN) and fuzzy logic controllers (FLC) by eliminating all the load current and grid voltage-based harmonics.

**Keywords:** Micro grid, PV Systems, dual multilevel converter, Fuzzy logic controller, ANN controller, ANFIS controller.

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## 1. INTRODUCTION

Generally, DERs plays a crucial role in the energy saving applications and creates echo-friendly environment [1-3]. Now a day, technology used in the power systems are changing drastically, thus they are updating towards small-decentralized DERs [4] from the conventional large-centralized power plants, respectively. The combination of multiple sources of small-decentralized DERs developed the distributed generation (DG), which is functioned based on the effective utilization of energy storage system and various renewable sources. This combination makes the DG system more efficient that the conventional larger power plants and showing the more advantages such as expandability, on-site generation, cost savings, uninterruptible service, high power quality and environmental-friendly environment [5]. The DG is configured with the combination of PV panels and hybrid controller-based DER systems. Here, these DER systems are treated as the primary energy distribution units. The PV panels are used to convert the solar radiation into energy, whereas the hybrid controllers are used to convert the flow of power into electrical energy. Here, the power speed and irradiance of sun is totally uncontrollable, unpredictable parameters. Thus, The DG needs the supporting energy source to control these primary DERs. Conventionally, the various hydrogen systems such as batteries electrolyzer, hydrogen storage tank and batteries are used as secondary energy storage system (ESS) in DG. These ESSs considered as the effective solution to meet the demand and generation in energy management process [7]. Whenever, the primary energy sources are generated the excessive power [8], then these ESSs are used to store them and avoids the shortage problems in the respective area. But there is a requirement of update the DG with current trends and technology. Thus, the power converters are used to control the DC power generated from ESS and DERs. These converters also maintain the reliable and sustainable operation, ensuring stability of energy sources. The converters are usually operated in the grid-connected mode, which interfaces the ac–dc and dc–dc power sources into the ESS and DER with a DC bus. The reactive and active powers to the grid are delivered by the dc–ac voltage source inverters in the DG, respectively. But these converters need the additional controlling mechanism. For this purpose, an advanced intelligent controlling method was applied in the standalone DG [14].

The classical controlling methods utilize mostly PI and state machine controllers, respectively. But they needed the much accurate parameters and accurate mathematical modeling of the environment [15]. Whereas the intelligent controlling methods utilize mostly fuzzy logics, machine learning, deep learning, and ANN, respectively. These artificial intelligence-based methods are more robust, accurate and efficient than the classical controlling methods. These methods also exhibit the dynamic nature improvement and do not require any exact modeling of the system. These controlling methods are used in stand-alone DGs to improve their performance and formed as grid connected DGs. Among the various artificial intelligence methods, ANFIS method improves the system performance by faster convergence as compared to the conventional controlling strategies. Inspired from these works, the major contribution of this work is as follows:

- Utilization solar power-based DER and controlling them using the ANFIS mechanism in shunt and series manner.
- Usage of DC links to separate the two VSIs, which leads to the operation of independent manner and resulted in enhanced flexibility there by the power generated from the DG is totally transferred to the DVSI, which helps to maximize the full capacity of DMLC.
- Implementation of ANFIS in DG shows the more advantages such as increases the life span of equipment, reduces the peak demand, improves the system capacity, reliability, improves the voltage profile, and also reduces the power losses.

Rest of the paper is organized as follows; *section 2* deals with related work and their problems. *Section 3* deals the detailed analysis of the proposed method. *Section 4* gives the simulation analysis and *section 5* concludes the paper with possible future enhancements.

## 2. RELATED WORK

In [7] authors developed the MPC based EC-DERs and reduced the short circuit current magnitude control by using the grid-connected (GC) and stand-alone (SA) mode of operation. But it needs to optimize more with considerable research should perform on it. This work is mainly focusing on reduction of power quality of issues. Mainly weaknesses were observed, Harmonic and Linear load sharing nature of various loads and its problems were not discussed, and Damping resistors were utilized in series connection series with the filter capacitors for resonance reduction. In [8] authors introduced the micro-turbine controlling strategy for DER, which is effectively used to wind-based power generation system. While implementing the same strategy in PV based solar system, the THD is increased. Thus, in [9-10] authors introduced the electronic device for controlling both PV and wind based DERs. But those are just test bids, the real time implementation of such systems resulted in higher manufacturing cost with power dissipation. In [11] authors newly introduced the IEC-61850 controlling model for utility based microgrid with the real time multi-level management. Then, later on IEC-61850 controlling model is used in the IED design also [12] for implementing the small-scale micro grid systems. In [13] authors introduced the relay-based switching techniques for controlling the grid voltage and load current in the smart grids, thus the system operates in automatic manner without usage of any external controller. The computational complexity of the system also reduced. But this method is suffering delivering the maximum power quality. Then, in [14] authors introduced the loop-based testis for real time microgrids. In [15] authors performed the study of various controlling strategies, which improves the power through the gain-voltage balance. Then, in [16] authors identified the time delay playing the major role in THD reduction process. The system taking much processing time to reduce the harmonics in power as the setting time increases, which resulted in increment of the THD. Thus, the authors maintained the secondary controlling strategy to monitor the setting time. Again, the islanded microgrids are much suffering with the setting time issues. Thus, in [17] authors introduced the voltage and current autonomous controlling environment, which reduced the harmonics and reactive power and maintains the setting time. These microgrids are suffering with the voltage regulation issues.

In [18] authors introduced the non-linear control strategy for distributive microgrids with event triggered environment. This method perfectly achieves the voltage regulation along with accurate current sharing properties. This method is suffering with the energy management issues. Thus, in [19] authors studied the various types of energy management systems for microgrids through the real time experiments. In [20] authors adopted perfect energy management system, which is implemented by using communication less distributed controlling approach. This method is perfectly suitable for storage and renewable energy generation systems. Then, in [21] authors introduced the smart power and energy management system by using the adaptive controllers. Then, in [22] authors utilize the concept of adaptive controllers in the MLCs. Here, the considerable power quality is achieved by using the reconfigurable emulators. In [23-24] authors developed various types of real time controllers such as distributed-IDS, IGBT based controlling system, and MCU-MIPS based environment. In [25], the authors developed distributed power generation system by maintaining the economic operation with respect to both the input and profit; in [26], hybrid Gaussian mutation with PSO was used to get the maximum profit in microgrids, respectively. To achieve the better controlling operation, in [27] authors adopted the Quantum Genetic Algorithm (QGA) for active control of micro-grid operation with uncertainties removal. But still hierarchical management problems were presented. To solve these problems, in [28] developed the modified GA for distributed management system problem optimization and low pollution with high efficiency was achieved by perfect usage of scheduling algorithm. In [29], a novel distributive power generation and transmission system was developed based on the optimal pollution treatment and operating cost. Here, to optimize the THD, Modified harmony search was used [30-31]. From above studies, it is observed that the by using optimization algorithms, all kind of linear and non-linear effects generated in the MPC based EC-DERs can be effectively eliminated and improves the power quality. It was seen from review works before that few major problems are still to be answered.

## 3. DUAL MULTILEVEL CONVERTER BASED MICROGRID SYSTEM

### 3.1 Dual Multilevel Converter

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Usually, microgrid is formed by the various loads and sources combination, which are operates as a single source power generator. The microgrids enhance the system efficiency by correcting the voltage sag, respectively. *Figure 1* presents the detailed operation of proposed DMLC based microgrid system.

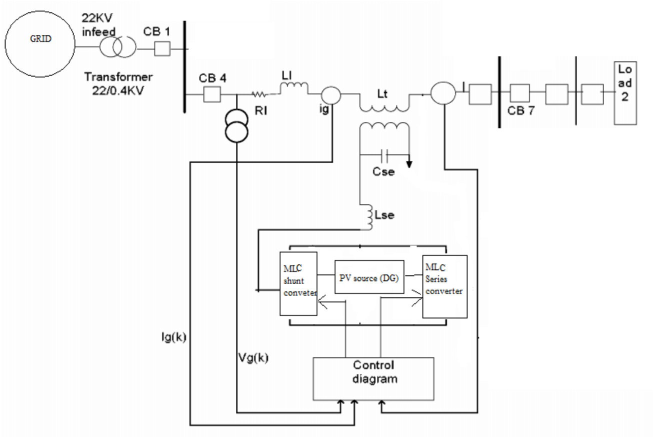


**Figure 1:** Proposed DMLC System

*Figure 2* presents the detailed architecture of DMLC. Here, DMLC is the best power quality improvement device in entire family of MLC compared to other approaches. The dual MLC is formed through separation of shunt and series controllers by using the common DC-link. Thus, the reactive power is perfectly exchanged between the controllers. Here, the shunt device is usually connected across the transmission system to compensate the system errors and acted as the compensated device, respectively. This compensation mechanism has the ability to generate or absorb the active power during the generation of connections. Thus, the voltage magnitude is perfectly controlled [5]. But the controlling of this power flow is uncertain and limited because bus voltage magnitude has maximum limitations and bus voltage can be changed only in certain range. Thus, series controllers are used to solve this problem. The series controllers or devices are connected in series with the major transmission line and influences the transmission line impedance, respectively. This impedance is either increased or decreased by the adding extra reactor or capacitor. The system also suffers with the inductive voltage drop problem. Thus, the newly introduced capacitor in the transmission line can compensate this voltage drop problem.

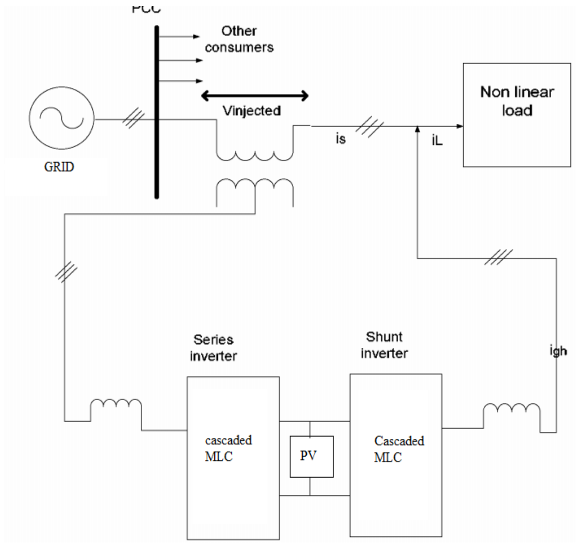


**Figure 2:** Constructional Structure of DMLC

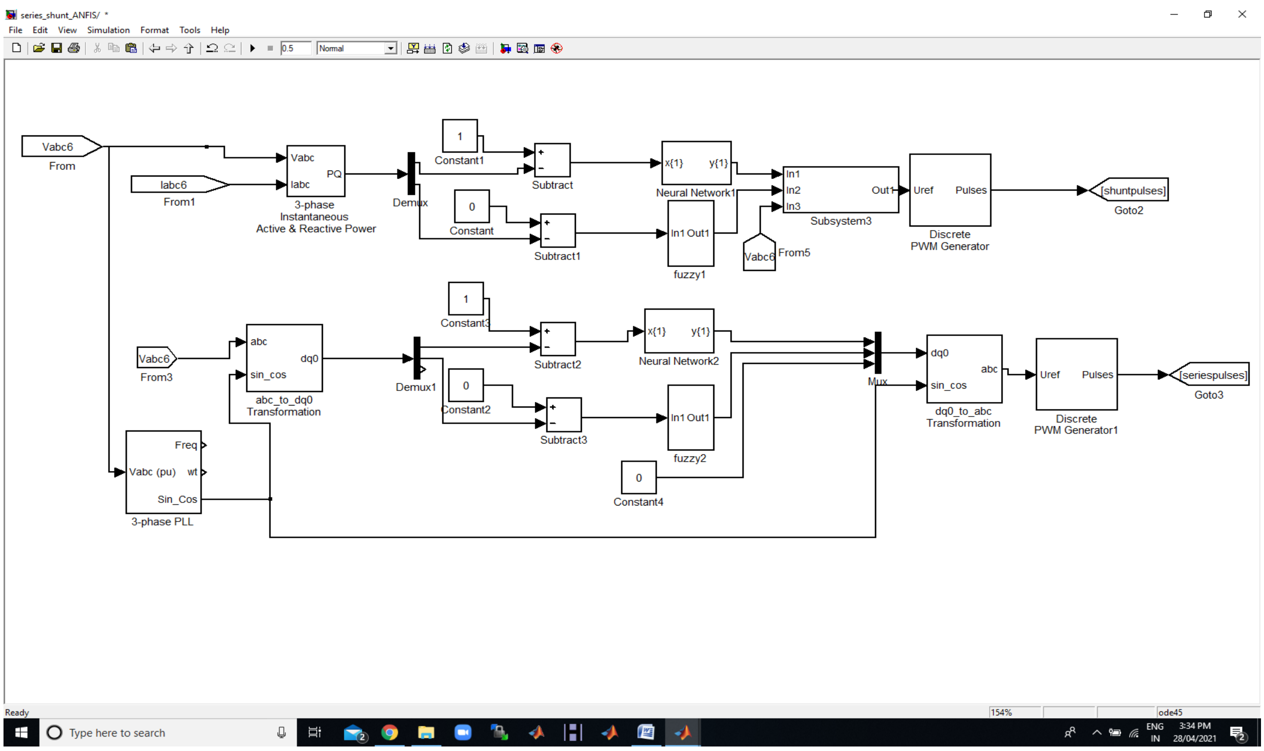


**Figure 3:** Control Diagram of ANFIS based shunt and series converter

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*Figure 3* presents the detailed control architecture of series and shunt converter. This controlling scheme utilizes park's transformation method [7] with appropriate generation of grid voltages and load currents. Here, the park's transformation was utilized to generate the two-phase currents commands from the three phase current coordinates through conversion process and calculates the error signal, respectively. Then, these reference signals were compared with the carrier wave in pulse width modulation (PWM) domain. Thus, the gate controlling signals are perfectly generated and transferred to two voltage source converters [8], respectively. The combined power quality controller is an improved method for controlling and eliminating the power quality issues. Then, the DMLC method also contains the ability to voltage drops without any external storage device. This is one of the major problems in the controlling mechanism. Thus, the DMLC method is incorporated with the distribution generation process and overcomes the already existed problems. Finally, the principal working procedure of distribution generation process is illustrated through two modes of operation. Initially, interconnected mode is used to transfer the power to both grid and load, respectively. Secondly, the islanding mode is used to transfer the power to load only.

## 3.2 Cascade Dual Multi Level Converter Operation

*Figure 4* presents detailed operation of voltage balancing between the cascaded H-bridge DMLC, respectively. It is consisting of $3-\emptyset$ clusters and three H-bridge cells. The DC capacitance voltage values are set to $Vc, 2Vc,$ and $4Vc$ in a phase cluster.

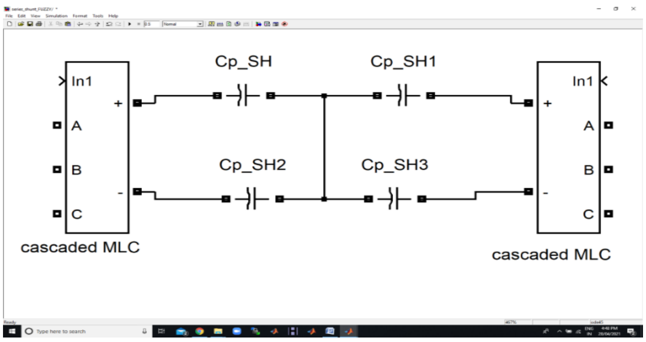
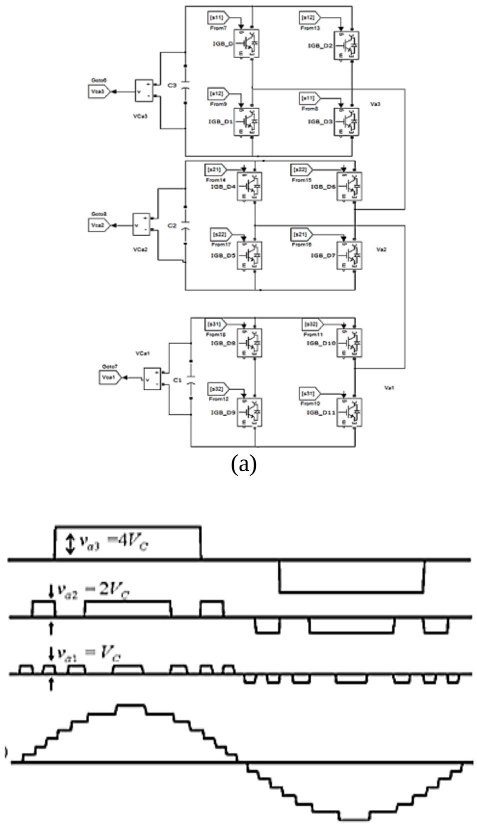



**Figure 4:** Capacitor voltage balancing between DMLC

The output waveform of the DMLC is presented in the *figure 5*, respectively. The -7 to +7 voltage level is generated by combining the capacitance voltages. Then, the cluster triggers or enhances the output to the maximum voltage level based on Va. The multiple numbers of switching patterns are used by the proposed controller to balance the DC voltage in each phase cluster and avoid the voltage dropping problem of phase cluster as shown in *figure 5(b)*, respectively. If the phase cluster generates the output voltage Vc, then it consists of three operational voltage patterns. They are "Vc", "2Vc-Vc", "4Vc-2Vc-Vc", here the charging and discharging capacitors are different. The patterns are formed based on the internal relationship between vc1, vc2 and vc3, respectively. The output pattern "Vc" is generated, if the 4vc1> =2vc2 and vc3 condition is selected. The output pattern "2Vc-Vc" is generated, if the 2vc2 > 4vc1 and vc3 condition is selected. The output pattern "4Vc-2Vc-Vc" is generated, if the vc3 > 2vc2 and 4vc1 condition is selected. Finally, the capacitor voltages are calculated at AC side phase angles of at 0, π/2, π, 3π/2 [rad] and utilizes the same switching patterns in the ¼ cycles, respectively.



(a)

(b)

**Figure 5:** Circuit configuration and operation. (a) Cascaded MLC circuit. (b) Output waveform

### 3.2.1 Advantages of DMLC Scheme

The proposed DMLC scheme exhibits the multiple advantages compared to the conventional single inverter process. The proposed DMLC also exhibits in multifunctional properties, they are

- *Enhanced reliability:* The total load current is mutually shared among the series and shunt VSI, if one VSI fails, then the other VSI continues its operation. Thus, the DMLC components failure rate is reduced. Thus, the system lost energy is also reduced, which leads to improved reliability by maintain the reduction of down time price.
- *Reduction in Filter Size:* The current transferred by each inverter is decreased and hence the current rating of filter inductors also reduced and resulted in reduced the filter size. The hysteresis current controller was utilized to maintain inverter reference currents. Usually, the switching frequency of inverter is used to control the filter inductance. Thus, the higher switching frequencies are

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generated by the semiconductor device. Thus, it resulted on reduction of inductance of filter, and which reduces the filter size.

- *Enhanced flexibility:* If the DC link of major inverter is disjointed from the system, then the load compensation of ability of auxiliary inverter is used to correct this problem. Then, the DC links are used to separate both inverters, thus they are operating in independent manner and resulted in enhanced flexibility.
- *Perfect usage of microgrid power:* The power generated from the DG is totally transferred to the MVSI, which helps to maximize the full capacity of DMLC. Here, the real power is transferred to the AC bus and reduces the reactive and harmonic power compensation problems. Thus, the active power generated from the DGs is improved.
- *Reduction of DC-Link Voltage Rating:* The zero sequence-based load currents are not delivered by the series VSI. Thus, the single capacitor is used along with the three-leg VSI topology. Hence, the series VSI DC- link voltage rating is decreased by 38% as compared to the conventional split capacitor VSI topology based single inverter system.

### 3.3 ANFIS Controller

This section deals with the implementation and usage of ANFIS based controlling scheme. Usually, the neural networks are consisting of two primary inputs, they are llde and lle and output is f {lle, llde}, respectively. Each input contains the 5 membership functions, respectively.

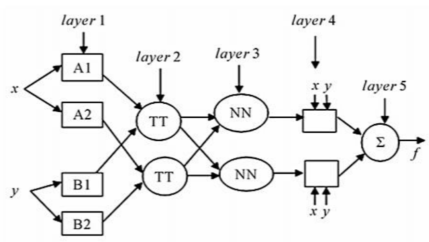



**Figure 6**: ANFIS architecture

*Figure 6* presents the detailed architecture of mamdani type based ANFIS controller. Here, mamdani type is used to generate the effective membership rules. Here, the Iilli and Ai are the membership rules used along with the sets and they are implemented by the logical AND operation. The system controlling parameter such as both non-linear and linear parameters is obtained by implementing the hybrid learning approaches. *Table 1* presents the proposed approach of ANFIS

**Table 1**: **Algorithm of ANFIS controller**

| |
|---|
| *Step 1*: Let the outcomes and inputs are in normalized with their best maximum values with the range over 0 to 1. |
| *Step 2*: Maintain the network with guaranteed number of input stages. |
| *Step 3*: Define the number of hidden layers in the network. |
| *Step 4*: Develop the robust feed forward neural network by perfectly utilizing 'poslin' and 'transig' system parameters. |
| *Step 5*: Maintain the network learning rate as 0.02. |
| *Step 6*: Define the number of iterations presented in the system. |
| *Step 7*: reach the outcome or output. |
| *Step 8*: Train the neural network with the available inputs and feed-backed outputs. |
| *Step 9*: Perform the network simulation by using ‘gensim’ approach on the available neural network |

## 4. SIMULATION RESULTS

### 4.1 Simulation Environment

This section gives the detailed analysis of simulation environment with results analysis of the proposed method along with ANFIS controller. The system is simulated under the presence various crucial hazards, such as distortions in micro grid currents, voltage fluctuations and manipulations in islanding condition to check the efficiency and accuracy of the proposed method. The fluctuations presented in the voltage can results in the swell/sag generation in amplitudes. The microgrid currents are usually distorted by the non-linear load changes. *Figure 7* presents the entire simulation

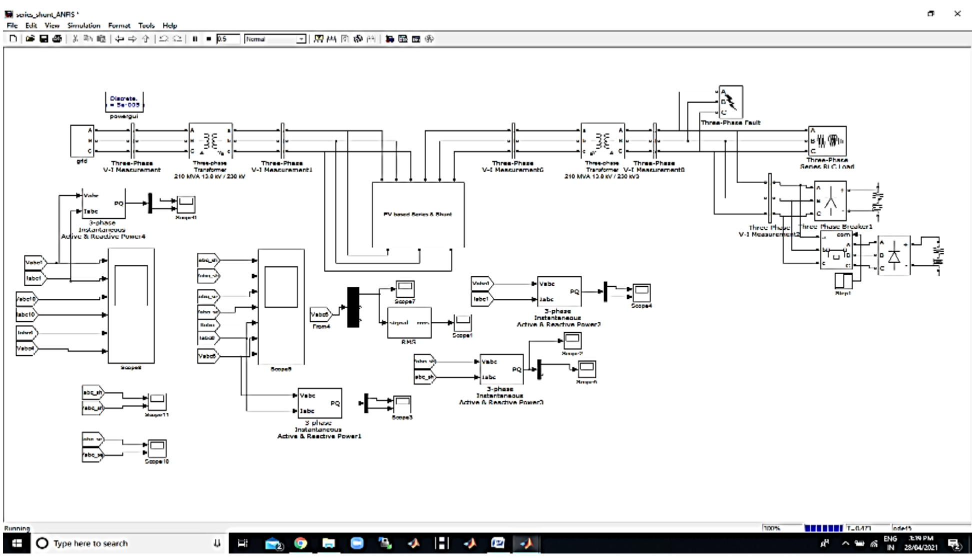


**Figure 7:** Simulation implementation of PV based DMLC with ANFIS Controller

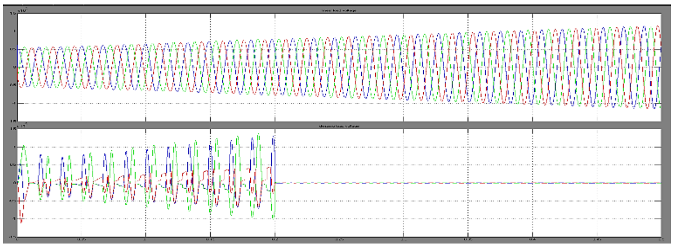
This section gives the detailed analysis of simulation environment with results analysis of the proposed method along with ANFIS controller. The system is simulated under the presence various crucial hazards, such as distortions in micro grid currents, voltage fluctuations and manipulations in islanding condition to check the efficiency and accuracy of the proposed method. The fluctuations presented in the voltage can results in the swell/sag generation in amplitudes. The microgrid currents are usually distorted by the non-linear load changes. Figure 7 presents the entire simulation environment of proposed method. The system contains various operational blocks, they are (from right to left) distributed energy source (PV) is replaced by the DC link capacitor, dual MLC with shunt and series converters, three phase non-linear and linear loads, a grid interfaced system. Here, converters are controlled and monitored by the ANFIS controller with three legs cascaded multi-level IGBT modules. The output of system is improved (noise eliminated) also by using the three-leg cascaded multi-level IGBT modules. By perfectly utilizing these modules, the above-mentioned fluctuations and distortions are eliminated. Mainly, the shunt and series controllers are used to reduce the distortions presented in microgrid currents as well as grid voltages, respectively.

## 4.2 Results and Discussion

The simulation is carried out in various cases; they are with presence of conventional fuzzy, ANN controllers, and proposed ANFIS controller.

**Case 1: with presence of conventional fuzzy controller**

In this case, the shunt and series controllers are implemented by the existing FLC. *Figure 8, figure 9 and figure 10* presents the simulation results of the load system voltages, and currents generated by using existing FLC. From the figures, it is observed that the outputs are distorted by utilizing the dynamic and non-linear loads. The settling time required to balance the currents is 0.32 seconds.



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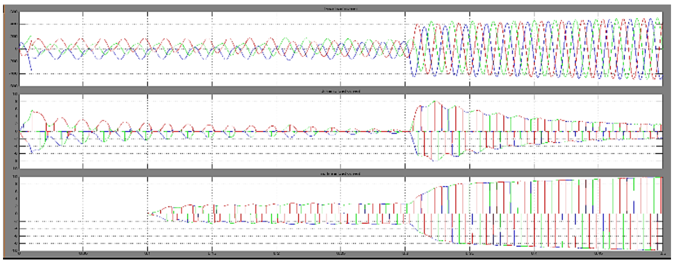


(b)

**Figure. 8:** Fuzzy based Simulation result for load. (a) Voltages (b) currents (settling time 0.32)

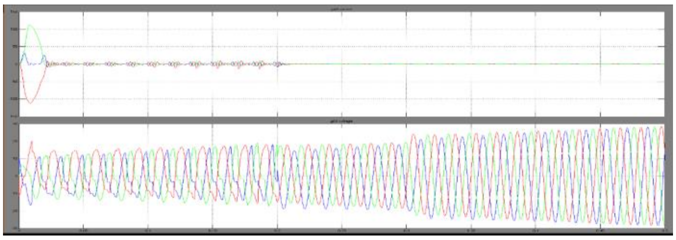


**Figure 9:** Fuzzy based simulation result of shunt converter currents and series converter voltages

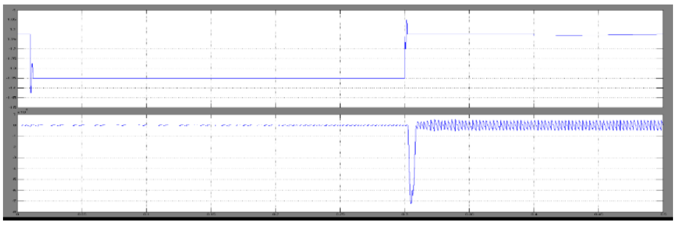
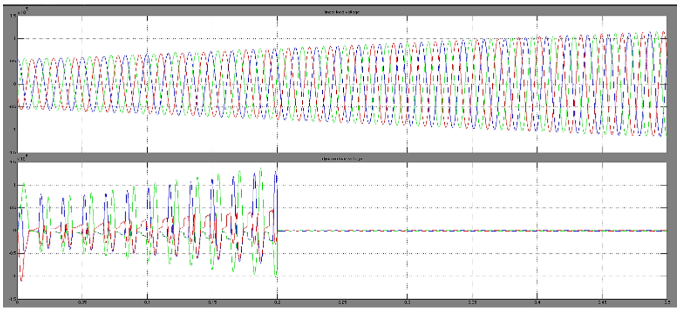


**Figure 10:** Fuzzy based simulation results of active and reactive powers of bus (settling time 0.32)

**Case 2: with presence of conventional ANN controller**

In this case, the shunt and series controllers are implemented by the existing ANN controller. *Figure 11* and *figure 12* present the simulation results of the load system voltages, and currents generated by using existing ANN controller. From the figures, it is observed that the outputs are distorted by utilizing the dynamic, linear and non-linear loads. The islanded condition operational performance with respect to reactive and active powers is presented in *figure 13*. The settling time required to balance the currents is 0.25 seconds set by the islanded.



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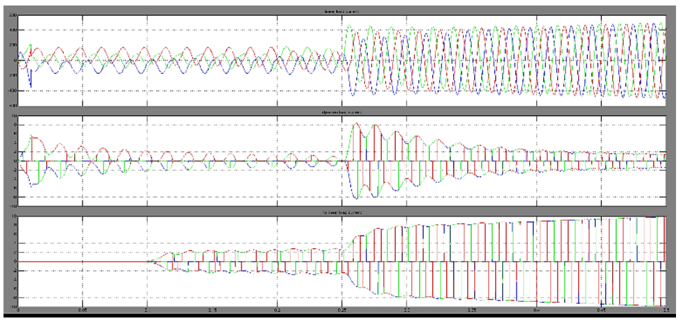


(b)

**Figure 11:** ANN based simulation result for load. (a) Voltages (b) Currents (settling time 0.25)

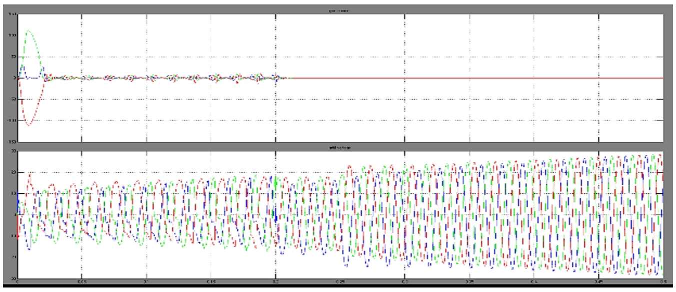


**Figure 12:** ANN based simulation result of shunt converter currents and series converter voltages

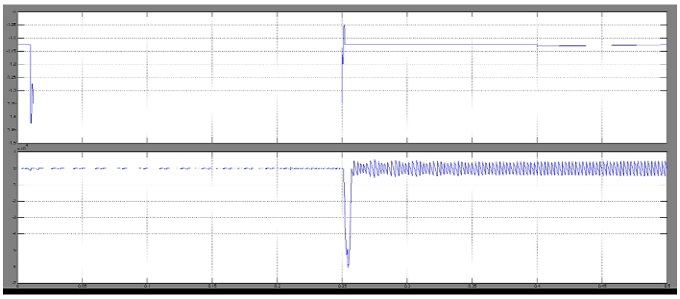
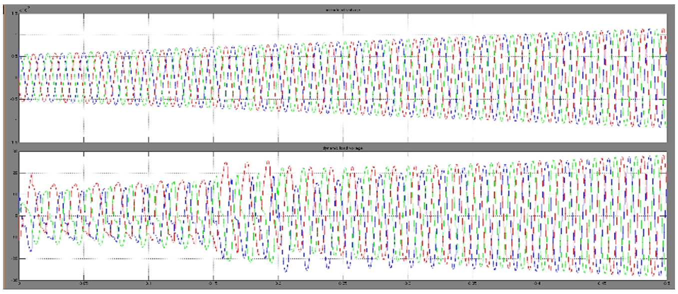


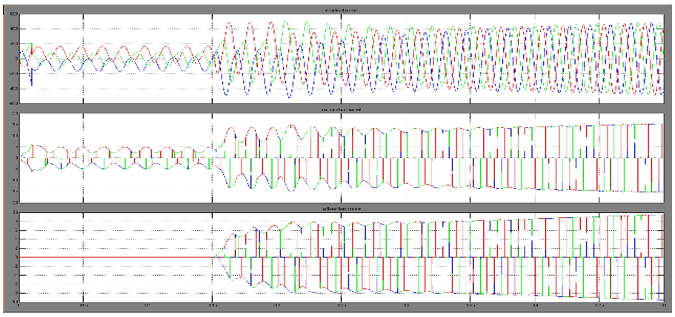
**Figure 13:** ANN based simulation results of active and reactive powers of bus (settling time 0.25)

**Case 3: with presence of proposed ANFIS controller**

In this case, the shunt and series controllers are implemented by the proposed ANFIS controller. *Figure 14* shows the simulation results of the load system voltages, and currents. The settling time required to balance the currents if 0.15 seconds. By comparing fuzzy, ANN, and ANFIS we can justify that the currents & voltages are balanced with the short time i.e., t= 0.15 sec. we can even find the disturbances in the voltages & currents are also solved in ANFIS control system.



(a)



(b)

**Figure 14:** ANFIS based simulation result for load. (a) Voltages (b) currents (settling time 0.15)

*Figure 15* specifies that with the help of the shunt converter, connected in parallel with grid & load system compensates current harmonics. With the help of the series converter, connected in parallel with grid & load system compensates voltage sags & swells the Figure shows the simulation result of shunt converter injected current & voltage injected by series converter. Initially from the 0.1 sec we find the disturbances in the voltage & current which are created by the dynamic and nonlinear loads in the system.

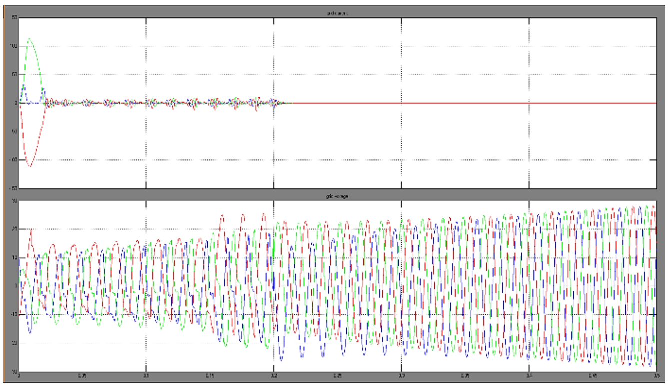


**Figure 15:** ANFIS based simulation result of shunt converter currents and series converter voltages

The islanded condition operational performance with respect to reactive and active powers is presented in *figure 16*. The settling time required to balance the currents is 0.15 seconds set by the islanded condition at the simulation time t=0.01 seconds. Then, finally the grid is disjointed from the system. Due to the series & shunt compensators connected in the grid system the active & reactive power stabilizes very fast at 0.15 sec and reaches its maximum value.

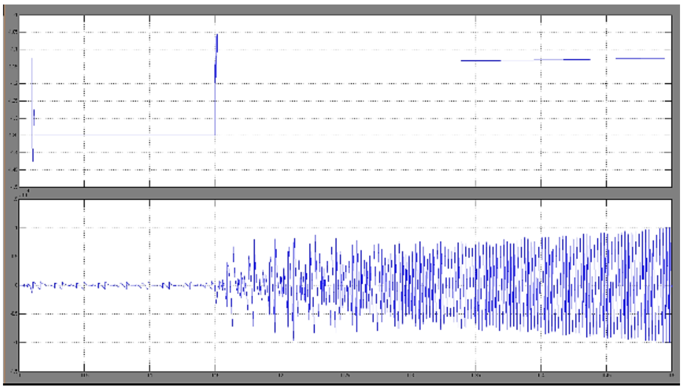


**Figure 16:** ANN based Simulation results of active and reactive powers of bus (settling time 0.15)

*Figure 17* presents the THD analysis of fuzzy controller, which is resulted in 29.13% of distortion. *Figure 18* presents the THD analysis of ANN controller, which is resulted in 26.82% of distortion. These two conventional approaches resulted in higher THD due to presence of harmonics in the generated power. Generally, these harmonics are generated due to non-linear systems with voltage fluctuations.

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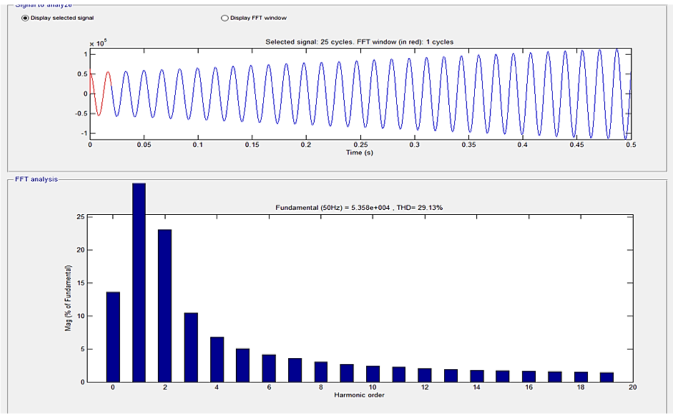


**Figure 17:** Case 1-fuzzy based THD: 29.13%

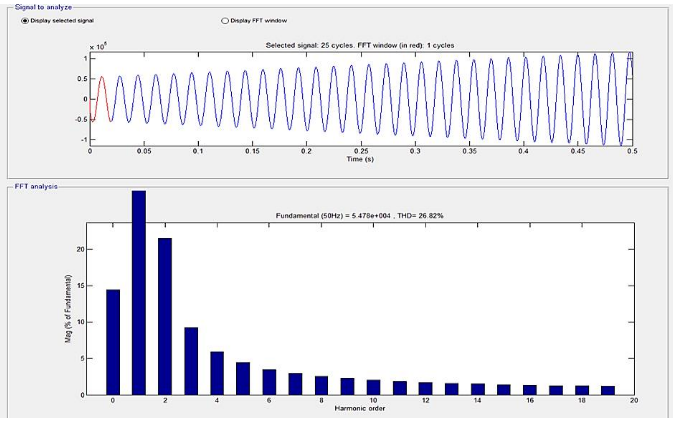


**Figure 18:** Case 2-ANN based THD: 26.82%

The major drawback of the exiting methods were they reduces only less amount and fixed harmonic disorder values and voltage sag swells, respectively. Thus, the proposed method is designed with the ANFIS controller and resulted in the maximum THD performance as presented in the *figure 19*, which can reduce the 14.18% of distortion. This performance is achieved by eliminating all the fixed and variable harmonic disorder values and voltage sag swells in the elaborated manner; thus, the stability, accuracy and robustness of the system is significantly improved as compared to the conventional approaches.

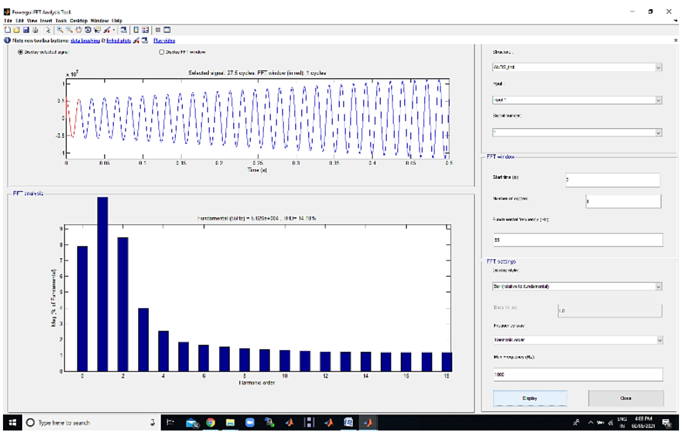

**Figure 19:** Case 3: ANFIS based THD: 14.18%

## 5. CONCLUSION

This work presented the implementation of the DMLC for the applications of microgrid or DG systems. Thus, the grid interface architecture was developed for the future microgrid technology, so the power quality of the system is improved. Usually, the microgrid itself controls and reduces the power quality related problems, but maximum efficiency is not achieved. Thus, the DMLC is a dual converter topology, which is introduced in the DG system. Here, the DMLC is controlled by using shunt and series based ANFIS controller, thus all types of voltage, current & active, reactive power fluctuations are effectively compensated. The THD analysis of the proposed ANFIS controller is resulted in better performance as compared to the conventional fuzzy and ANN controllers. From the simulation results it is also observed that the system stability is achieved in reduced setting time (0.15 sec) as compared to the conventional fuzzy and ANN approaches and perfect stability of voltages, currents and active reactive power were achieved in the short setting time, respectively.

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