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Modified Fuzzy Controller for Renewable Energy Management System Powered AC Micro-grid by Five Level Inverter with SVPWM Based on novel Optimization

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Abstract: Hybrid microgrids that run on renewable energy are gaining popularity all over the world. PV and PMSG-based wind energy conversion systems are well-known and straightforward to install among numerous renewable energy sources. However, both wind speed and sun irradiation are uncertain and vary arbitrarily. As a result, the power generated by both PMSG and PV panels cannot be consistent. At the same time, the load varies erratically. Hybrid systems should have storage components to keep the balance of power between generation and load. A tiny battery, in addition to the fuel cell and electrolyzer, is included in the system to make it more cost effective. As a result, all Microgrid components must have a strong energy management mechanism to improve power quality. In standalone Microgrids, frequency response and power balancing are critical during rapid changes in source and load. To keep the energy management system in the framework, a Modified Fuzzy rule based innovative controller is built to achieve valuable and rapid reaction. A MIWO based SVPWM selection procedure is also used to a five level H-Bridge inverter to achieve additional quality power at the load bus. The THD of voltage diminished from 4.82% to 0.41% and current THD is from 4.43% to 0.77% when the modified compensator is connected in the system.

1.INTRODUCTION

Everywhere in the world, the demand for power is expanding dramatically. Similarly, the world is striving to use Non-conventional sources to generate power in order to meet the consumer requirements by providing high-quality power [1]. Now a days the Renewable Energy sources are used as PV based Distributed Generation systems. In many regions, establishing standalone microgrids based on renewable energy sources might be a viable approach to lower the demand for electricity from utility networks. More nonconventional sources can improve system reliability [2, 3]. Solar energy systems based on PV panels and wind energy systems based on electrical power generation are the most prominent renewable energy conversion technologies that may be simply implemented around the world. Because it is directly coupled, The PMSG is the ideal solution for medium-sized wind turbine power generation applications. [4]. Due to fast fluctuations in both solar irradiation and wind velocity, the use of continuous supply necessitates the use of energy storage devices. As a result, in many regions, a battery is integrated into a PV or wind-based power generation system. Unfortunately, batteries have a high maintenance cost and a short life period (they must be replaced frequently), which might result in significant long-term operational costs. To address these challenges, electrolyzer and Fuel Cell (FC) sets are designed to function for an extended period of time in systems with small size batteries capable of maintaining balancing power amid sudden changes. Because of the slow dynamics of the electrolyzer and fuel cell, the battery must maintain the electrical power balance to keep the system stable [4]. This type of configuration can reduce total system costs. Yet, in order to maintain good energy balance and power quality, a proper coordination controller must be established among all of the components in a microgrid.

The gains of the PI controller will be adjusted at a specific time or change. As a result, the same advantages cannot be applied to all scenarios, particularly the microgrid, which includes renewable energy sources, electrolyzers, fuel cells, batteries, and quick variations in demand. For Power quality applications optimization methods are also employed in the converters operation [5, 6]. Modified Fuzzy controllers, which may alter gains in reaction to rapid changes in the system, are thus designed to provide fast response to any changes [7, 8]. Although all PV, wind, battery, electrolyzer, and batteries may give active power to loads, the bulk of loads will require reactive power due to their uses [9, 10]. As a result, the inverter must correct the useless power using the proposed controller in order to meet load demand. In addition, the real power is adjusted by adjusting the frequency of the microgrid at the site of PCC. Standard converters, on the other hand, can inject more harmonics into the load than multilayer inverters. In medium power applications, H-Bridge 5-level inverters are more cost effective than other layouts. Furthermore, the THD can be lowered further by employing an inverter with a pulse generator based on the SVPWM technology. Because of the numerous possible combinations of space vector regions and the increased number of switches in the 5 level inverter, to give the inverter a precise sequence of switching pulses, the optimization technique can simply address the problem. This can improve the power quality by increasing the fast responsiveness on voltage at the PCC during unexpected fluctuations. The following are the main goals of this framework:

- MIWO is applied to the SVPWM of a 5-level inverter to know the proper sequence of pulses in real time.
- The battery, FC, and electrolyzers are connected in a microgrid to create a economical system.
- Modified-Fuzzy controllers were designed to respond quickly amid rapid changes.
- The inverter compensates for both frequency and reactive power.
- Created a ground-breaking coordinated energy management solution for all microgrid connected devices

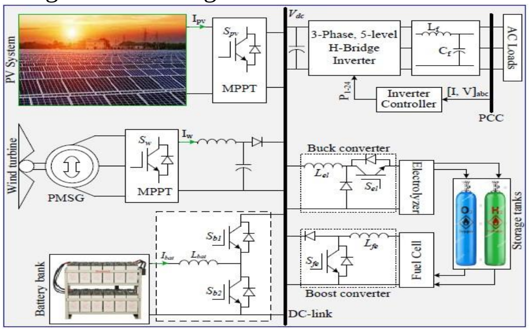

Fig.1. PV, wind, Electrolyzer, fuel cell, and battery-powered hybrid standalone Micro-grid.

2. METHOD

MPPT devices with proper algorithms are required for nonconventional sources such as PV and wind systems. As a result, this study investigates boost converters for MPPT devices using P&O algorithms for both renewable systems. The responses of both converters are linked via a DC-link. A bidirectional DC to DC converter is integrated between the battery and by using a DC-link to control charging and discharging current of the battery. The amount of current going through the electrolyzer determines the amount of hydrogen produced. As a result, a buck converter is connected between the DC-link and the electrolyzer to boost the current flow. Similarly, due to the lower voltage of the FC, a boost converter is put between the FC and the DC-link. A 3-phase 5-level H-bridge inverter connects the AC loads to the DC-link. Fig. 1 depicts the whole microgrid block diagram. [3, 4] considers the wind rotor, PMSG, PV, electrolyzer, FC, and battery specs.

Many writers propose similar types of systems, and a few of those that have recently been published are given here. The authors of [11-18] did not consider Modified-Fuzzy controllers for quick response, and many of them did not employ multilayer inverters to improve voltage profile. No authors have addressed the MIWO-based SVPWM inverter approach.

3.Modified Fuzzy Logic Controller

Because of fixed gains, the PI controller may not generate trustworthy reference signals immediately during sudden changes. Modified-Fuzzy systems are machine learning models that can alter weights/gains in response to system changes. As a result, even amid random changes, the modified-fuzzy model may generate accurate reference signals. The ANN learning method is interfaced with the Modified-Fuzzy system to provide quick weight updates. Figure 2 depicts the block diagram of a Modified-Fuzzy system with an ANN interface, while Figure 3 depicts the relevant Modified rule weights. The system's inputs will be

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the error and the changing error.

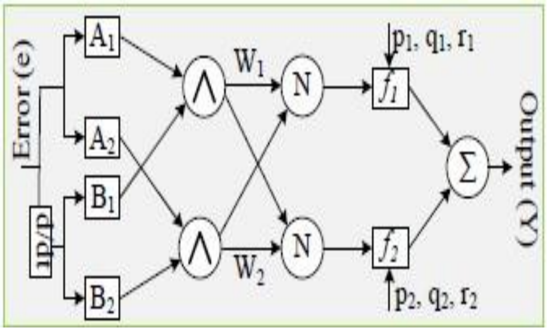

Figure 2. A Modified-Fuzzy system with an ANN interface.

Eq. (1) - (3) gives the mathematical formulas for the Modified-Fuzzy system.

$$f_1 = p_1 X_1 + q_1 X_2 + r_1 \quad (1)$$

$$f_2 = p_2 X_1 + q_2 X_2 + r_2 \quad (2)$$

$$Y = W_1^N f_1 + W_2^N f_2 \quad (3)$$

Where $p_{1,2}$; $q_{1,2}$; and $r_{1,2}$ are constants that serve as tuning parameters.

To get a quick reaction, trained ANN systems can update the required weights. This Modified-Fuzzy model, as built, can be conveniently employed in controllers of microgrid-connected converters. The related controller's error signal can be sent into the Modified-Fuzzy system to generate a relevant reference e signal.

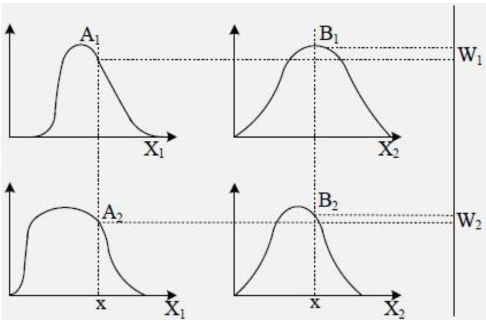

Fig. 3: Modified-Fuzzy rules-weight

4.DC SIDE CONTROLLERS

Nonlinear properties of wind turbine power vs. speed and PV power vs. voltage exist. Appropriate MPPT controllers are necessary to obtain the maximum power from both sources. To extract the most power from a PV system, use the boost converter in conjunction with the P&O algorithm. As a consequence, between the DC-link and the PV system, a simple boost converter is placed. To eliminate the usage of several voltage sensors, the MPPT controller uses DC-link voltage rather than voltage across the PV system. Figure 4 displays a simplified design of the MPPT controller's P&O algorithm for the PV system. To get the most out of the wind turbine, it must be run at a specified speed, which must be governed by any converter. However, because the wind turbine is directly linked to the PMSG shaft, the wind turbine speed may be regulated by modifying the PMSG speed. Three phase generation from PMSG to DC is converted utilizing a regulated rectifier to avoid the use of too many converters. The same rectifier is used to regulate the current of the PMSG in order to keep the turbine operating at the right speed for it to produce its maximum amount of power because speed is relying on the flow of current. As a result, 6 pulses (Sw) are created by applying the P&O algorithm with reference to the DC current injected into the DC-link from the PMSG. Figure 4 displays the required P&O approach, as well as an appropriate controller for generating pulses to a three-phase regulated rectifier. Because the outputs of the two MPPT converters are not identical, the diode can be useful in pushing the required current to the DC-link.

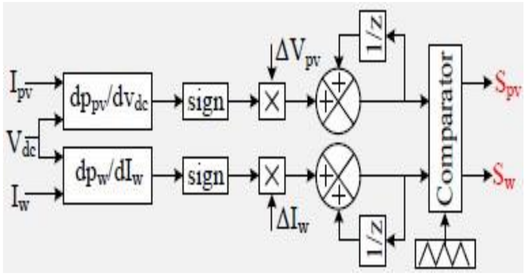

Fig. 4 PV and wind turbine MPPT controllers based on the P&O methodology

It is necessary to maintain a steady DC-link voltage. Typically, the power difference between total generation and load will be reflected in the DC-link. If the generation is more than the load, and vice versa, the DC-link voltage will be larger. As a result, the DC-link will regulate the charging and discharging of battery through the DC-DC converter. As a result, the modified-Fuzzy controller generates the reference battery current ($*I_{bat}$) signal by comparing the DC-link voltage (Vdc) to its reference value (*Vdc). By comparing $* I_{bat}$ with actual battery current, the hysteresis controller will produce the pulses (i.e., $S_{b1,2}$) for the converter (I_{bat}). However, in this framework, a modest battery size is considered to respond during transients. As a result, under steady-state operation, the battery shouldn't drain or charge. This is accomplished by preserving surplus power in response to a power mismatch between generation and load via either FC or electrolyzer. As a result, the I_{bat} has to compare with zero to accumulate pulses for the Buck-Boost converter.

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Positive battery current indicates that generation surpasses load, whereas negative current indicates that generation exceeds load. The Modified-Fuzzy controller generates the duty cycle reference signal for the relevant converters by comparing the actual battery current to the zero reference signal. When compared to PI, this Modified-Fuzzy controller can detect both positive and negative indicators of battery current in real time. Figure 5 depicts the corresponding DC-link voltage controller. Until the battery current in a constant state of operation hits zero, the FC or electrolyzer can keep the power balance.

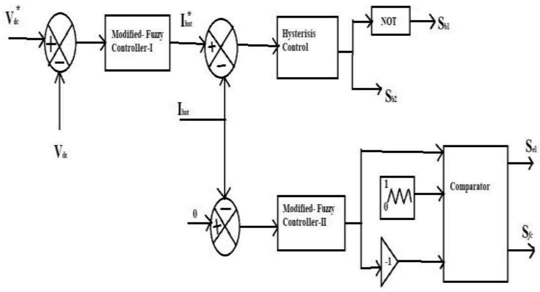

Fig. 5 DC-link voltage controller based on battery, FC, and electrolyzer

5.AC SIDE CONTROLLER

When compared to conventional switching inverters, switching strategies based on SVPWM can reduce THD. Additionally, the new SVPWM method and the 5 level inverter may be the best options for middle power uses that require high-quality electricity may provide additional benefits to the system [19]. As a result, in this research, an H-Bridge inverter with a 5 level SVPWM switching pattern is created to supply AC power to the PCC, which is attached to all different kinds of AC loads. Figure 6 depicts the three phase 5-level H-Bridge inverter.

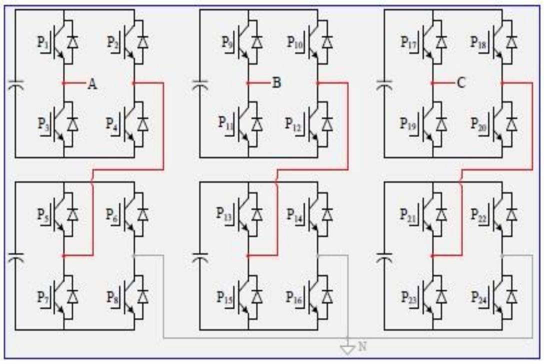

Fig. 6: Three phase 5-level H-bridge inverter

Once the DC-link voltage has been stabilized, by changing the inverter, it is possible to keep the voltage at the PCC. However, the microgrid's periodicity is also very important, and changes in frequency at PCC might be caused by the active power consumed by the load. As a result, it is possible to produce the actual load current component by comparison of frequency with its threshold value. The RMS voltage at PCC can also be changed to alter reactive power. The true dq currents at PCC compared with reference signals for the real and reactive current components after receiving them both in order to produce the necessary voltage signals for the dq components using the appropriate modified-fuzzy controllers. The 5-level inverter's full controller schematic is shown in Figure 7. The SVPWM generator will produce the proper pulse patterns for the inverter using the output reference voltage signals for the direct and quadrature axis. The 5-level inverter's pulse pattern is shown in Figure 8.

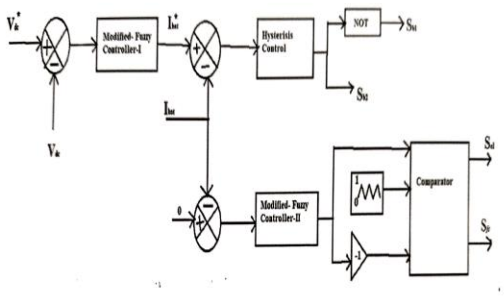

Fig. 7: Proposed inverter controller

6.RESULTS AND DISCUSSION

1. SVPWM with 5-Level MIWO Integration

Figure 8 depicts the 5-level SVPWM, generalized with suitable level representation. As per the generalized SVPWM approach, any combination of pulses is possible, and a few can be removed. The 5-level SVPWM is made up of multiple 2-level hexagons, each with seven pulse combinations, as seen in Fig. 9. In 5-level SVPWM spectrum, the reference voltage (Vref) can rotate by going over each hexagonal with 7 possible pulses. The Vref is derived from the below equations.

$$V_{ref} = \sqrt{V_\alpha^2 + V_\beta^2}$$

$$M = \frac{V_{dc}}{n-1}$$

Table 1: 0 to 90^0 pulse switching sequence.

S. No	Vector	Phase-A	Phase-B	Phase-C
1	0, 0, 0	---	---	---
2	1, 0, 0	2,3,7,8	10,11,14,15	18,19,22,23
3	2, 0, 0	1,2,7,8	10,11,14,15	18,19,22,23
4	3, 0, 0	1,4,7,8	10,11,14,15	18,19,22,23
5	4, 0, 0	1,4,5,8	10,11,14,15	18,19,22,23
6	1, 1, 0	2,3,7,8	10,11,15,16	18,19,22,23
7	2, 1, 0	1,2,7,8	10,11,15,16	18,19,22,23
8	3, 1, 0	1,4,7,8	10,11,15,16	18,19,22,23
9	4, 1, 0	1,4,5,8	10,11,15,16	18,19,22,23
10	1, 2, 0	2,3,7,8	9,10,15,16	18,19,22,23
11	2, 2, 0	1,2,7,8	9,10,15,16	18,19,22,23
12	3, 2, 0	1,4,7,8	9,10,15,16	18,19,22,23
13	4, 2, 0	1,4,5,8	9,10,15,16	18,19,22,23
14	2, 3, 0	1,2,7,8	9,12,15,16	18,19,22,23
15	3, 3, 0	1,4,7,8	9,12,15,16	18,19,22,23
16	4, 3, 0	1,4,5,8	9,12,15,16	18,19,22,23
17	2, 4, 0	1,2,7,8	9,12,13,16	18,19,22,23
18	3, 4, 0	1,4,7,8	9,12,13,16	18,19,22,23
19	4, 4, 0	1,4,5,8	9,12,13,16	18,19,22,23

$$\begin{pmatrix} SV_1 \\ SV_2 \\ \vdots \\ SV_{K-1} \\ SV_K \end{pmatrix} = \begin{pmatrix} (L-2)V_1 \\ (L-2)V_1+(1)(V_2-V_1) \\ \vdots \\ (L-2)V_1+(K-1)(V_2-V_1) \\ (L-2)V_1+(K)(V_2-V_1) \end{pmatrix}$$

Where SV_k indicates kth support vector.

In Table-1 the 5-level H-bridge inverter illustrates the possible combinations of all 24 switches in the range of 0 to 90^0 (total 19 combinations). The remaining pulses are simply created by combining these 19 possibilities.

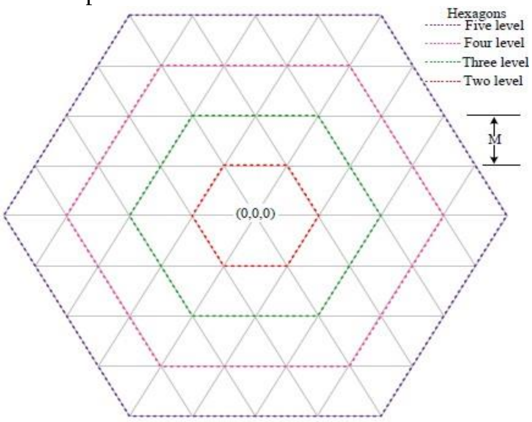

Fig. 8. 5-level SVPWM inverter operating settings with vector support

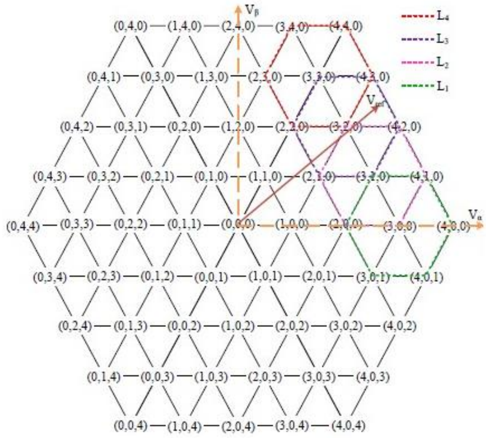

Fig. 9: A 5-level inverter's space vector Sequence.

In Fig. 9, several permutations of two level vectors are accessible; therefore, it is critical to determine the optimal location that can provide the best inverter output. The monarch butterfly optimization (MBO) and Grey wolf optimization (GWO) are used for finding optimal best location [5, 6]. The MIWO method, which may readily spread multiple weeds to the entire SVPWM spectrum during the process, can identify the optimal vector/location. The MIWO method is an easy and efficient optimization technique that was influenced by weed colonisation. It is proved that when compared to new evolutionary-based algorithms, the MIWO has a higher capacity in looking for the optimum spot or agent, as well as a higher flexibility to changing external factors. [12]. As a result, MIWO is used in this framework to determine the ideal vector point for generating a correct pulse to the inverter. The Cauchy density function employed in MIWO has primarily two parameters- location and scale. The 5-level SVPWM must also identify the right location as well as the optimal vector location parameter. The standard deviation (σ) is nothing more than the scale values. Because the MIWO can manage high-dimensional test functions, it can respond to challenging search issues with quicker convergence to the best solution. By employing the mean of the parent weed's location and the variable standard deviation, the newly produced offspring weeds are typically distributed throughout the search region.

$$\sigma_j = \frac{(w-j)^q}{w^q}(\sigma_{initial} - \sigma_{final})$$

$$SV_{k+1}^j = SV_k^j + x\sigma_j * Cauchy(0,1) * \left(SV_{best} - SV_k^j\right)$$

Where $x = \frac{V_{ref}}{V_{dc}} * \tan\left(\frac{V_\beta^j}{V_\alpha^j}\right)$, j is iteration, q is non-linear quantity

In this study, the modulation index is set at 3. The letter 'w' stands for the number of parent weeds.

Case-1: System response with MIWO-SVPWM

At t=2.5 sec, the microgrid is evaluated with and without MIWO for a sudden change in demand. When the load abruptly changes, the inverter controller uses SVPWM to try to find correct switching pulses. When compared to the typical 5-level SVPWM approach, the MIWO algorithm takes much less time to identify and has less dip and rise in line to line voltage. Figure 10 shows the line-to-line Effective voltage response with traditional and MIWO combined SVPWM methods.

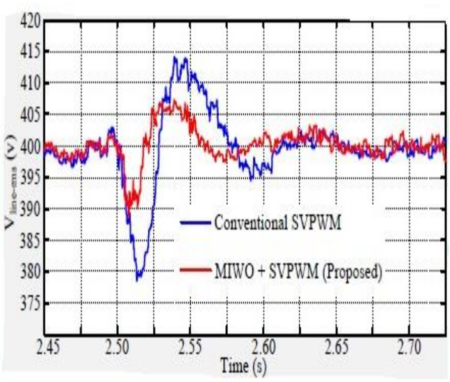

Fig. 10: Line-to-line voltage response with conventional and proposed (MIWO) SVPWM

Case-2: *Response of the mechanism to different modifications*

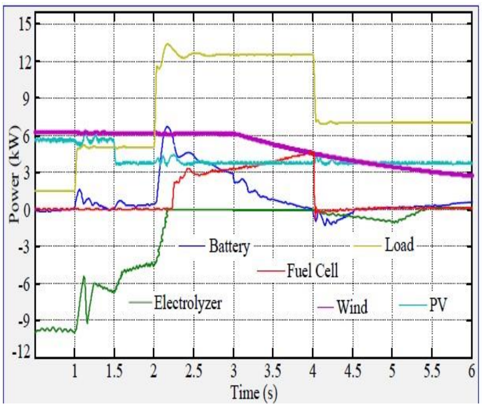

Fig. 11: Changes in power in a standalone microgrid.

Case 3: The system's THD response: FFT analysis yields THD for both line voltage and current. According to Fig. 12, the voltage THD is 0.41%. Similarly, 0.77% for current was obtained and shown in Figure 13. Both THD levels are within acceptable limits. THD percentages for systems without SVPWM, standard SVPWM, and suggested SVPWM are shown in Table 2.

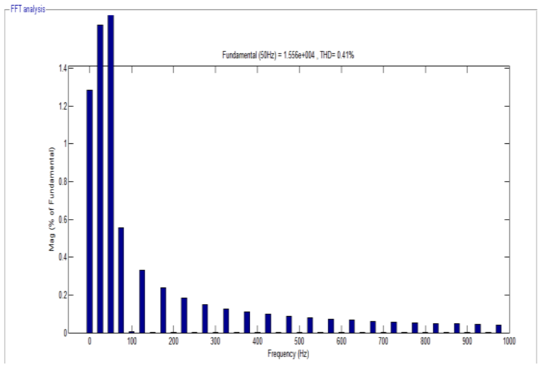

Fig. 12: THD of line voltage

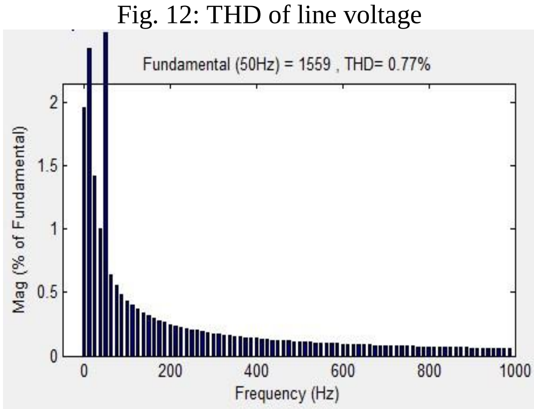

Fig. 13: THD of line voltage

Table-2: System THD comparison table

		Without-SVPWM	Conventional-SVPWM	MIWO SVPWM
THD	V	4.82	3.68	0.41
	I	4.43	2.78	0.77

7.CONCLUSION

Modified-Fuzzy controllers are used to build an effective energy control system for standalone microgrids built on PV, wind, battery, FC, and electrolyzers. The proposed controllers achieve quick frequency response. A proper coordinating energy management system is built among all of the microgrid's components. PCC also maintains power quality during all types of adjustments. A 5-level SVPWM-based H-Bridge inverter is integrated into the system to increase voltage quality. The MIWO algorithm is combined with the SVPWM approach to quickly find correct switching patterns and achieve fast voltage responsiveness at the PCC. To respond to transient periods, a small battery bank is contemplated, in order to keep power equilibrium between generation and demand during steady-state operation, FC and electrolyzers are recommended. When the proposed method is used the voltage THD is reduced from 4.82% to 0.41% and current THD also diminished from 4.43% to 0.77%.

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