Energy Management System and Enhancement of Power Quality with Grid Integrated Micro-grid using Adaptive Fuzzy Logic Controller

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Abstract- Microgrids (MGs) are a flexible way to incorporate renewable energy sources into the grid. Micro grid (MG)offers a different way to generate electricity at the supply voltage level through installation of small distributed energy sources. Through their interconnection, the power electronics components contribute to MG's adaptability and dependability. Power quality issues are caused by grid's many non-linear, unbalanced loads. Intelligent controllers must be implemented to boost Micro-grid power quality, battery characteristics, MPPT for solar, wind power. Adaptive controllers are favoured in this study. By controlling charging, discharging of battery units in response to generation-demand mismatches, battery status, integrated micro-grids that make use of adaptive fuzzy logic controllers and fuzzy logic controllers can reduce frequency fluctuations. In this article, MPPT is achieved by the application of Petrurb & Observe (P&O), Incremental Conductance (IC) technique. The proposed model's dynamic behaviour is analysed over operational conditions. During grid isolation, measurements of solar irradiance, temperature, wind speed are taken from connected systems, calculations of actual, reactive power are made. The results are obtained by MATLAB/ SIMULINK.

Keywords Microgrid, Power Quality, MPPT, Adaptive Controllers, P&O Metho, IC Method, MATLAB.

1. Introduction

A power system community that collaborates to manage electric power grid by pooling resources from multiple renewable energy sources[1]. Besides importance of electricity grid, energy crisis also has a major impact on a country's economy. The microgrid is proposed as a solution to the energy crisis (MG). There are three main benefits to using energy storage: (a) reduced environmental consequences, leading to cheaper equipment; (b) improved energy stability efficiency; (c) ride-through capability[2]. Grid issues include stability, load disruption, and uncertainty. An intelligent controller, Adaptive Fuzzy Logic Controller, is introduced to solve grid issues and boost electricity quality[3]. Microgrids incorporate "renewable sources," "storage systems," and "controllable loads" to automate energy management decisions. In order to regulate operation of energy management system, the suggested adaptive FLC handles parameters such as dc-link voltage, actual power, reactive power, and harmonic distortions[4]. Compared to a "BESS" with constant voltage of islanded MG, a "FBESS" with fuzzy logic improves dynamic power, responsive control. As a result, FLC algorithms have been improved to import service to PV-battery systems while still preserving grid voltage stability[5]. Fuzzy logic controllers can determine amount of energy stored by regulating the flow of power from the "BES," "Power Exchange Grid (PEG). This study pioneers a new method of adaptive FLC-based energy management for rethinking dynamic grid control. With goal of reducing load variations, uncertainty associated with integration of renewable energy sources, adaptive intelligence for energy management of linked MG is a key component in maximizing optimal distribution benefits[6]. Peak power, short-circuit current density, current error, solar irradiance are solar energy parameters calculated in this work. This study analyses "output energy (power coefficient)," voltage, current, frequency of wind energy[7]. Two main components of any control technique are 1) maintaining a constant voltage on dc bus 2) dividing up the load amongst multiple parallel power sources. Thirdly, standard of available electricity. The dc-link voltage is required for grid-coupled PV converters[8]. This proposed setup makes advantage of DC-link voltage, internal current control loops. In aforesaid resilient system, dynamic reaction (DR) of EMS is a critical limitation that will affect grid loads. Isolated microgrids are particularly affected by this situation due to low system inertia brought about by widespread adoption of renewable energy sources (RES). Inertia constant, frequent fault occurrence, extended fault cleaning time are all examples of DR difficulties[9]. SoC, SoH of battery have an effect on DR. Energy merchants can maximize their profits by employing load management technologies, which improve dynamic response. Active losses in DER windings, converter switches were inflated by these simulations[10]. In order to address these challenges, a hybrid frame of active, reactive power flow in MG with PV generation is developed[11].

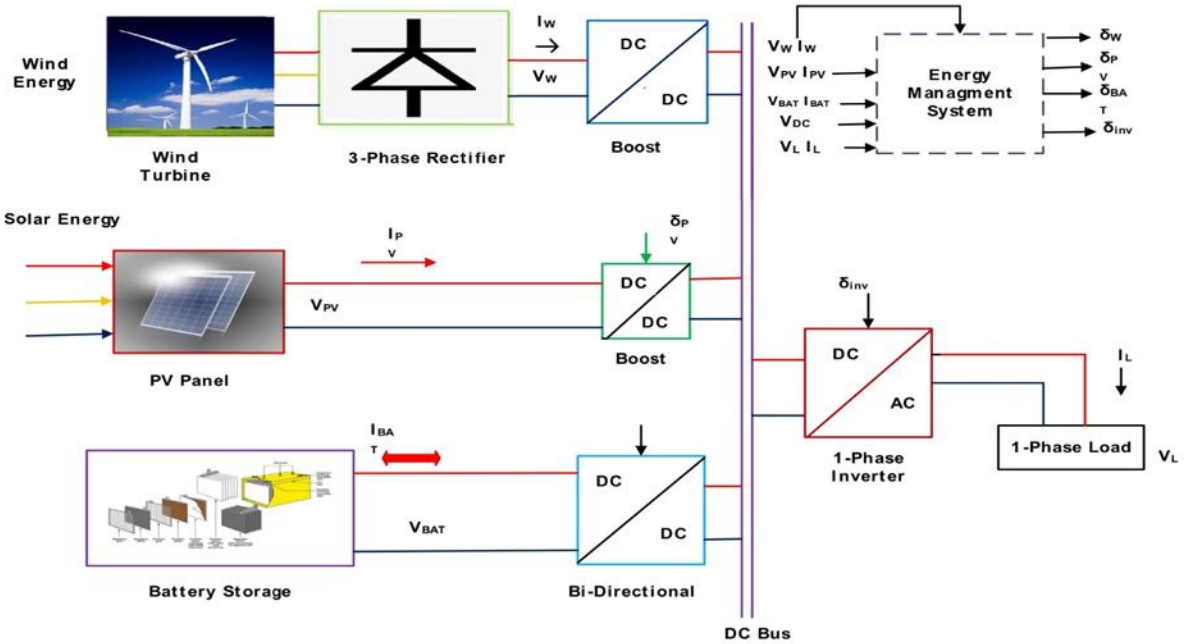


Figure 1. Energy Management System

2. System Description

Grid-connected photovoltaics, wind energy conversion systems, battery storage are all part of proposed system (BESS). When energy production exceeds consumption, batteries are utilized to store surplus power[12]. Hybrid systems with VSI employ DC link capacitor voltage sensors to manage AC or DC voltage levels[10]. A BESS's current and temperature can be calculated using data from a current sensor[13]. The CS is accurate to within 1.0 at temperatures ranging from -400C to +850C, has a measuring range of up to 2000A. The system's reliability is enhanced by the larger IGBTs employed[14]. The FOFLC is used to trace changes in battery, PV voltages as well as to keep output voltage constant . The proposed system is shown in Figure 2.

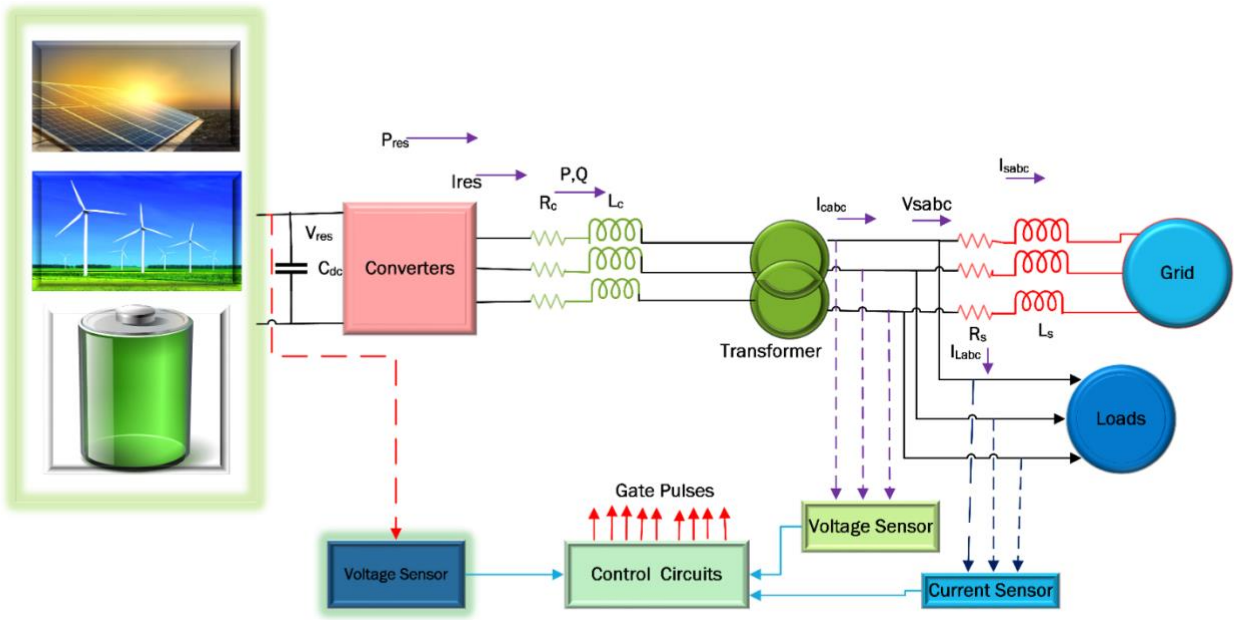


Figure 2. Proposed System Configuration

3. P&O MPPT Method

The P&O method is used to keep tabs on MPP since it is easy, does not demand any prior familiarity with sun intensity or cell temperature. PV operational will be delegated to MPP in event of a voltage or power increase[15]. In the event of a decline in voltage, the PV operational point will move closer to MPP. For more upheaval on the path to MPP, choose right fork. If increasing the voltage results in a decrease in output, operating point of PV module is to right of MPP, further perturbation to left is necessary to reach MPP. From V(t),I(t), we may calculate P(t), which we then use to evaluate P. (t-1). Maximum power is achieved at a value of 0 for P[16]. The size of steps While P&O method is fast, it does alter appearance of MPPT in a PV module. Because of smaller step size, there is a lag in beginning of action, but the influence builds more gradually[17]. The P & O flow chart is presented in Figure 3.

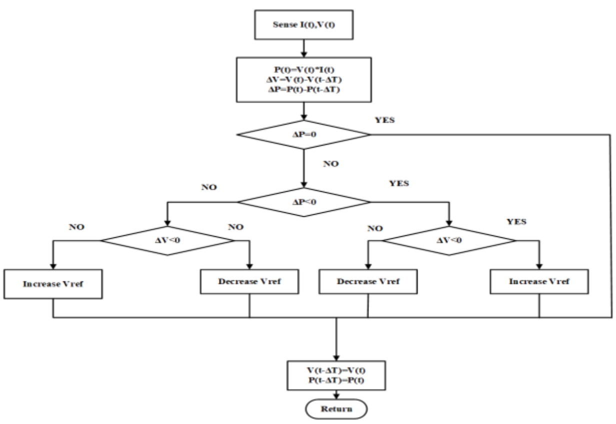


Figure 3. Flow chart of P & O Method

The algorithm steps for P& O method

- The voltage, current V(t), I(t) of the PV module are used as input signals for MPPT algorithm.
- The power P(t) is calculated by V(t)*I(t) and change in input signal ΔV,ΔI are calculated by using formula ΔV=V(t)-V(t-δT),ΔI=I(t)-I(t-δT) respectively.
- The second step is followed by ΔP=0 if it is YES Vref is increased which can be termed as Vrefmax.
- If Second step is NO it will be followed by ΔP<0.
- If 4^{th} step is YES or NO will be followed by Δ V<0 which is used to calculate Vrefmax, Vrefmin.
- Vref is limited by maximum, minimum values (Vrefmax,, Vrefmin) of $Vref$ to prevent DC-DC Converter in module level power electronics
- The steps from (1) to (8) are repeated to operate DC–DC converter at MPP of PV module.
- In the last step of MPPT modelling change in voltage, power is calculated.

4. Incremental Conductance (IC) Method

The IC method is based on PV array power curve with a slope of zero[18]. To keep tabs on the I/V comparison for IC MPP, we do -I/V till -I/V = -I/V. The PV array keeps producing electricity even after its maximum output has been reached. IC is a robust algorithm that features fast sampling rates, effective tracking, operating voltage adjustment with no oscillations[19]. The reaction time is reduced, extracted power is easier to regulate[20]. The IC flow chart is presented in Figure 4.

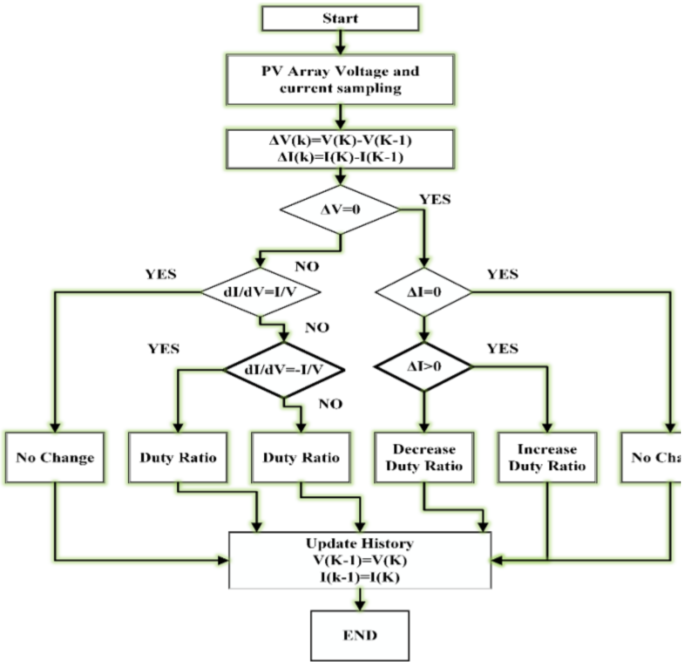


Figure 4. Flow chart of IC Method

The algorithm steps for IC method

- In this expression, V(k) is the current, I(k) is voltage, V(k-1), I(k-1) are previous values.
- When determining an advanced value, the system checks to see if the voltage and current differences between the two values are zero.
- In the case where V=0 and I=0 both have the same impedance, the duty ratios will be identical.
- If voltage differential ΔV=0, current differential zero ΔI>.0, the solar radiation changes.
- If dI/dV=I/V, duty ratio is increased, if dI/dV=-I/V the duty ratio is decreased.
- Duty ratio goes up when the difference between the present numbers is more than zero and down when it is less than zero.
- If the voltage difference is non-zero, the system is not at its maximum power point (MPP), as indicated by slope of power curve being zero.
- If the conductance variance is greater than negative conductance values, the duty ratio will increase (positive slope of power curve) and vice versa (negative slope of power curve).

5. Control of Power Quality Issues in Grid and Control Strategy

The introduction of sinusoidal current into grid is a fundamental unbiased element of enhancing power quality, this remains true even when nonlinear/asymmetrical loads are coherent[21]. The ability of fuzzy logic controllers to eliminate harmonics utilizing dominant sinusoidal signals, **as** well as to spread THD across voltage, current, is investigated[22]. With a controller and current loop, it can inject power into electric grid. In this research, FLC is used as a control method for battery storage systems to maintain a constant voltage from within a set range of millivolts (MG). The dynamic response of islanded MG is intended applications of this BESS FLC technology, which employs a robust control approach[23]. The FLC is used because it can effectively mimic human logical reasoning while still being inexpensive, flexible, individually tailored, highly efficient, dependable. The FLC recognizes that need for load can be satisfied by both technological, economic factors. In this study, we suggest EMS for reducing power profile variations in grid. The suggested EMS uses a low complexity FLC that has 25 rules to create a battery SoC. This method is based on tracking energy conversion rate, system on a chip (SoC) of battery regulates amount of energy sent out to and taken in from grid[24]. The purpose of this work is to propose an enhanced FLC-based EMS design for reducing power peaks in grid power profile while keeping battery SOC development within secure bounds, hence reducing complexity of FLC.

Battery charging and discharging schedules, as well as EMS deployment, are all under the control of an FLC-based architecture. Since they can handle poorly stated or described nonlinear systems, adaptive fuzzy logic controllers (AFLCs) are widely used in modern industry[25]. AFLCs have been used to regulate a wide variety of critical nonlinearities in nonlinear systems. This study shows that by modifying adaptive FLC, EMS parameters can be optimized.

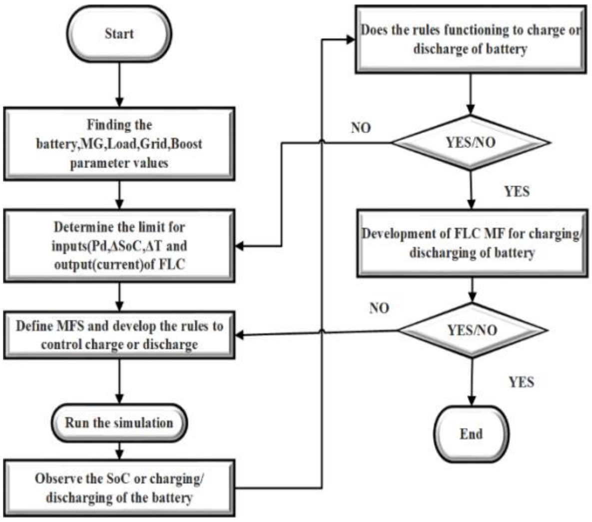


Figure 5. Flow chart of FLC

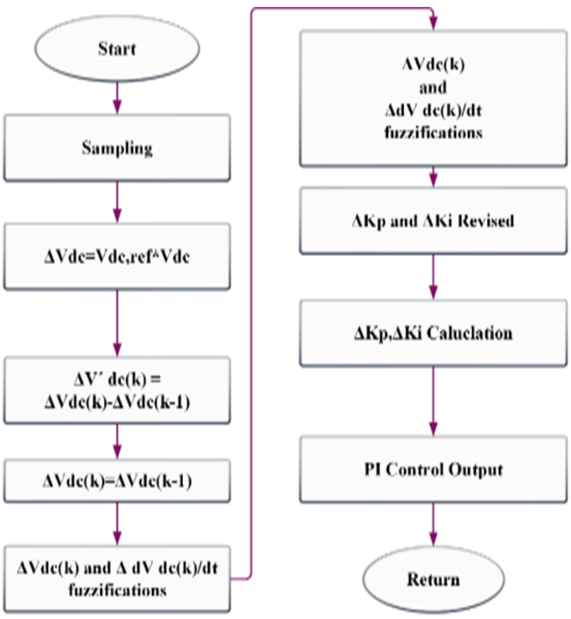


Figure 6. Flow chart of Adaptive FLC

6. Implementation of Control Techniques

The proposed FLC is depicted in Figure 7. The suggested FLC has two inputs, two output membership function is shown in Figure 8, Figure 9.

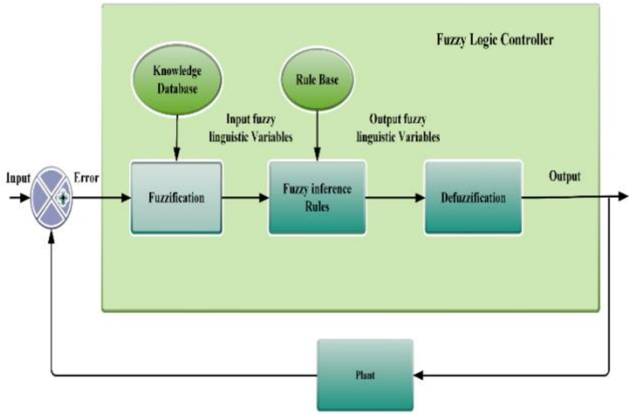
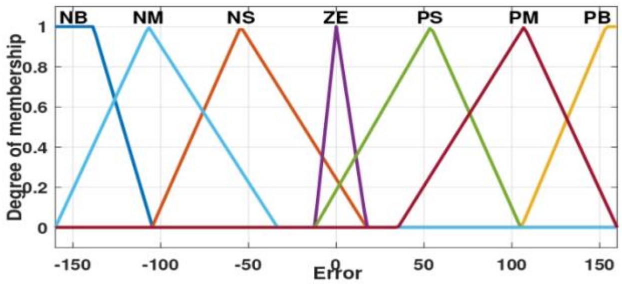
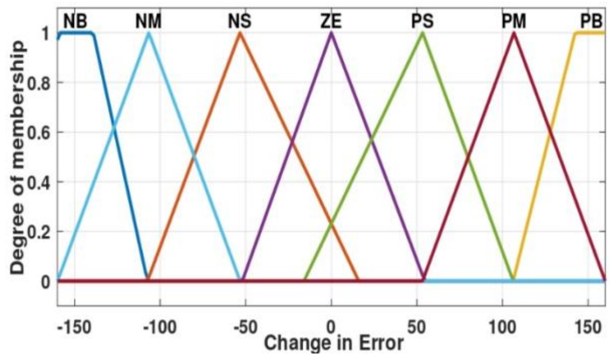


Figure 7. Fuzzy Interference Systems



(a) Membership function for input 1



(b) Membership function for input2

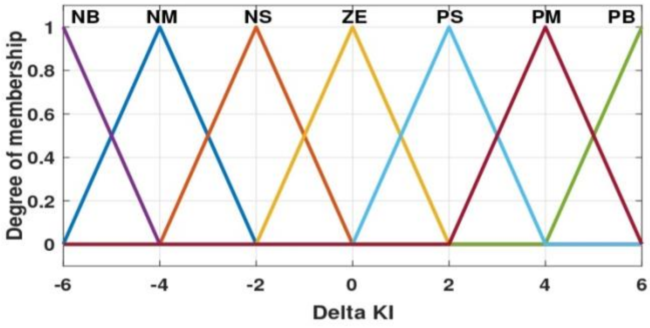
Figure 8 Membership Function for error, change in error

The gain values kp,ki are calculated from (1) &(2)

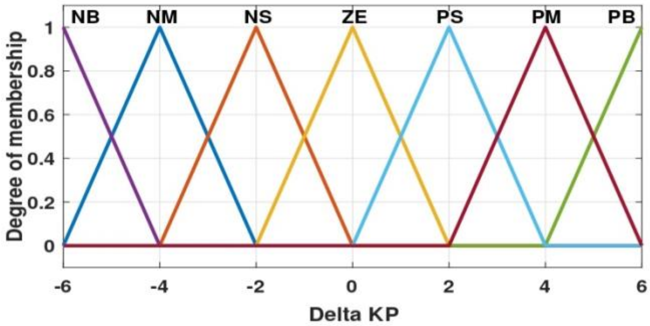
$kp=Kp+\Delta Kp$…………(1)

$ki=Ki+\Delta Ki$……………(2)

The values of FLC's initial gains (kp,ki) and their respective scaling factors (Kp, Ki) are substituted. When Vdc,ref,Idc,ref are inputs and Kp,Ki are outputs, the proposed control structure can be used in wind energy management systems [26]. Equations 1 and 2 can be used to calculate resulting gain values. In Table 1 the guidelines for proposed FLC are given.



(a) Membership function for output 2



(b) Membership function for output 2

Figure 9. Membership Function for ΔK_p, ΔK_i

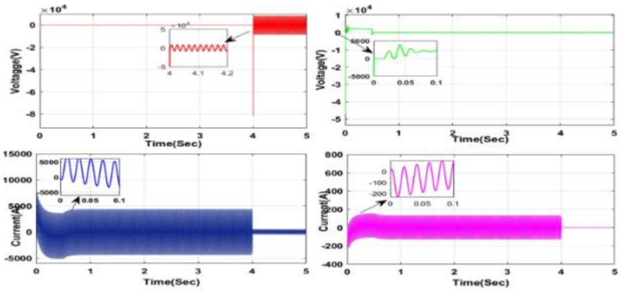
The gain values can be derived from equations 1& 2. The rule table for suggested FLC is given in Table 1.

Table 1. Rule Table

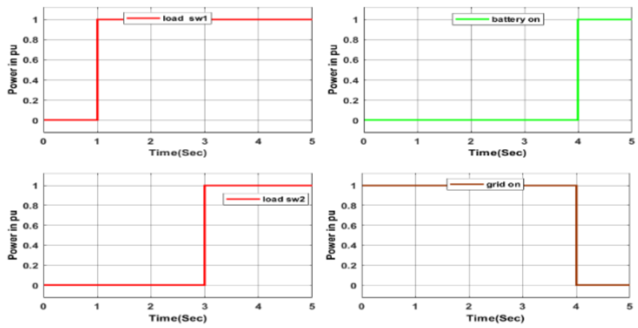
	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

7. Simulation Results

This section explains simulation results. THD findings for V_s, I_s, V_L, I_L with FLC and adaptive FLC show variation, results for the Grid and PV voltage as well as EMS system with FLC, FLC exhibit variation. There are two situations where EMS is mentioned in this work. Condition 1: Grid is 'ON', Battery is 'OFF'; Condition 2: Grid is 'OFF', Battery is 'ON'. The efficiency, effectiveness, dependability of major grids can all benefit from this idea's implementation of RES capabilities, functional load control[27]. The final findings of planned MG with EMS are shown in Figures 10 and 11. A controller in an energy management system switches on, off power in a calculated manner.

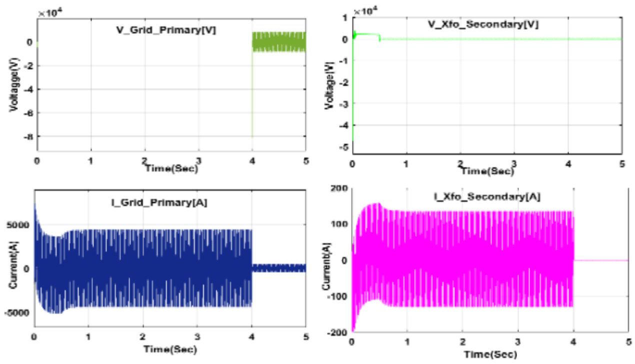


(a) Variation of PV voltage and current under variable condition with Adaptive FLC

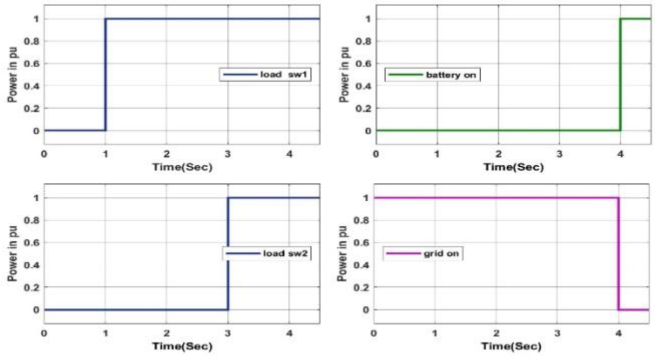


(b) Variation of power under variable conditions

Figure 10. Energy Management Control with Adaptive FLC



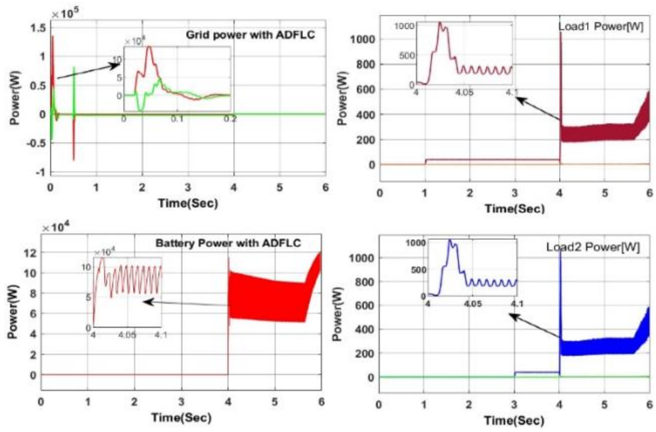
(a) Variation of Grid, PV voltage and current under variable condition with FLC



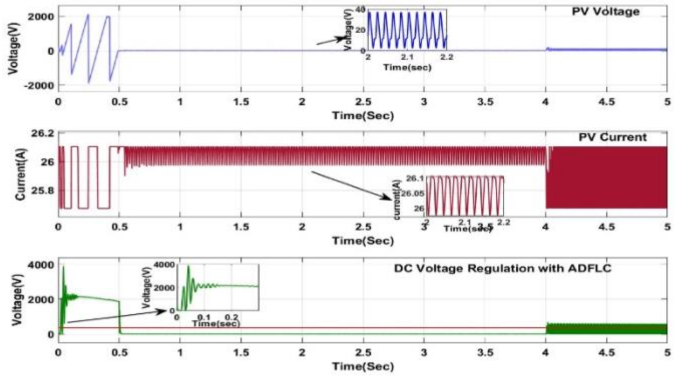
(b) Variation of power under variable condition with FLC

Figure 11. Energy Management Control with FLC

When grid is activated, battery is discharged, loads are activated automatically. Figure 11 illustrates the EMS powers. Power on grid stabilized in as little as 0.03 seconds thanks to a highly effective controller[28]. The controller shortens the time it takes for transient to disappear. The charging process starts after 4 seconds. At 1 second, load1 is activated, at 1.003 seconds, transients associated with load1 are at their lowest. Load 1 experiences transients for 4 seconds before they are eliminated at 4.03 seconds, resulting in a stable state of load power 1; load 2 is turned on for 3 seconds before experiencing transients for 4 seconds, resulting in a stable state of load power 2 at 4.02 seconds. Figure 12 shows how adaptive FLC and DC voltage regulation with proposed controller affects power consumption of the grid, battery, load under varying conditions[29]. Figure 13 shows how grid power, battery power, load power vary under different scenarios with FLC, DC voltage regulation with proposed controller. Figure 12(b) and Figure 13 display a comparison of DC voltage regulation using FLC, the suggested controller (b)After implementing proposed controller, DC voltage's dynamic performance was shown to dramatically increase[30].

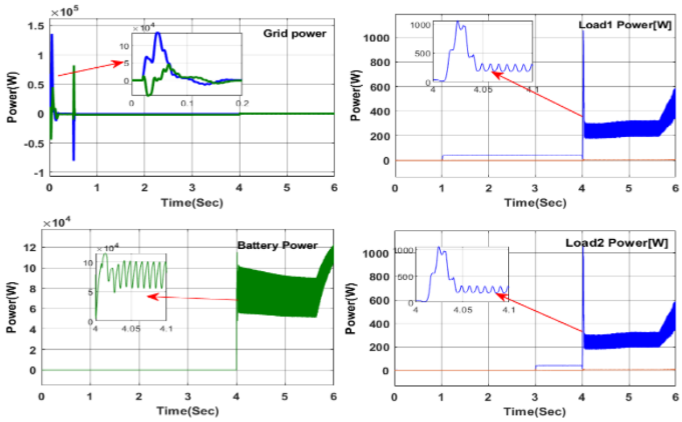


(a) Variation of Grid Power, Battery Power and Load different Conditions with adaptive FLC

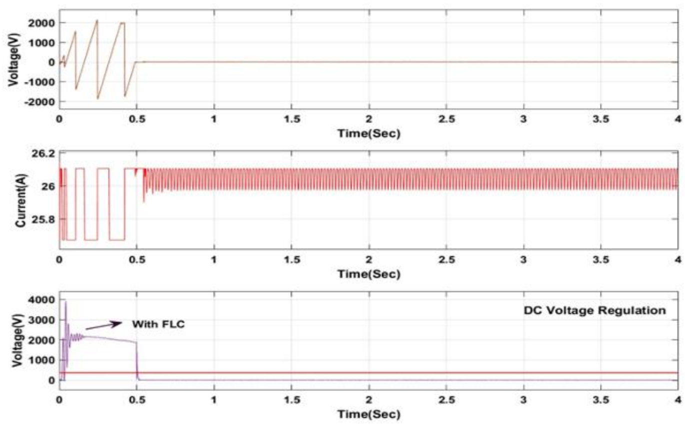


(b) Results of V_{PV}, I_{PV}, and Vdc Regulation with adaptive FLC

Figure 12. Simulation results of different performance parameters under variable condition with adaptive FLC



(a) Variation of Grid Power, Battery Power and Load different Conditions with FLC



(b) Results of VPV,IPV, and Vdc regulation with FLC

Figure 13. Simulation results of different performance parameters under variable condition with FLC

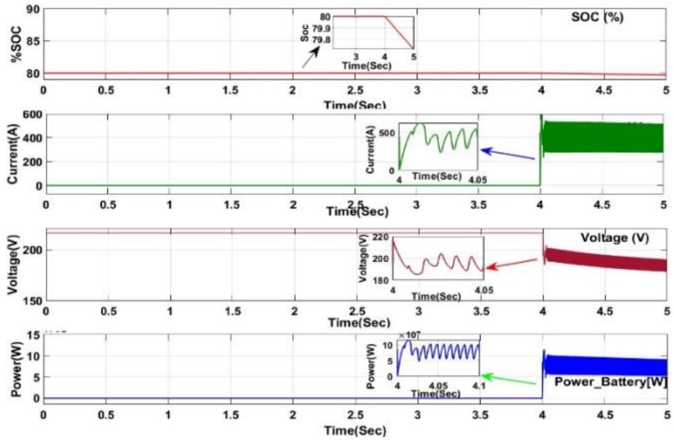


Figure 14. Performance of %SoC, Battery Voltage, Current, Power during Battery "ON" with adaptive FLC

During Battery "ON," graphs in Figures 14, Figure15 show the results of FLC, adaptive FLC in terms of %SoC, voltage, current, and power. In the suggested approach, proposed controller restores steady-state grid power in 0.03 seconds. If implemented, proposed controller would boost integrated MG's dynamic performance.

As can be seen in Figures 14, Figure15, percentage of SoC has increased thanks to FLC. Within allowed period, %SoC increased from 84.5% to 86.2%, improvements were also seen in BMS metrics. To settle tension between ideal load voltage, one that is actually supplied, suggested controller smoothest source voltage in question by reducing presence of odd harmonics. The suggested controller has been shown to efficiently calculate reference values more quickly than FLC, to efficiently regulate voltage more quickly. Source and load currents are seen to be in harmony in proposed system, with less distortion than in FLC. In Figure.16, the phase-to-load voltage compensation findings, while in Figure.17, the phase-to-load current compensation results alongside simulation results from proposed control technique, compensated device. The THD values of parameters are shown in Figure 17 to Figure 24.

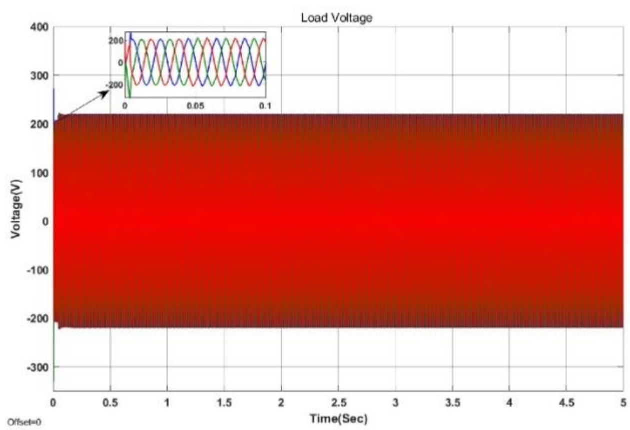


Figure 15. Simulation Results of Load Voltage

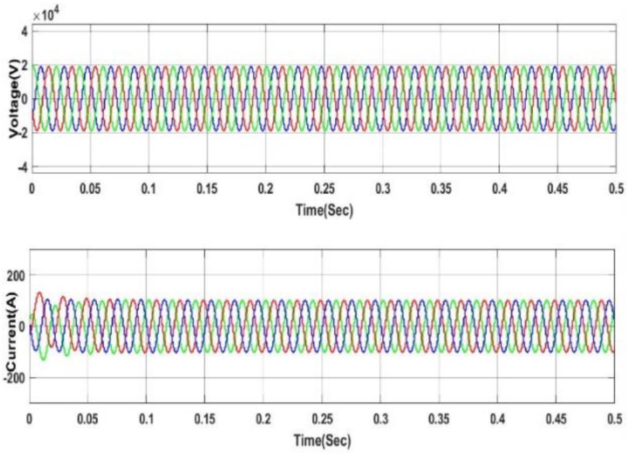


Figure 16. Results of Source Voltage, Current

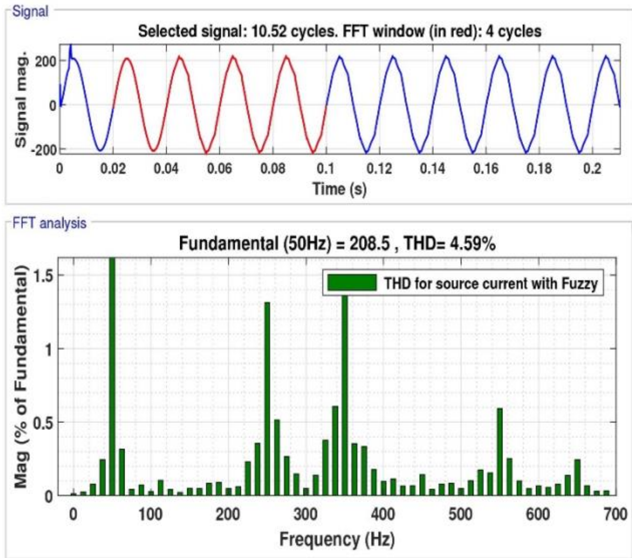


Figure 17. Total Harmonic Distortion I_s with FLC

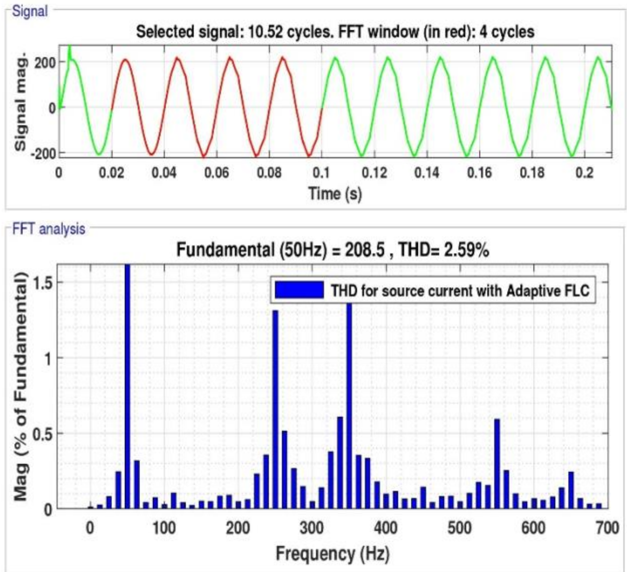


Figure 18. Total Harmonic Distortion I_s with Adaptive FLC

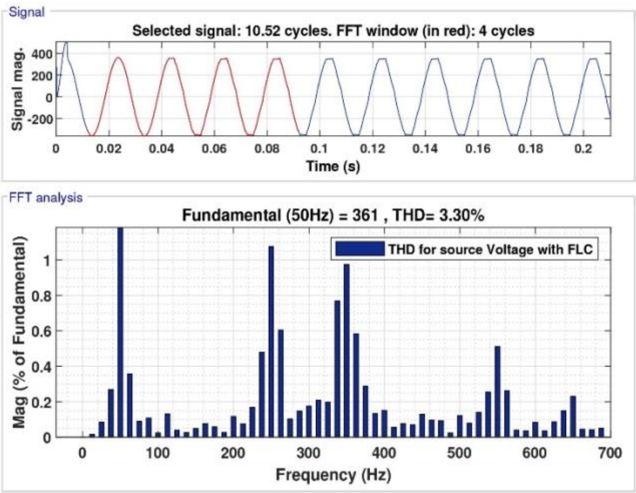


Figure 19. Total Harmonic Distortion Vs with FLC

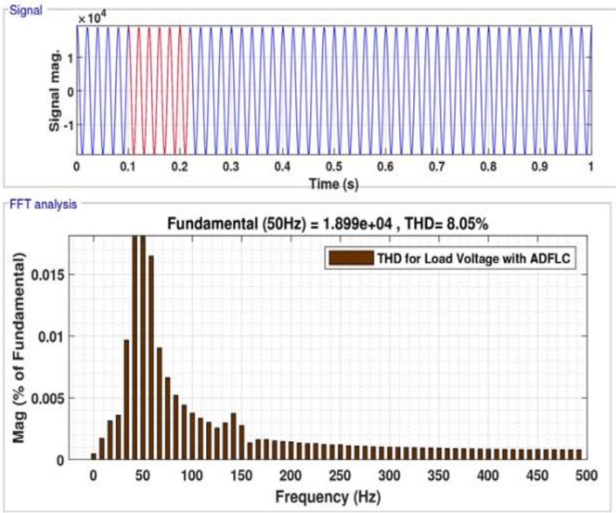


Figure 22. Total Harmonic Distortion VL with Adaptive FLC

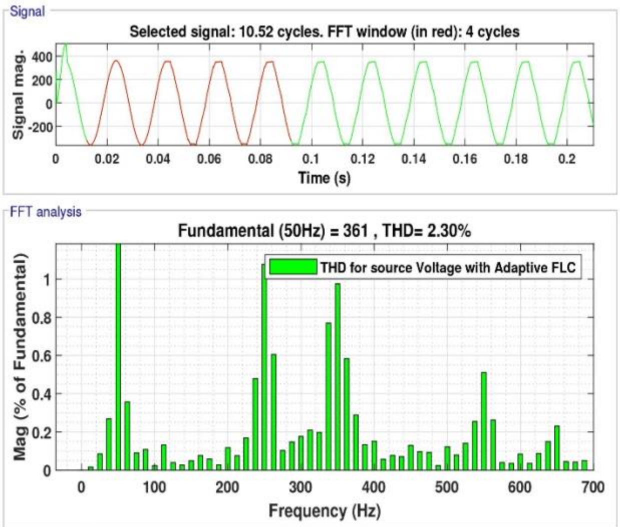


Figure 20. Total Harmonic Distortion Vs with Adaptive FLC

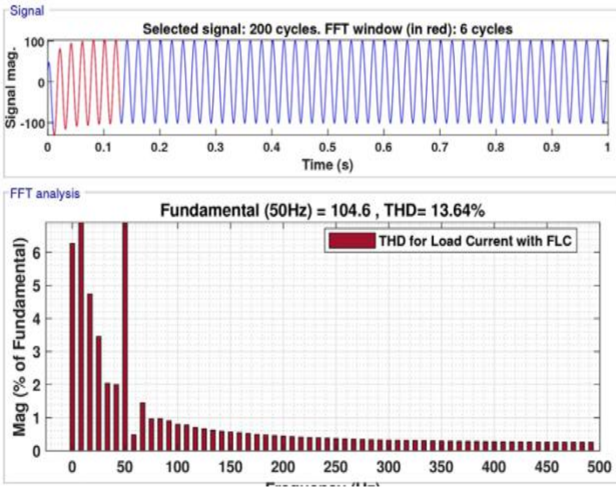


Figure 23. Total Harmonic Distortion I_L with FLC

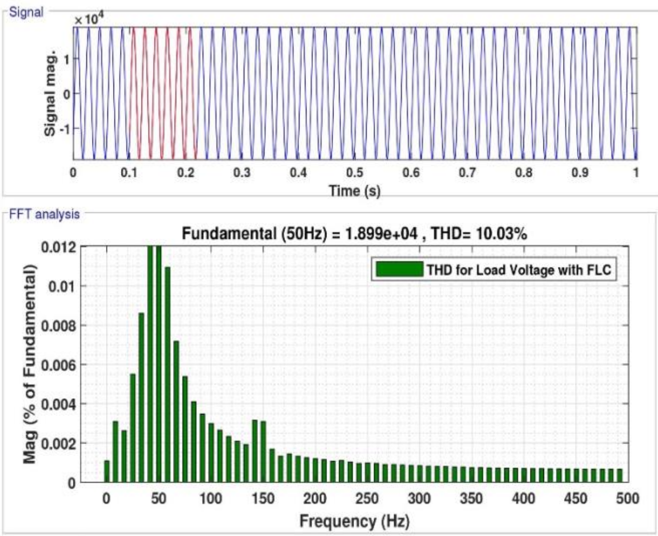


Figure 21. Total Harmonic Distortion VL with FLC

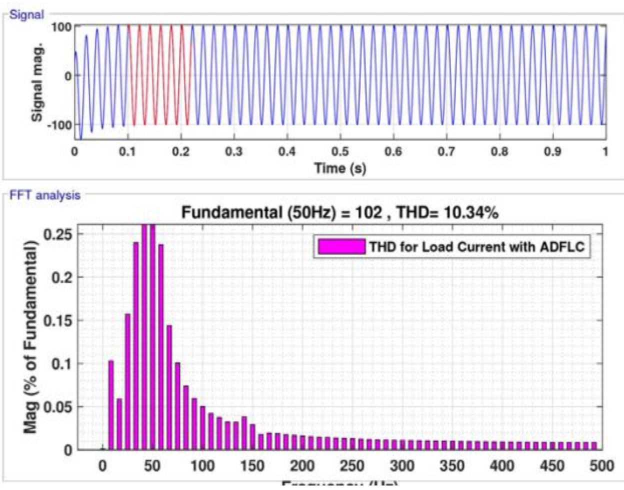


Figure 24. Total Harmonic Distortion I_L with Adaptive FLC

Table 2. Comparison of THD for V_S, V_L, I_s, I_L using FLC and Adaptive FLC

S.No	Controller	THD for I_s	THD for I_L	THD for V_s	THD for V_L
1	FLC	4.59%	13.64%	3.30%	10.03%
2	Adaptive FLC	2.49%	10.34%	2.30%	8.05%

8. Specifications of Load, Battery and Solar Panel

Load Specifications:

In this proposed work the type of load is non-linear load which consists of RL, LL and CL for both load1 and load2.R=20Ω, LL=15mH, CL=3µF.

Table 3. Battery Specifications

Nominal Voltage	200V
Rated Capacity (Ah)	40
Initial State-of-charge	80%
Battery Response time(s)	30/10

Table 4. Solar Panel Specifications:

Number of parallel strings	40
Series connected modules per string	10
PV Module data	1Soltech 1STH-215-P
Maximum Power	213.15W
Open Circuit Voltage Voc(V)	36.3V
Voltage at maximum power point Vmp(V)	29V
Temperature Coefficient of Voc(%deg.C)	-0.36099
Cells per module (Ncell)	60
Short circuit current (Isc(A))	7.84
Current at maximum power point	7.35
Temperature Coefficient of Isc(%deg.C)	0.102

9. Conclusion

With help of MATLAB/SIMULINK, an adaptive FLC-based EMS was developed for integrated grid that is coupled to distribution power systems. One of benefits of EMS is increased reliability that comes from using appropriate FLC. In other words, results indicate a shorter adjustment period. To maximize effectiveness of energy management system is a secondary goal. As for third goal, it entails using the MPPT algorithm to keep tabs on maximum power point. This research presents an adaptive FLC-based energy management system for monitoring peak power consumption. To improve power quality, decrease total harmonic distortion (THD) in micro-grids, new techniques based on incremental conductance (P&I) have been developed. Adaptive FLC has been shown to improve power quality. The results reveal that with adaptive FLC, source voltage THD is 2.30%, source current THD is 2.59%.

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