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Power Factor Compensation for A Three Phase Bidirectional Interlinking Ac-Dc Hybrid Microgrid System by Using Fuzzy Logic Controller

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ABSTRACT

This paper presents the modelling and simulation of Fuzzy logic controllers (FLCs) which have been widely used in power electronics and control applications, including power factor compensation in three-phase bidirectional interlinking AC-DC converters for hybrid micro-grid systems. The paper aims to improve the power factor of a three-phase bidirectional interlinking AC-DC converter in a hybrid micro-grid system using a fuzzy logic controller (FLC) based power factor compensation technique. The proposed system employs a DC source, AC grid, and renewable energy sources to power a load. The FLC is designed to regulate the power factor of the converter by adjusting the duty cycle of the converter's switches. The simulation results show that the proposed FLC-based power factor compensation technique effectively regulates the power factor of the converter and maintains it at unity. Additionally, the proposed technique demonstrates superior performance compared to other conventional techniques, such as PI control and adaptive control, under various operating conditions. This paper demonstrates the potential of FLC-based power factor compensation techniques for improving the performance of micro-grid systems, especially in hybrid micro-grid systems, where multiple energy sources are used to power a load. The proposed technique can enhance the system's efficiency, reduce the power loss, and increase the system's stability. The simulation model is implemented and tested using Matlab/Simulink.

Keywords: Hybrid AC-DC microgrid, bidirectional interlinking converter (BIG), constant power control, Three-phase microgrid, Fuzzy Logic Controller (FLC).

I. INTRODUCTION

In a hybrid AC-DC microgrid, the construction of a robust conversion system capable of initiating the Islanding operation when an unforeseen event happens is necessary for the customers' uninterrupted power supply [1], [2], [3]. The creation of an energy flow control system that uses reactive current injection techniques to assist in power factor correction/compensation (PFC) for the local AC distribution public grid at the point of common coupling (PCC) is another crucial component of contemporary HMG [4], [5], [6].

Due to the restricted supply of reactive power, a single household HMG might provide a minor contribution for PFC at the PCC for a local public grid. An increased number of HMG employing this method in a certain local population might have a more substantial influence on the calibre of the power delivered by adjusting the power factor at the common coupling point.

The DQ synchronous reference frame control for Three-phase systems is proposed by the control technique used in references [7], [8], [9], and [10] by converting the AC signals into DC signals for the most efficient form of processing. Three control loops for the active-reactive power and output DC voltage are used in several obvious applications [11], [12], and [13] to use this transformation. The current study demonstrates the method's ability to modify the phase of the current supplied or injected from the AC Grid in order to compensate for/correct the power factor at PCC by working in either rectifier or inverter modes.

II. SYSTEM DESCRIPTION

The bidirectional interlinking converter is used to distinguish between the two AC and DC circuits in the residential Three-phase hybrid micro-grid, as illustrated in Figure 1. (BIC). The AC grid, the point of common coupling (PCC), the islanding switch, the AC load, and an LCL passive filter are all components of the AC circuit. The capacitive filter (C), the DC load, and/or the storage component are all components of the DC circuit (DC Source)/Solar-PV-array . Transfer from/to the AC and DC circuits is ensured by the bidirectional interlinking H-bridge converter (BIC).

Three distinct operating instances are used to determine the energy management for the bidirectional interlinking converter. The scenario for the first two cases allows for the management of reactive power, while the third example emphasises running at unity power factor. All of the electrical DC consumers are supplied with electricity thanks to the Rectifier's working mode (case 1), which enables the transfer of electrical energy from the AC Grid to the DC-Grid.

The AC load is powered directly by the AC grid and the DC load, and a power electronic converter interfaces it with the DC-link voltage. In scenario 2, the inverter's working mode supplies the DC load directly from the DC source(solar-pv-array) while simultaneously enabling energy to pass through the AC grid to the AC load through the interlinking converter. The AC-DC hybrid microgrid is islanding when an unforeseen event (defect incidence, quality condition failure, independent micro-grid operation), unlike the prior example, in which there is a physical link to the AC public grid. The DC Source in this instance secures the power supply for both types of consumers.

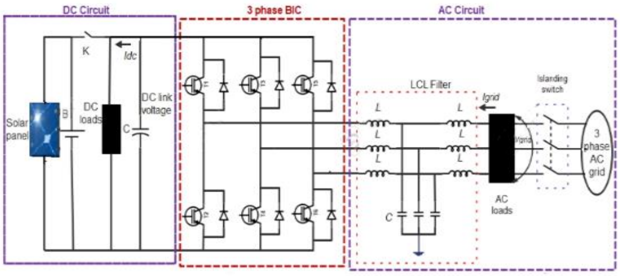


Fig-1: 3-phase Hybrid Microgrid Topology

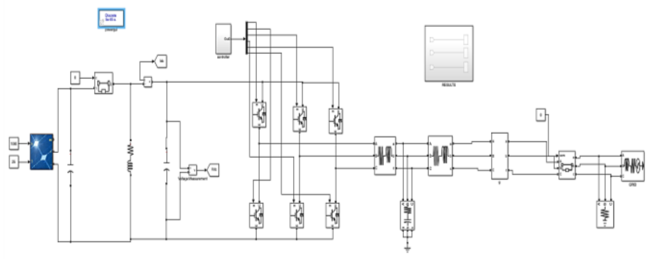


Fig-2 : Simulink diagram

III.CONVERTER CONTROL STRATEGY

The control strategy based on the reactive power control (Fig. 2) is using as measured inputs the AC voltage signal at the PCC (V_{grid}), the input current (I_{GRID}), the DC voltage (V_{dc}) and the DC current (I_{dc}). These signals are also presented in Fig. 1. By applying the Three-phase DQ transformation for the V_g and I_g signals, the and V_q voltages and I_d and I_q currents are being obtained in DQ rotation references frame. The references control signals are the DC voltage ($V_{dc_{ref}}$), the active power (P_{ref}) which is obtained using to DC-link current and voltage and the reactive power (Q_{ref}) defined by the AC public grid. The outputs of this control system are the PWM signals for switching the interlinking converter transistors.

The first control loop regulates the DC voltage (Vdc) obtaining the required reference for the $I_{dc_{ref}}$ DC current.

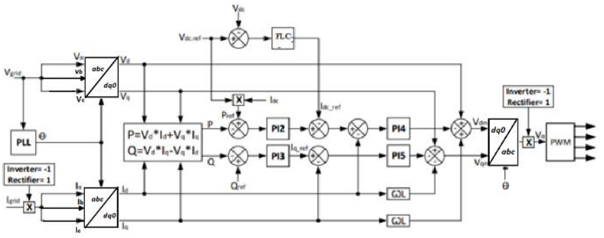


Fig-3: Control Strategy Schematic

This is accomplished by comparing the DC voltage (V_{dc}) to the required reference ($V_{dc_{ref}}$), obtaining a steady state error that is compensated by FLC controller.

The outputs of P-Q calculation block are measured value of the active (P) and reactive (Q) powers base on equation (1). These signals will be compared with the references for the power control (P_{ref},Q_{ref}) and the results are being compensated by PI2 and PI3 controllers, returning the references for the two current control loops ($I_{d_{ref}}$, $I_{q_{ref}}$) [14]. The outputs of PI4 and PI5 controllers represents the signals (V_{dm},V_{qm}), that after their 'abc' transformation will become the inputs for the sinusoidal PWM generator (PWM).

$$\begin{cases} P = \mathrm{V_d I_d} + \mathrm{V_q I_q} \\ Q = \mathrm{V_d I_q} - \mathrm{V_q I_d} \end{cases} \quad (1)$$

IV. CONTROL TOPOLOGY

A. SOLAR BASED SYSTEM

Generation of electricity by using solar energy depends upon the photovoltaic effect in some specific materials. There are certain materials that produce electric current when these are exposed to direct sun light. This effect is seen in combination of two thin layers of semiconductor materials. One layer of this combination will have a depleted number of electrons. When sunlight strikes on this layer it absorbs the photons of sunlight ray and consequently the electrons are excited and jump to the other layer. This phenomenon creates a charge difference between the layers and resulting to a tiny potential difference between them. The unit of such combination of two layers of semiconductor materials for producing electric potential difference in sunlight is called solar cell. Silicon is normally used as the semiconductor material for producing such solar cell. Here solar irradiance 1000 and nominal temperature of PV 25^{0} c.

B. FUZZY BASED CONTROLLER

Fuzzy logic is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables. Fuzzy logic is able to give results in the form of recommendation for a specific interval of output state, so it is essential that this mathematical method is strictly distinguished from the more familiar logics, such as Boolean algebra. This paper contains a basic overview of the principles of fuzzy logic.

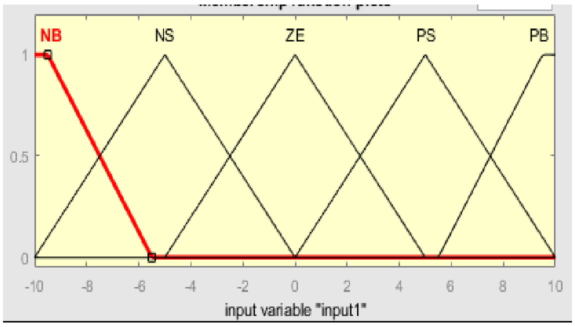


Fig-4: MEMEBERSHIP OF THE INPUT VARIABLE-1

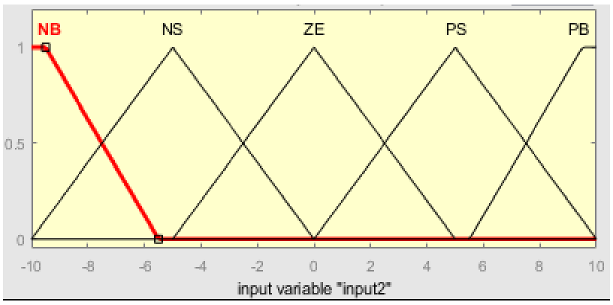


Fig-4a: MEMEBERSHIP OF THE INPUT VARIABLE-2

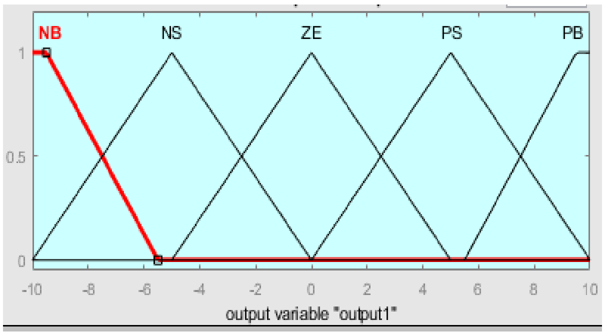


Fig-4b: MEMEBERSHIP OF THE OUTPUT VARIABLE

e/ce	NB	NS	ZE	PS	PB
NB	ZE	NS	NB	NB	NB
NS	ZE	NS	NB	NS	NB
ZE	PB	PS	ZE	NS	NB
PS	PB	PS	PS	ZE	NS
PB	PB	PB	PB	PS	ZE

TABLE 1: FUZZY RULES

The input to the fuzzy operator has two or more relationship values from fuzzifier input variables. The output is a single truth value. If input 1 is declared to indicate the error means it while the input 2 indicates the changing error. The linguistic variables contain eight fuzzy subsets in which five subsets are used which are described as follows:

(1) Negative error speed Big (NB)
(2) Negative error speed Small (NS)
(3) Positive error speed Small (PS)
(4) Positive error speed Big (PB)
(5) Zero error speed (ZE)

V. SIMULATION RESULTS & DISCUSSION

The simulation model (Fig. 1) of three-phase AC-DC Hybrid Micro-Grid was simulated in Matlab/Simulink software and it is based on the HMG topology and control structure (Fig. 2). In case 2 and 3 (inverter mode) the measured value of the I_{grid} and the modulating signal V_{grid} must be shifted with 180 degrees by multiplying them with constant -1 (Fig. 2). In the case 1 (Rectifier operating mode) the I_{grid} is the same with the measured value and the V_{grid} is the related signal by dq_0 to 'abc' transformation block.

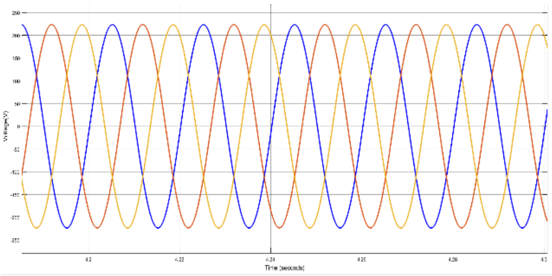
Parameter		Value
AC Grid Voltage (Vac)		440 [V]
Ac Grid Frequency (f)		50 [Hz]
DC Bus Voltage (Vdc)		380 [V]
AC/DC Converter switching freq.		20 [kHz]
LCL Filter	L1	923 [mH]
	L2	100[mH]
	CF	6.5 [mF]
	RF	1.193 [Ohm]
DC Capacitor filter		1.6 [mF]
DC Load Nominal power		2000 [W]
AC Load Nominal active power		1600 [W]

TABLE 2 : System Parameters

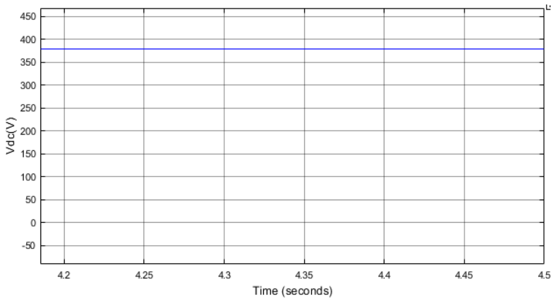
Case-1: RECTIFIER OPERATING MODE

(a) Resistive Load

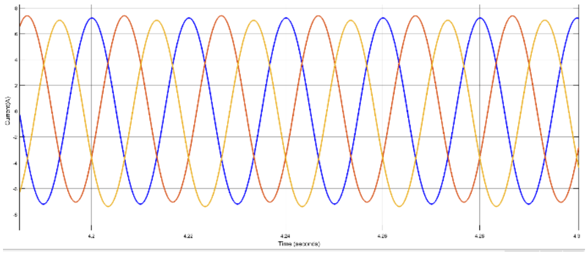
P= 2000 W; Q= 0 VAR; CosØ=1



Vg



Vdc



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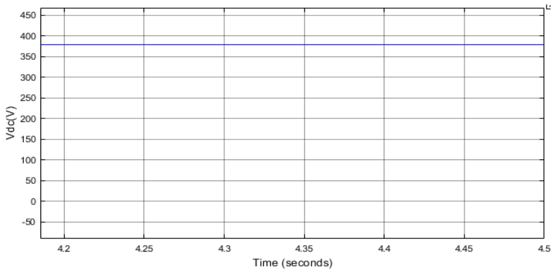
(b) Inductive Load

P= 2000 W, Q= 1000 VAR, CosØ=0.96



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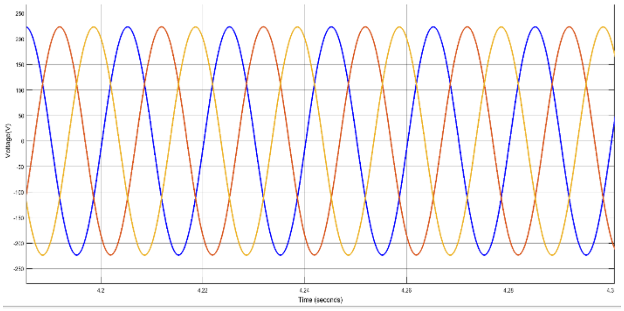

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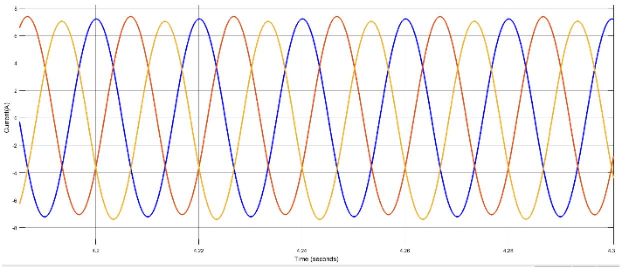

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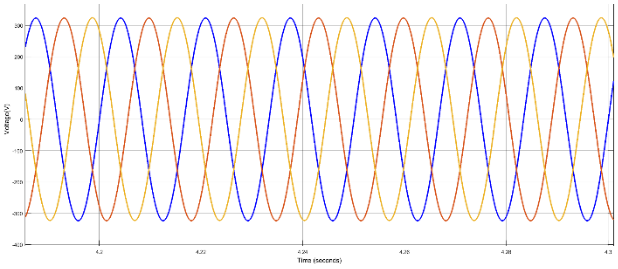
(c) Capacitive Load

P= 2000 W; Q= -1000 VAR; CosØ=0.96



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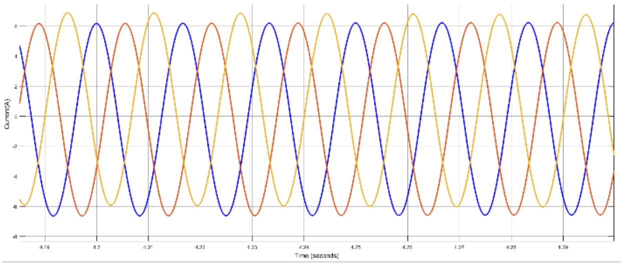

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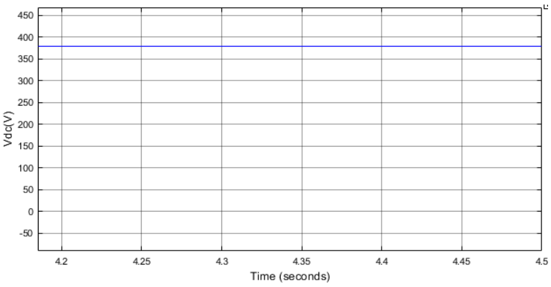


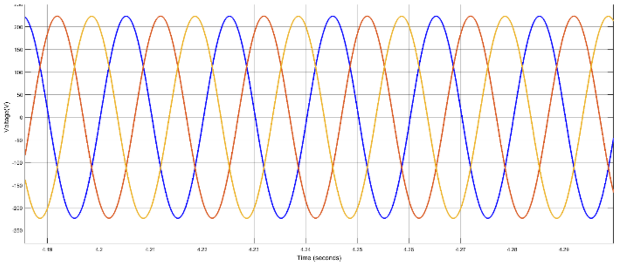
Vdc

Fig. 5: Simulation results of rectifier mode

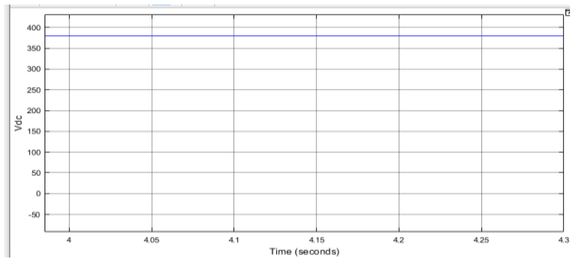
Case-2: INVERTER OPERATING MODE

(a) Resistive Load

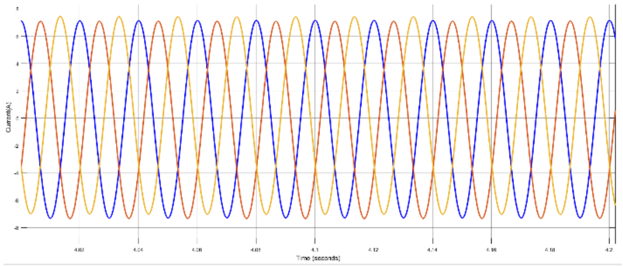
P=2000 [W], Q=0 [var], cosØ=1



Vg



Vdc



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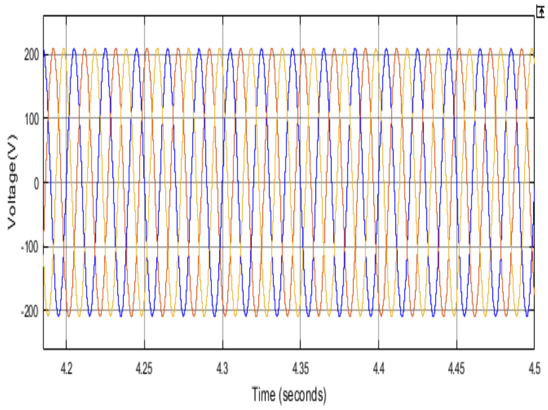
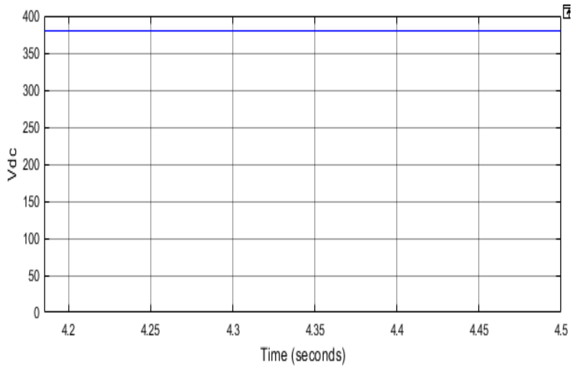
(b) Inductive Load

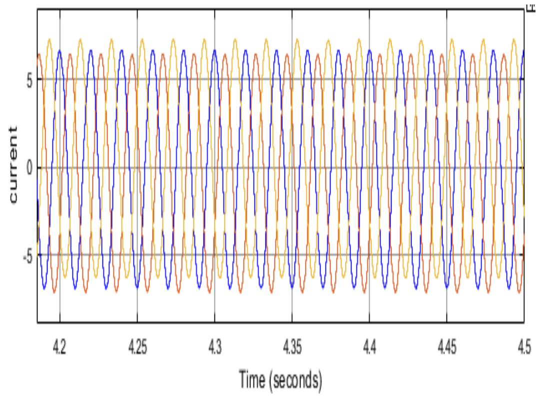
P=2000 [W], Q=0 [var], cosØ=0.99



Vg



Vdc



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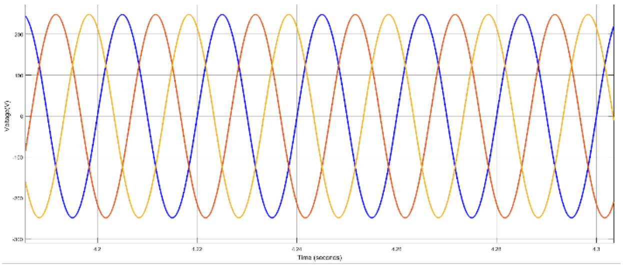
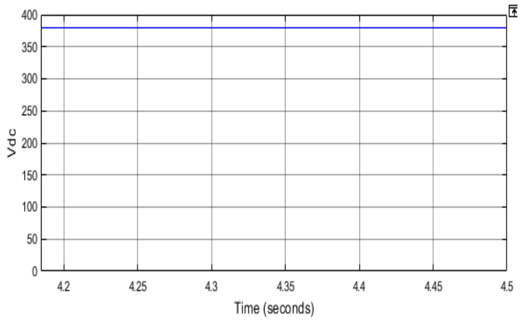
(c) Capacitive Load

P=2000 [W], Q=1000 [var], cosØ=0.99



Vg



Vdc

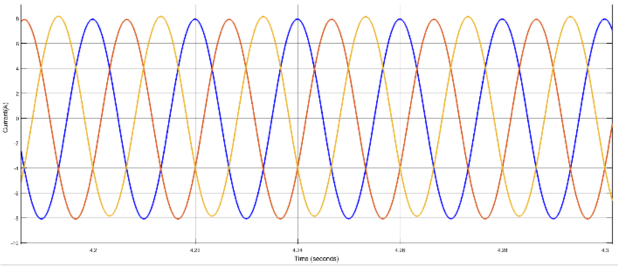


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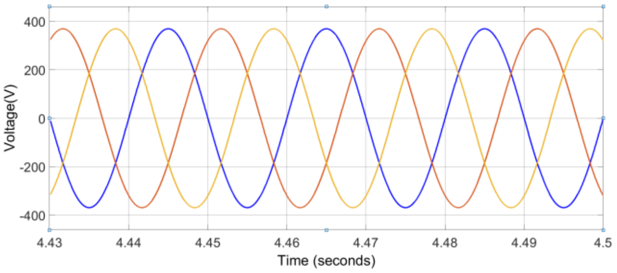
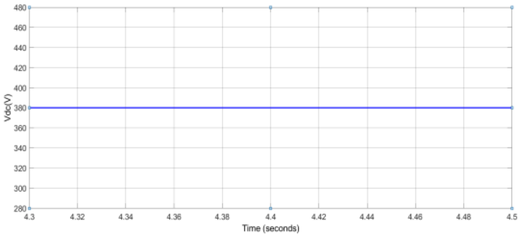
Fig. 6: Simulation results of inverter mode

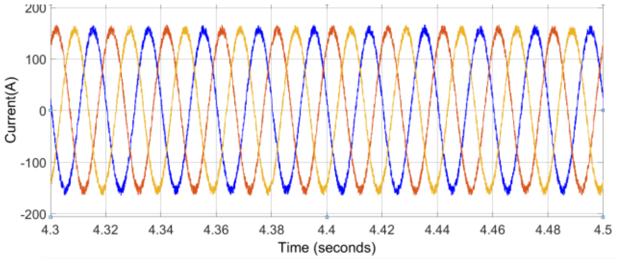
Case-3: ISLANDING OPERATING MODE



Voltage



Vdc



Current

Fig. 7: Simulation results of islanding mode

Method	Controller	THD (V)%	THD (I)%
Existing	PI	8.36	5.42
Proposed	FLC	2.32	5.11

Table 2: THD Comparison in islanding mode

From the above table, it is clear that proposed FLC provide less harmonics compare to existing PI controller.

VI. CONCLUSION

The performance of a Fuzzy Logic Controller (FLC) based Power Factor Compensation (PFC) for a three-phase bidirectional interlinking AC-DC converter in a hybrid micro-grid system has been studied in this paper. The aim of the paper was to improve the power quality of the micro-grid system by compensating for the reactive power. The FLC-based PFC controller was designed to regulate the DC-link voltage of the converter by controlling the reactive power flow. The simulation results showed that the proposed controller improved the power factor and reduced the total harmonic distortion (THD) of the AC voltage. The controller also provided a fast response to load changes and ensured stable operation of the micro-grid system. In conclusion, the FLC-based PFC controller proved to be an effective solution for improving the power quality of the micro-grid system. The controller was able to regulate the reactive power flow and maintain a stable DC-link voltage, resulting in improved power factor and reduced THD. The proposed controller can be implemented in practical micro-grid systems to improve their power quality and stability. However, further testing and validation on a physical system may be necessary to confirm the performance of the controller in real-world scenarios.

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