# Direct Fuzzy Logic Controller for Voltage Control of Standalone Three Phase Inverter

Xiancheng Zheng, Haider Zaman*, Xiaohua Wu, Husan Ali, Shahbaz Khan
School of Automation, Northwestern Polytechnical University
Xi'an, China
*hdrzaman@nwpu.edu.cn

***Abstract*—This paper presents an adaptive control strategy for voltage regulation of three phase inverter in the standalone application. A direct type adaptive fuzzy logic controller (FLC) is employed which reduces the computational cost and guarantees stable load voltage during both steady state and load disturbance. To validate the effectiveness of the proposed control strategy, the output voltage and power flow waveforms of 80kW inverter are presented. In addition, the frequency spectrum of the load voltage is presented to evaluate the harmonic distortion. The system is simulated in Matlab/Simulink software with off-grid linear as well as nonlinear loads. The nonlinear load employed for performance evaluation is a three phase diode rectifier with inductive filter.**

***Keywords— fuzzy logic controller (FLC), three phase inverter, voltage mode control.***

## I. Introduction

The distributed generation systems (solar, fuel cell, wind turbine etc.) are rapidly growing which are helpful in reducing the carbon emission and fossil fuel utilization [1]. To power up ac loads with dc power sources such as solar and fuel cell, the inverter is an important dc-ac converter. The wind turbine on the other hand generates variable frequency ac voltage which at the early stage is converted into dc. These power sources are connected to the grid through inverter for injecting power into utility, but in remote areas they are normally used in the standalone or off-grid mode [2]. The uninterruptable power supplies, islanded microgrids and HVDC Light are examples of standalone inverters.

In standalone application inverter has to achieve stable load voltage, low total harmonic distortion and enhance the system response to reject load disturbances [3]. For easier implementation, researchers have utilized various types of proportional-integral (PI) and PI-derivative (PID) controllers to control the three phase inverter [4]. However, these controllers are valid under small-signal assumption, and lack in intelligence invoke the interest in the adaptive controller such as fuzzy logic, neural network, neuro-fuzzy etc. The main advantage of these intelligent controllers is their capability to handle system nonlinearity and controller design do not need mathematical model of the system [5]. Fuzzy logic controller (FLC) is the simplest among the various intelligent controllers. In addition, the FLCs are robust and less sensitive to source and load variations as compared to conventional controllers [6].

In this paper, fuzzy logic based control for a two-level inverter is proposed, because the multilevel inverters requires complex control algorithms and increases the overall cost of the system [7]. The three phase inverter in off-grid mode, powering three phase balanced resistive load ($R$) is shown in Fig.1. The dc-port voltage $v_{dc}$ of the inverter is supported by $v_{abc}$ source, after rectified and filtered respectively by a three phase bridge rectifier and $LC$ filter ($L_{dc}$ and $C_{dc}$). The inverter ac output voltage $v_{ABC}$ is sensed and converted to per unit values prior to $dq$ transformation. The sinusoidal reference tracking problem transforms into a dc tracking problem when designed in the $dq$-frame, facilitating the controller design even in variable-frequency scenarios [2]. The compensators process the direct ($V_d$) and quadrature ($V_q$) components of load voltage to produce the control signals (modulation index $m_d$ and $m_q$). The control signals are transformed into $abc$-frame and finally translated into gate pulses for driving the MOSFETs. Fig.1 shows the gate signals ($u_1$, $u_3$ and $u_5$) for the upper half of the three phase bridge inverter only, the MOSFETs in the same phase leg are triggered through complementary gate signals ($u_4=\bar{u}_1$, $u_6=\bar{u}_3$ and $u_2=\bar{u}_5$) to protect the circuit from the shoot through state.

## II. The Fuzzy Logic Controller

The architecture of FLC is shown in Fig.2, with three cascaded blocks fuzzifier, inference engine and defuzzifier at the output terminal. The fuzzification stage converts the measured quantities from the process (load voltages $v_{ABC}$ in this case) into fuzzy sets to be used by the inference stage. The inputs to the direct adaptive fuzzy logic controller are $e_d$ and $\dot{e}_d$; for the sake of consistency and to avoid abuse of symbols $x_1= e_d$ and $x_2= \dot{e}_d$ are used in the rest of the paper. Because of the normalized load voltages, the universe of discoures for these variables is from -1 to 1. Input, out of this range generates large error signal and has a membership degree of 1. For reducing the computational complexity, the triangular and trapezoidal membership functions are utilized in this work instead of gaussian membership function. Using triangular membership functions, the controller manages to reduce the error signal in a faster manner that increases the system transient response [8]. The membership functions are labeled as NB for "Negative Big", NS for "Negative Small", " PS for "Positive Small", PB for "Positive Big" as shown in Fig.3. On the x-axis is the error between the direct/quadrature component of reference and the

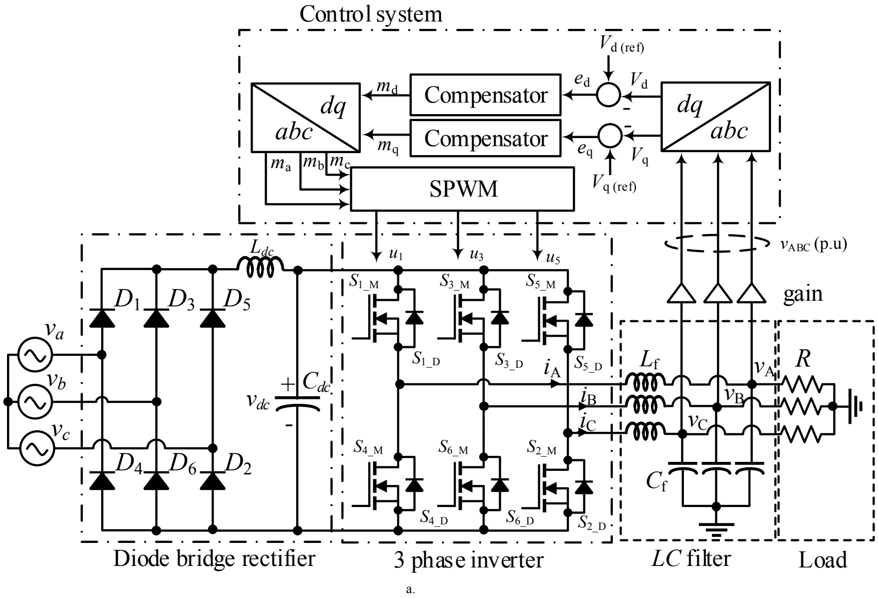



Fig. 1 Three phase inverter with feedback voltage controller

actual load voltage and the y-axis is the corresponding degree of memebership $\mu$.

$$m=\frac{\sum_{k=1}^{m}\mu_k w_k}{\sum_{k=1}^{m}\mu_k}$$

$$m=\xi^T(x)\,w$$

Where $\xi_i(x)=\dfrac{\mu_i}{\sum_{k=1}^{m}\mu_k}$

the weights $w_i$ are the controller parameters and adapted every sample time using

$$\dot{w}=\gamma \mathbf{e}_x\, p_n \xi(x)$$

where $\gamma > 0$ is an arbitrary constant, $\mathbf{e}_x = V_{x,ref} - V_x$, $d/dt\,(V_{x,ref} - V_x)$, $x\ \varepsilon\ d,q$ and $p_n$ is the last column of a positive definite matrix $P$. In this work the following positive definite matrix is used

$$P=\begin{bmatrix} 3.75 & 0.5 \\ 0.5 & 2.75 \end{bmatrix}$$

The inference process generates fuzzy output set according to the IF-THEN rules. With these rules, the fuzzy controller behaves intelligently and capable of imitating humanlike decision. There are 16 rules of "IF-THEN" logic related to the inputs and outputs as shown in Fig.4. This logic makes the control function into a FLC.

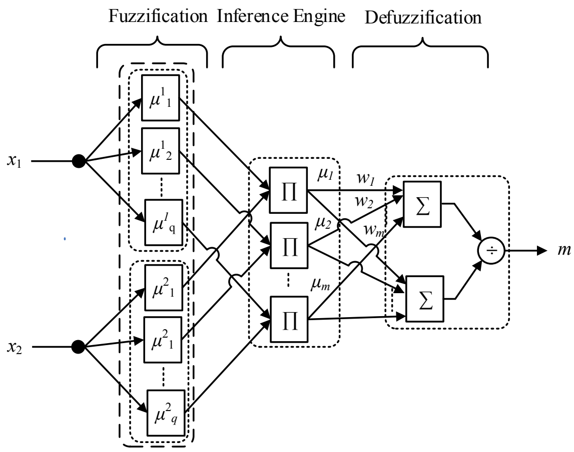



Fig. 2 Architecture of fuzzy logic controller

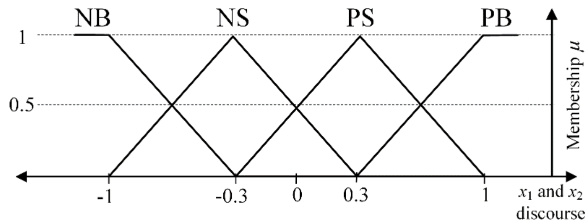



Fig. 3 Membership functions for error $x_1$ and change of error $x_2$

**Rule 1: If** $x_1$ is NB and $x_2$ is **NB Then *m* is NB**
**Rule 2: If** $x_1$ is NB and $x_2$ is **NS Then *m* is NB**
**Rule 3: If** $x_1$ is NB and $x_2$ is **PS Then *m* is NS**
.
.
.
.
**Rule 16: If** $x_1$ is NB and $x_2$ is **PS Then *m* is NS**

Fig. 4 Rule-base for the voltage controller

(b)

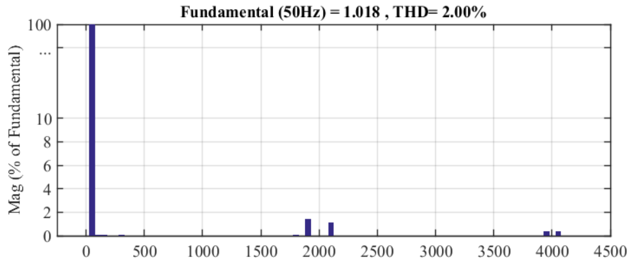


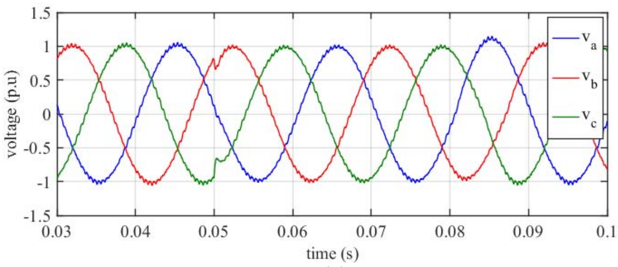

Fig. 3 frequency spectrum of load voltage

## III. RESULTS AND DISCUSSION

To validate the effectiveness of the proposed FL based control strategy the three phase inverter system is simulated in Matlab/Simulink software. The inverter accepts dc input voltage of 800V from diode bridge rectifier and generates 380V phase to ground voltage at 50 Hz frequency. The dc side inductive and capacitive filters are respectively 20 mH and 30 $\mu$F. While the ac output inductive and capacitive filter used are respectively 2 mH and 30 $\mu$F for minimizing the distortion. A high switching frequency is desirable for reducing the inductive and capacitive filters, but on the other hand increases the switching losses [9]. In this evaluation of fuzzy logic controller a 2 kHz switching frequency is used.

The standalone inverter control system was tested at different load variations -- linear and nonlinear load changes. Sample results of the scenarios are presented in this section. Fig.5 shows the load voltage waveform, power flow and fft plot of voltage waveform at linear load scenario. It is observed in Fig. 5 (a) that waveforms are nearly sinusoidal with frequency of 50 Hz and having peak voltage of 1.0 p.u. The resistive load of 3Ω is applied initially demanding 50 kW of active power. For 0.03 seconds (0.05-0.08 seconds) the load demand changes to 75 kW and switches back to 50 kW at 0.08 seconds as shown in Fig. 5(b).

The 50 Hz component clearly dominates the fft plot of the voltage waveform as shown in Fig. 6. The side bands of the carrier frequency are at 2000$n$±50 Hz, where $n$ is an integer number. The computed total harmonic distortion is 2%, and complies with the IEC standards [10]. It is observed from the transient response that the developed FLC controller compensates the overall transient effects and approaches the steady state.




(a)

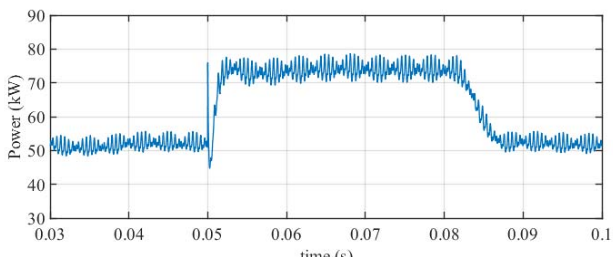
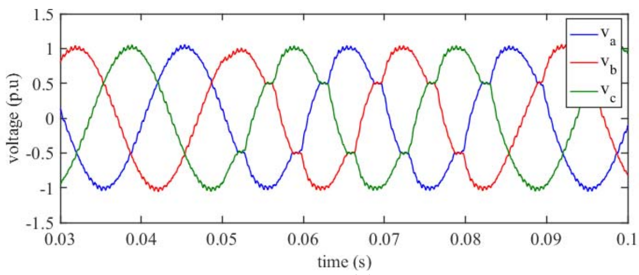


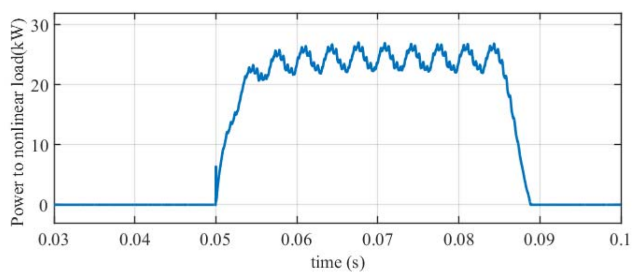

Fig. 2 Step change in linear load (a) load voltage in p.u (b) active power flow

Fig.7 shows the load voltage waveform, power flow and fft plot of voltage waveform at non-linear load scenario. Till 0.05 seconds the converter supplies power to a linear load and is shown in Fig.7(a) that waveforms are nearly sinusoidal with frequency of 50 Hz and having peak voltage of 1.0 p.u. A three phase diode rectifier with inductive dc-filter is applied as nonlinear load at 0.05 second for two voltage cycles. Fig.7(b) shows the change in active power demand of the nonlinear load.

At every commutation (current transfer from one diode to another of the diode bridge used as nonlinear load) voltage dents can be seen in Fig.7(a), however the controller strictly ensured 1.0 p.u load voltage. The inductive filters act as commutation inductors for the diode bridge. The 50 Hz component clearly dominates the fft plot of the voltage waveform as shown in Fig.8. The side bands of the carrier frequency are at 2000$n$±50 Hz, where $n$ is an integer number. The computed total harmonic distortion 9.93 % when feeding a highly nonlinear load.




(a)




(b)

Fig. 4 Step change in non-linear load (a) load voltage in p.u (b) active power flow

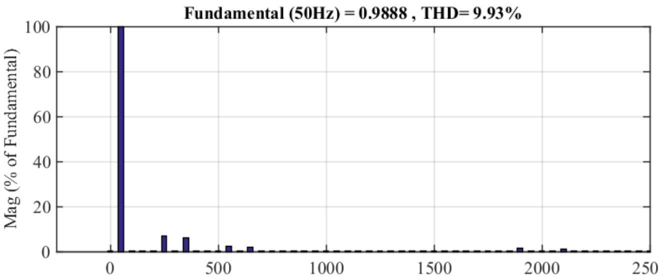



Fig. 5 frequency spectrum of load voltage under nonlinear load condition

## IV. Conclusion

A fuzzy logic controller for standalone three phase inverter has been presented in this paper. The parameters of the controller are updated every sample time to adjust according to operating condition. The performance of the proposed FLC has been evaluated both under linear as well nonlinear load condition. Furthermore the controller has been tested for step load change. It is shown through the time domain voltage plots that inverter control system is capable of producing stable voltage waveform. The THD has been used as the waveform quality evaluation parameter, which is 2% in case of linear and 9% in case of nonlinear load.

## References


[1] C. M. Liaw, K. W. Hu, Y. Lin, and T. Yeh, "An Electric Vehicle IPMSM Drive with Interleaved Front-end DC/DC Converter," *IEEE Transactions on Vehicular Technology,* vol. PP, pp. 1-1, 2015.

[2] A. Yazdani and R. Iravani, *Voltage-sourced converters in power systems: modeling, control, and applications*: John Wiley & Sons, 2010.

[3] M. Shahparasti, M. Mohamadian, M. Amini, and A. Yazdian Varjani, "A novel single loop control structure for standalone inverter with multi loop harmonic compensation," in *Power Electronics, Drive Systems and Technologies Conference (PEDSTC), 2013 4th*, 2013, pp. 306-310.

[4] M. Naim, B. Singh, S. P. Singh, R. Mishra, P. N. Verma, D. Kumar, *et al.*, "Investigation of transient performance of VSI-fed IM drives with SVPWM technique based on P, PI, and PID controllers," in *Power, Control and Embedded Systems (ICPCES), 2012 2nd International Conference on*, 2012, pp. 1-7.

[5] S. H. Zak, *Systems and control*: Oxford University Press New York, 2003.

[6] J. H. Lilly, *Fuzzy control and identification*: John Wiley & Sons, 2011.

[7] J. W. Jung, N. T. T. Vu, D. Q. Dang, T. D. Do, Y. S. Choi, and H. H. Choi, "A Three-Phase Inverter for a Standalone Distributed Generation System: Adaptive Voltage Control Design and Stability Analysis," *IEEE Transactions on Energy Conversion,* vol. 29, pp. 46-56, 2014.

[8] D. Q. Dang, Y. S. Choi, H. H. Choi, and J. W. Jung, "Experimental Validation of a Fuzzy Adaptive Voltage Controller for Three-Phase PWM Inverter of a Standalone DG Unit," *IEEE Transactions on Industrial Informatics,* vol. 11, pp. 632-641, 2015.

[9] A. Kovari, I. Kadar, and S. Halasz, "The influence of inverter control algorithm and DC link voltage on the inverter switching loss," in *Industrial Technology, 2004. IEEE ICIT '04. 2004 IEEE International Conference on*, 2004, pp. 590-595 Vol. 2.

[10] F. Botterón and H. Pinheiro, "A three-phase UPS that complies with the standard IEC 62040-3," *IEEE Transactions on Industrial Electronics,* vol. 54, pp. 2120-2136, 2007.