

# ANALYSIS OF FUZZY LOGIC CONTROLLED PV BASED ZETA CONVERTER FED SAF FOR INDUCTION MOTOR

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**Abstract** In the modern power system, harmonics are serious concerns for power system engineers due to the increasing use of nonlinear loads. This paper deals with reducing the supply current harmonics in an induction motor drive using solar PV powered Fuzzy logic controlled Zeta converter fed Shunt Active Filter (FLC ZCSAF). Numerous research works are addressed to reduce the harmonics by using active filters connected at the load end. This paper presents a new topology of introducing the shunt active filter (SAF) at the supply end to reduce source current harmonics, enhance the power quality and improve the performance of VSI fed induction motor drive. In this system, a simple and efficient method of increment conductance based MPPT algorithm is used for obtaining the peak power from solar PV array panels. The PI and FL controlled solar PV supplied zeta converter fed SAF system has been modeled and simulated using MATLAB/Simulink software. The results indicate that using a fuzzy logic controller, supply current harmonics are greatly reduced. The simulation result obtained using PI and Fuzzy logic controllers were compared and discussed. The experimental setup has been developed to validate the simulation results.

**Keywords** Fuzzy logic controller, Induction motor, Shunt active filter, Solar PV, Total harmonic distortion, Zeta converter.

## List of Abbreviations

FLC	- Fuzzy Logic Controller
IC MPPT	- Incremental Conductance MPPT
MPPT	- Maximum Power Point Tracking
PI	- Proportional Controller
PV	- Photo Voltaic Array
SAF	- Shunt Active Filter
THD	- Total Harmonic Distortion
VSI	- Voltage Source Inverter
ZCSAF	- Zeta Converter Controlled Shunt Active Filter

## 1. Introduction

In recent trends, remarkable developments in the power electronic converter-fed AC induction motor drive is a great attraction in various field applications due to many advantages such as soft starting, smooth speed control, low cost, less maintenance and higher performance, etc. More use of nonlinear loads causes harmonic generation and its associated problems in the power system. The reduction of harmonics problems and maintaining the power quality in the power system is a big task to power system engineers. To meet the increasing demand for electrical energy, the alternative energy sources like solar and wind energies are gaining more attraction in the present scenario. The solar energy is widely used for different applications due to less complexity and implementation. Various research works are carried out on extracting maximum power from solar PV modules by using different maximum point tracking (MPPT) techniques like Hill Climbing, Perturb & Observer (P&O), Incremental conductance (InCond) were used for extracting the maximum power from solar PV modules[1,2,8-11] and [16-20]. Due to real-time atmospheric conditions, to maintain the PV output, DC-DC buck-boost converter topologies have been employed. The induction motor drive is popularly used in the modern industries, commercial sectors and domestic appliances etc. The modern electric drive is employed with power electronic converters and it introduces the harmonics into the connected power system. The harmonic distortion is a key source of many power quality problems such as heat losses in electric machines, de-rating of power, a false trip indication to circuit breakers and relays etc. The numerous research articles have been reported to reduce the harmonics, reactive power

compensation and power factor improvement with different filter arrangements [3-7].

## 2. Proposed System

This work proposes a novel scheme to reduce the supply current harmonics by adding a shunt active filter (SAF) on the source side. The existing method of VSI fed induction motor drive with SAF is shown in Fig.2.1. Most of the literature discusses the mitigation of harmonics by using the shunt active filter at the point of common coupling (PCC) [8-15].

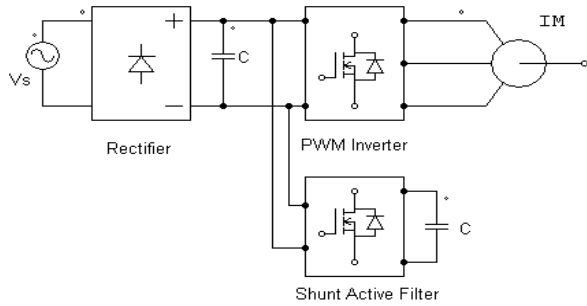


Fig.2.1. Existing method of VSI fed induction motor with SAF

The block diagram of a proposed induction motor drive with solar PV powered FLC ZCSAF is shown in Fig.2.2. In this proposed system consists of single phase diode bridge rectifier as a front end converter supplied by the single-phase AC source. A DC link capacitor provided to regulate constant DC input voltage to PWM controlled voltage source inverter (VSI). The regulated stator voltage has been applied to control the speed of three phase induction motor.

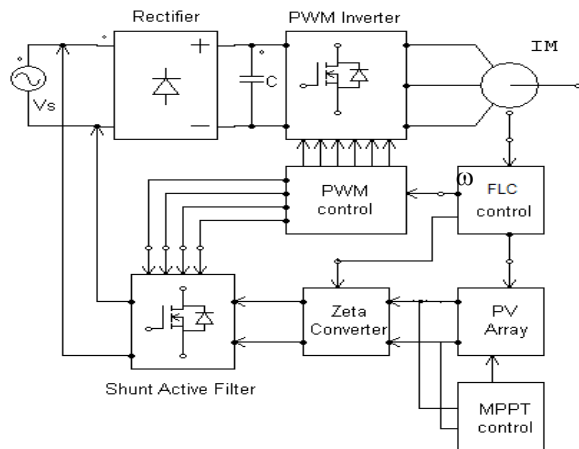


Fig. 2.2 Block diagram of proposed Induction motor with solar PV powered FLC ZCSAF

The entire control action is carried by PI and Fuzzy logic controllers. The power converter fed induction motor behaves as a nonlinear load and introduces the harmonic disturbances in the connected power system. The active filter is used to generate opposite harmonic currents to cancel the harmonics generated by the non-linear loads to satisfy the harmonic limits indicated by international standards IEC63000-2. This paper suggests the optimal controller based on modeling and simulation result of PI and Fuzzy logic control systems. The solar PV powered zeta converter controlled shunt filter is utilized for reducing the source current harmonics generated by VSI fed induction motor drive. Zeta converter is a single stage DC-DC buck-boost converter. It behaves like SEPIC converter. It has two operating modes such as continuous current mode (CCM) and discontinuous current mode (DCM). In this work, CCM mode operation has considered for zeta converter. Scheme of zeta converter is depicted in Fig.2.3. The zeta converter has many advantages such as inherent DC isolation between input and output, less DC output voltage ripple, simple compensation, and continuous output and behaves like a buck-boost converter.

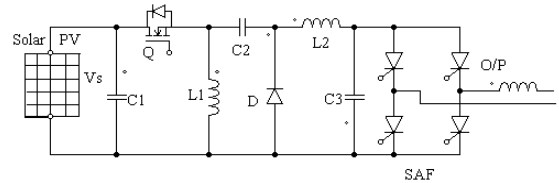


Fig.2.3. Schematic diagram of Zeta converter controlled Shunt Active Filter (ZCSAF)

The output voltage equation of boost converter is given in equation (1)

$$V_o = \left( \frac{\delta}{1-\delta} \right) V_s \quad (1)$$

From equation (1),  $V_o$  – output voltage of zeta converter,  $V_s$  – input voltage to the zeta converter and  $\delta$  – duty factor. The controlled output voltage of zeta converter is supplied to the input of shunt active filter. The input given to zeta converter is from MPPT controlled solar PV array module.

## 3. Control Techniques

### a. MPPT Algorithm for Solar PV array

In the recent years, various MPPT algorithms have been reported in the literature to extracting optimal output power from the solar PV panels [2, 8, 11, 15, 18]. These algorithms differ from many features like cost, complexity, and efficiency. A

simpler and less expensive proposed incremental conductance MPPT control technique has been adopted in this system. The incremental conductance MPPT algorithm is capable of extracting maximum power from solar PV panels with varying irradiance of atmospheric conditions. The enormous amount of solar energy available in the solar system that can be utilized to meet out the electrical energy demand. Many control techniques have been proposed to extract the optimal electrical power from solar photovoltaic array modules. The simple and efficient method of Perturb & Observe based MPPT control algorithm is used in this system to get maximum power from the solar PV array module with varying atmospheric conditions [10-12]. The output power is obtained as the product of output voltage and current (i.e  $P_v = I_v \times V_v$ ).

#### b. Fuzzy Logic Controller (FLC)

The fuzzy logic controller has found many control applications due to the handling of imprecise inputs and no need of extensive mathematical equations. It has three basic functional blocks, namely fuzzification, rule evaluator, and defuzzification. The Fuzzy logic controller membership functions are represented by linguistic input variables, inference mechanism which develops the control action using rule evaluation block and defuzzification functional block which converts the fuzzy output control signals into a real-time signal of the system. The fuzzy set has two input variables, i.e. error voltage (e) and change in error voltage ( $\delta e$ ) and the fuzzy controller produces the desired output signal to meet the real-time system requirements [5-20]. In the fuzzy logic controller, control action based on the generated error signal, i.e. difference between the reference input signal and the desired output signal. These error signals (e,  $\delta e$ ) is represented by means of fuzzy linguistic variables such as negative small (NS), negative medium (NM), negative big (NB), Negative very big (NVB), positive small (PS), positive medium (PM), positive big (PB) and positive very big (PVB). These fuzzy variables are represented by triangular membership functions in the fuzzification process. Mamdani type inference engine is used as it is more suitable for human input.

#### 4. Simulation results and Discussion

The proposed system has been modeled and simulated in the MATLAB/Simulink environment. The simulation results are presented in this section.

Simulink model of open loop control of induction motor with solar PV powered ZCSAF is depicted in Fig.4.1. The Simulink model of Zeta controlled shunt active filter is shown in Fig.4.2.

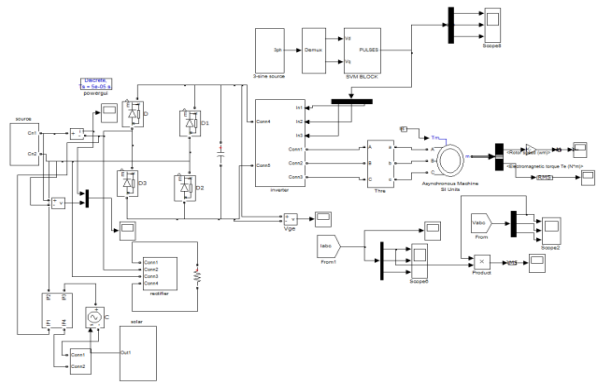


Fig. 4.1 Simulink model for open loop control of induction motor with PV powered ZCSAF

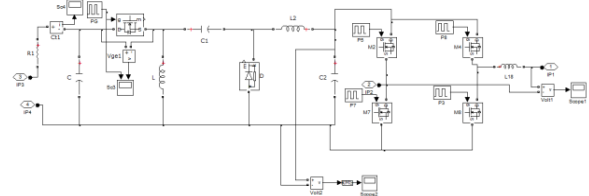


Fig.4.2. Simulink circuit of Zeta converter controlled shunt active filter (ZCSAF)

The source current harmonics are controlled by varying the input voltage of the SAF using voltage controller. The peak power has been extracted from standalone solar PV array module using incremental conductance based maximum power point (ICMPPT) technique. The 100V DC output of solar PV is given as input of zeta converter. The duty cycle of zeta converter is varied to obtain DC output voltage from 100 V to 110V and applied to SAF. The scheme is shown in Fig.4.3. The controlled output voltage of zeta converter is supplied to shunt active filter to reduce the source current harmonics and also to enhance the power quality. Owing to a sudden change in the output of zeta converter, the corresponding speed varies from 900rpm to 1250 rpm represented in Fig.4.4. The torque response of the system is shown in Fig.4.5 and it settles at 15Nm.

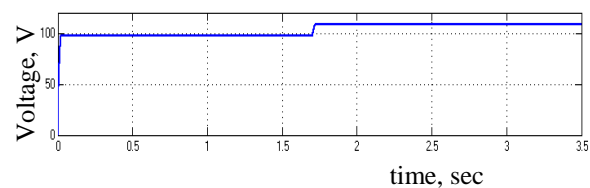


Fig. 4.3 Output voltage waveform of Zeta converter

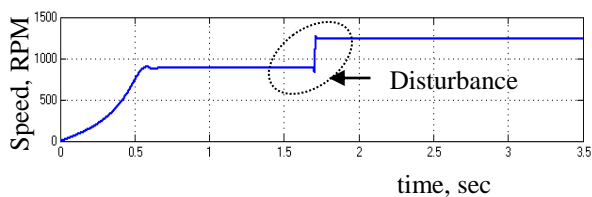


Fig.4.4 Speed response of induction motor with change in input voltage

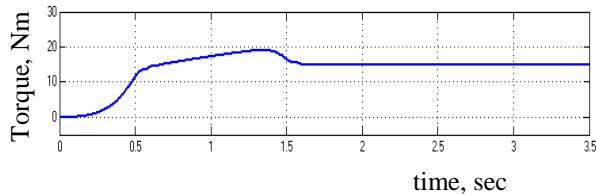


Fig.4.5 Torque response of induction motor with change in input voltage

Closed loop PI controlled induction motor with solar PV fed zeta converter controlled shunt active filter is simulated and the simulation results obtained are discussed below. The speed response of induction motor with PV based zeta converter controlled SAF is shown in Fig.4.6. It has been observed that the motor speed changes in very short time interval due to changes in input voltage and it settles at 980rpm. The torque response of induction motor is shown in Fig.4.7. From the torque response, starting torque rapidly increases and it reaches the final value of 4Nm at 0.8sec. The FFT analysis of source current harmonic THD level is shown in Fig. 4.8. The closed loop PI controlled induction motor with PV fed zeta converter controlled shunt active filter shows THD of about 3%.

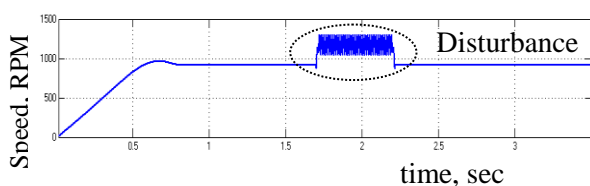


Fig. 4.6. Speed response of PI controlled induction motor with PV powered ZCSAF

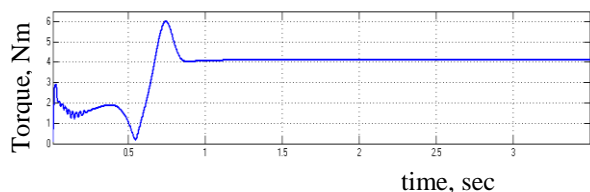


Fig. 4.7. Torque response of PI controlled induction motor with PV powered ZCSAF

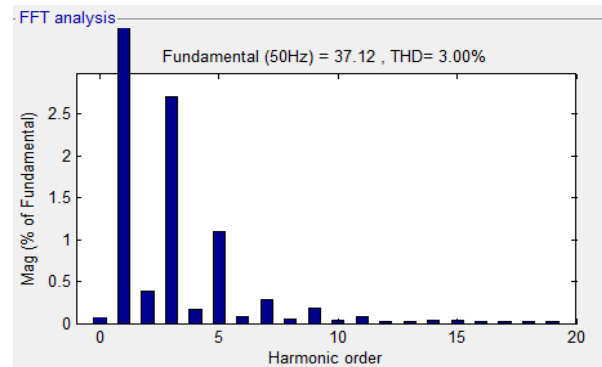


Fig. 4.8 FFT analysis of source current harmonic THD in PI controlled ZCSAF for induction motor

The Simulink model of the closed-loop Fuzzy logic controlled induction motor with solar PV fed zeta converter controlled shunt active filter is shown in Fig.4.9. The speed response of induction motor with PV based zeta converter controlled SAF is shown in Fig.4.10. It has been observed that the motor speed is promptly reached the steady state value of 900rpm with the presence of voltage disturbances

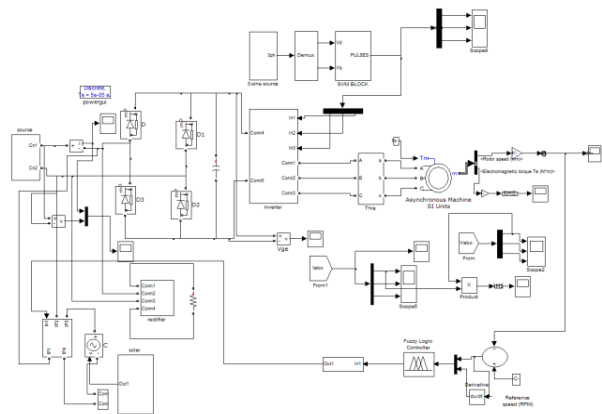


Fig.4.9 Simulink model of induction motor with PV powered FLC ZCSAF

The fuzzy logic controller effectively reduced the speed disturbances and enabled to obtain a smooth speed operation. The torque response of FLC induction motor is shown in Fig.4.14. From the torque response, starting torque rapidly increases and it reaches the final value of 10Nm at 0.6sec. The FFT analysis of source current harmonic THD level is shown in Fig.4.15. The closed loop Fuzzy logic controlled induction motor with PV fed zeta converter controlled shunt active filter shows THD about 2.66%. The comparison of time domain parameters for the proposed system is given in Table 1 and the comparison source current harmonic THD is given in Table 2.

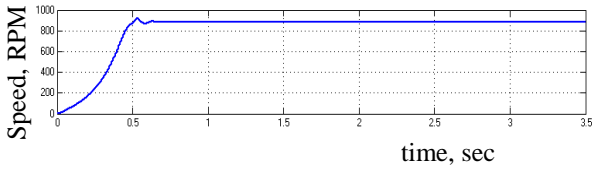


Fig. 4.10. Speed response of Fuzzy induction motor with PV powered FLC ZCSAF

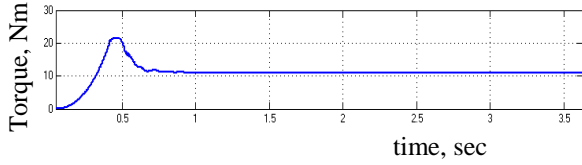


Fig. 4.11. Torque response of induction motor with PV powered FLC ZCSAF

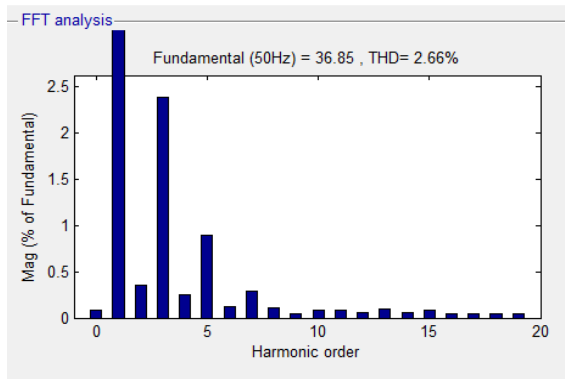


Fig. 4.12 FFT analysis of source current harmonic THD in PV powered FLC ZCSAF

Table 1 Comparison of Time domain parameters for proposed system

Type of controller	Rise time sec	Peak time sec	Settling time sec	S.S error % $e_{ss}$
PI controller	1.18	1.19	2.4	5
Fuzzy logic controller	0.6	0.65	0.72	1.2

Table 2 Comparison of source current harmonic THD in ZCSAF

Type of controller	%THD
PI controller	3.0
Fuzzy logic controller	2.66

## 5. Hardware Results

The experimental arrangement of the proposed system is shown in Fig.5.1. The hardware implementation is designed to validate the simulation results. In this prototype system 0.5 HP, 415V, 50Hz, 1.4A, 990 RPM rated three phase squirrel cage induction motor is used as a nonlinear

load. The experimental arrangement consists of single phase diode bridge rectifier board, control board, single phase active filter, Zeta converter, three phase MOSFET inverter board and three phase squirrel cage induction motor. The output voltage from the solar PV array is 50V and is shown in Fig. 5.2. Zeta converter boosts the solar DC output voltage from 50V to 100V by a varying duty cycle of active switch and the corresponding switching pulse waveform is shown in Fig.5.3. The output voltage of zeta converter is shown in Fig.5.4. The switching pulses for  $S_1$  &  $S_3$  of shunt active filter are shown in Fig.5.5. The switching pulses for  $M_1$  and  $M_3$  of the three phase inverter are shown in Fig. 5.6. The output voltage for R phase of the three phase inverter is shown in Fig.5.7.

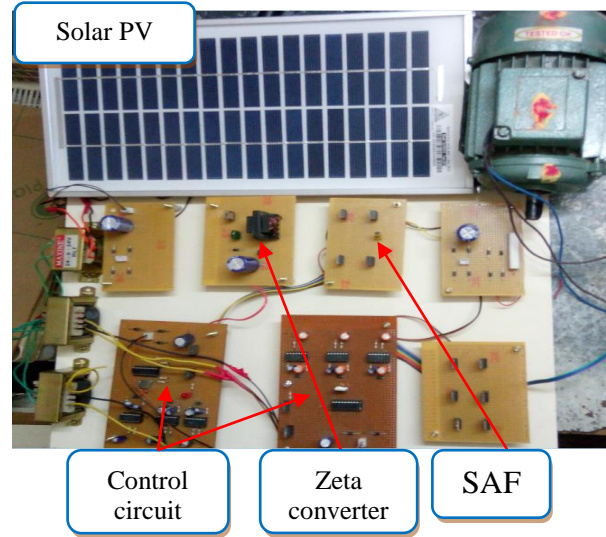


Fig. 5.1. Experimental setup of the proposed system

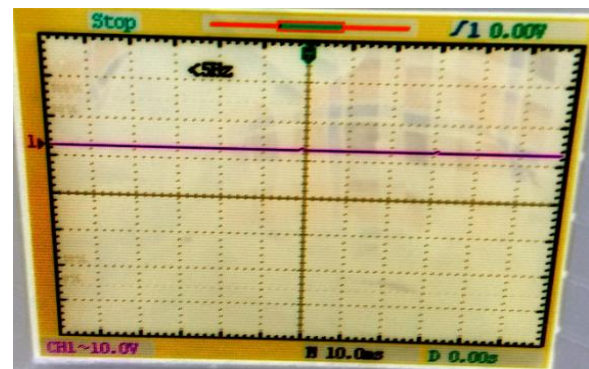


Fig. 5.2. Output voltage of solar PV Array



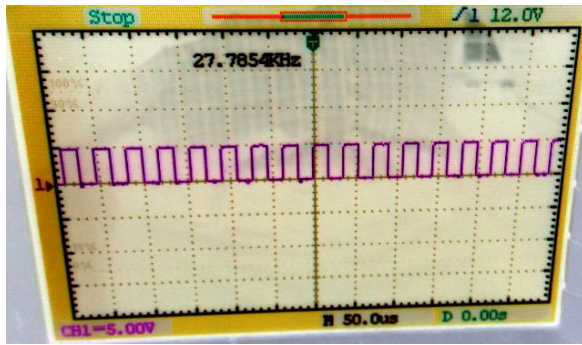


Fig. 5.3 Switching pulse applied to  $Q_1$  of Zeta converter

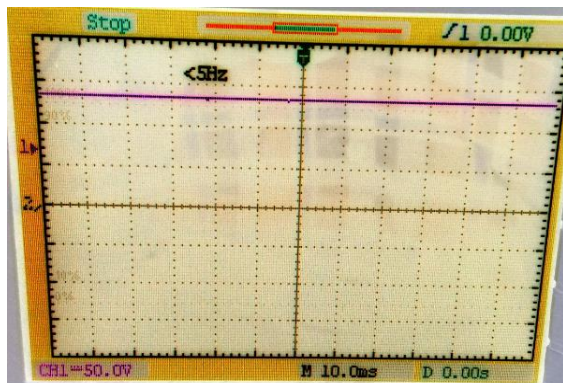


Fig. 5.4 Output voltage waveform of Zeta converter



Fig. 5.5 Switching pulses applied to three-phased inverter switches of  $S_1$  &  $S_3$

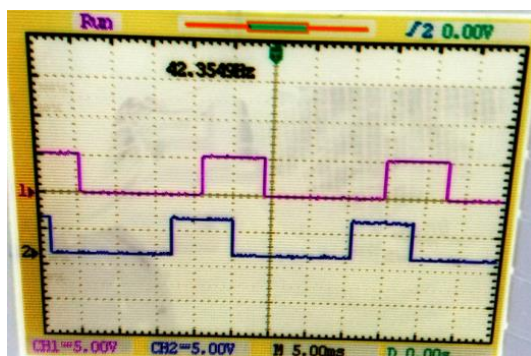


Fig. 5.6 Switching pulses applied to SAF switches of  $M_1$  &  $M_3$

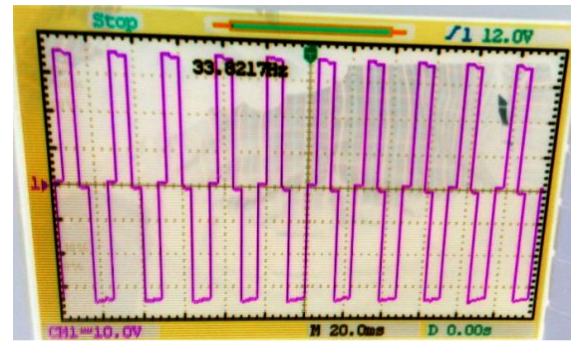


Fig. 5.7 Output voltage waveform of 3-phase inverter (R-phase)

## 6. Conclusion

The closed loop PI and FLC ZCSAF for three phase VSI fed induction motor has been modeled and simulated. The performance study of zeta converter controlled SAF based induction motor has been presented. The results indicate that the speed response of FLC ZCSAF controlled induction motor is smarter than the PI ZCSAF induction motor drive system. The FLC has greatly reduced the speed changes, i.e. disturbances and the source current harmonic THDs about 2.66%. The FL controller reduces the source current harmonic THD about 11.33% as compared to PI controller. Considering the performance of the PI and FLC, the proposed Fuzzy logic controlled induction motor with solar PV powered zeta converter controlled SAF is more suitable for industrial applications.

## Appendix-A

The parameters used for the MATLAB simulation are 4-pole, 3 $\phi$ , 5.4HP/4kW, 415V, 50Hz, 990 RPM squirrel cage induction motor. The motor parameters are

Stator resistance $R_s$	= 1.405 $\Omega$
Stator inductance ( $L_{ls}$ )	= 5.839 mH
Rotor resistance ( $R_r$ )	= 1.395 $\Omega$
Rotor inductance ( $L_{lr}$ )	= 5.839 mH
Mutual inductance ( $L_m$ )	= 0.1722 H
Inertia (J)	= 0.0131 kg-m <sup>2</sup>
Friction coefficient (F)	= 0.2985 N-m-s
Solar PV Output voltage ( $V_{pv}$ )	= 50 V
Insolation level	= 1000 W/m <sup>2</sup>
Solar PV current ( $I_{pv} = I_{ref}$ )	= 4.85A

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