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# Open Ended Winding Motor Drive Using A Floating Bridge Multi-Level Converter

**S. Anusha[1], E. Mounika[1], M. Anka Rao[2]**
[1]PG Student, Dep. of EEE, JNTU College of Engineering, Ananthapuramu, Andhra Pradesh, India
[2]Assistant Professor, Dep. of EEE, JNTU College of Engineering, Ananthapuramu, Andhra Pradesh, India

## ABSTRACT

This paper presents the use of a dual bridge inverter topology for an open ended winding induction motor drive. A three phase induction machine with open stator phase windings along with dual-bridge inverter supplied from a single dc voltage source together represents a drive. To accomplish multi-level output voltage waveforms a floating capacitor bank is utilized for the second of the dual extensions. The capacitor voltage is controlled utilizing excess switching states at half of the principle dc interface voltage. The primary controller (master controller) is designed as a Fuzzy logic controller. This specific voltage proportion (2:1) is utilized to make a multi-level output voltage waveform with three levels. An altered modulation conspire is utilized to enhance the waveform nature of this dual inverter. The most commonly used controller for the speed control of Induction Motor is Proportional Integral (PI) controller. PI controller has high starting overshoot, sensitivity to controller gains and sluggish response due to sudden disturbance. So, to overcome these problems, replacement of PI controller by fuzzy logic controller is proposed. At last, point by point simulation is exhibited for the motor drive working as an open loop v/f controlled motor drive and as a closed loop field oriented motor controller.

**Keywords :** Field oriented control (FOC), floating bridge, open ended winding induction machine, space vector, fuzzy logic control.

## I. INTRODUCTION

Now-a-days, many industrial applications have begun to require high power. Some appliances in the industries however require medium or low power for their operation. Using a high power source for all industrial loads may prove beneficial to some motors requiring high power, while it may damage the other loads. Some medium voltage motor drives and utility applications require medium voltage. The multi level inverter has been introduced since 1975 as alternative in high power and medium voltage situations. The Multi level inverter is like an inverter and it is used for industrial applications as alternative in high power and medium voltage situations. Multilevel inverters have become more popular over the years in electric high power application with the promise of less disturbances and the possibility to function at lower switching frequencies than ordinary two-level inverters.

Dual inverter can be operated as a standard single-sided three-phase inverter if there occurs a failure in one converter. So, more reliable are the dual inverters. In contrast with the traditional system with two isolated DC sources and a transformer, this paper presents a dual two-level inverter for an open-end winding induction motor (IM) drive application to reduce the size and weight of the system. For different applications, different number of dual inverter topologies were considered with different space vector modulation schemes to generate different level output voltage waveforms. A block diagram of a traditional open-phase load and converters is shown in Figure 1. The main disadvantages of this variation of the topology are reduction in the number of voltage levels and lower dc bus voltage utilization. So, to balance the power flow between the two inverters in a dual-inverter system, there proposed a modulation technique. In traditional topology, with reduced modulation index, transformer size can be reduced.

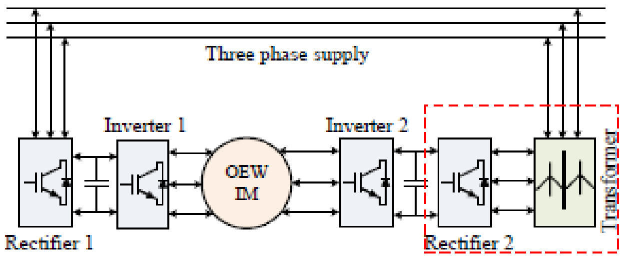


**Figure 1.** Block diagram of traditional topology

## II. PROPOSED SYSTEM

### 1.Floating capacitor bridge inverter

To allow the supply of reactive power, a suitable control scheme with a floating capacitor bridge topology was introduced, which offsets the voltage droop in high-speed machines. In this paper, a circuit topology is analyzed, which is used as a three-level open-end winding IM drive. It has dual inverter at the primary side of the converter with a single dc voltage source and a floating capacitor bank at its secondary as shown in Figure 2. So, while achieving multilevel output voltage waveforms, eliminating the requirement for a bulky isolation transformer is the aim of this topology. By using the redundant switching vectors along with a modified space vector modulation (SVM) scheme, which avoids unwanted voltage levels in the phase voltage waveforms during the dead-time intervals, thus improving the overall waveform quality, the voltage across the capacitor bank is controlled.

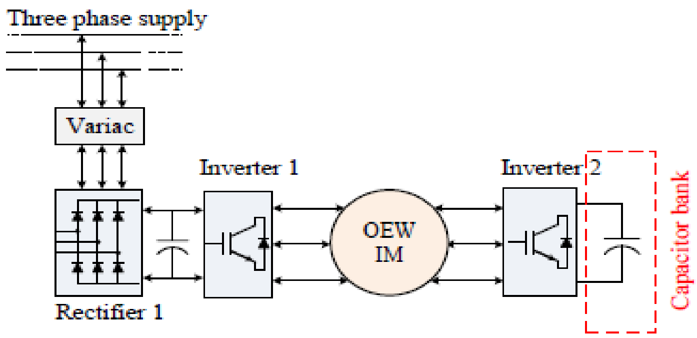


**Figure 2.** Block diagram of floating bridge topology

### 2.Principles of operation:

The schematic diagram of floating capacitor bridge inverter is shown in Figure 3. The charging and discharging of floating capacitor can be shown by analysing switching states. The space vector diagram for the topology is shown in Figure 4, which is derived by assuming that both converters are supplied from isolated dc sources with a voltage ratio of 2:1.

In Figure 4, the red numbered switching combinations discharge the floating capacitor, while the green numbered switching combinations charge the floating capacitor.

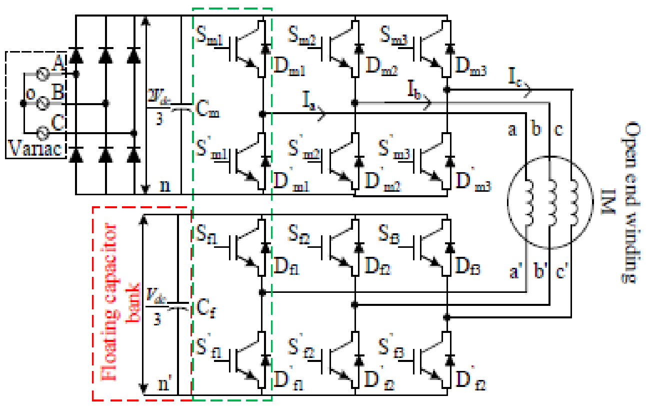


**Figure 3.** Power flow diagram of floating bridge topology

The blue numbered switching combinations hold the last state of capacitor and are, therefore, neutral in terms of the state of charge of the floating capacitor. As an example state (74) shown in Figure 5 gives the switching sequences for both converter's top switches, 7 (1 1 1) represents the top three switches for main inverter and 4 (0 1 1) represents the switching states for top three switches of the floating converter.

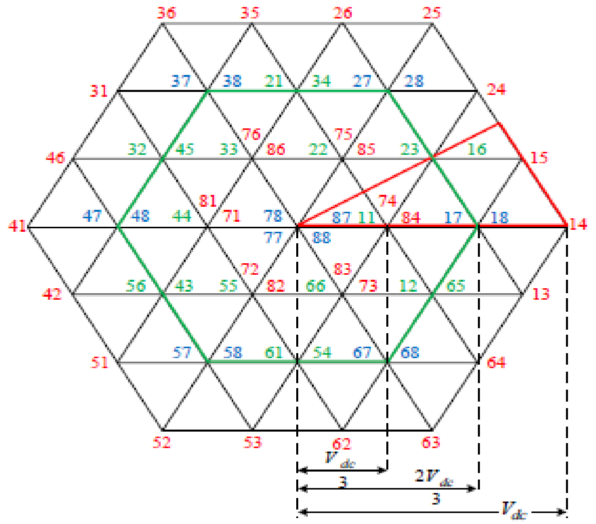


**Figure 4.** Space vector of dual two-level inverter(source ratio 2:1).

It can be seen from Figure 5 that combinations (11) and (16) will direct the current through the positive to negative terminal of the floating capacitor and thus will act to charge the capacitor.

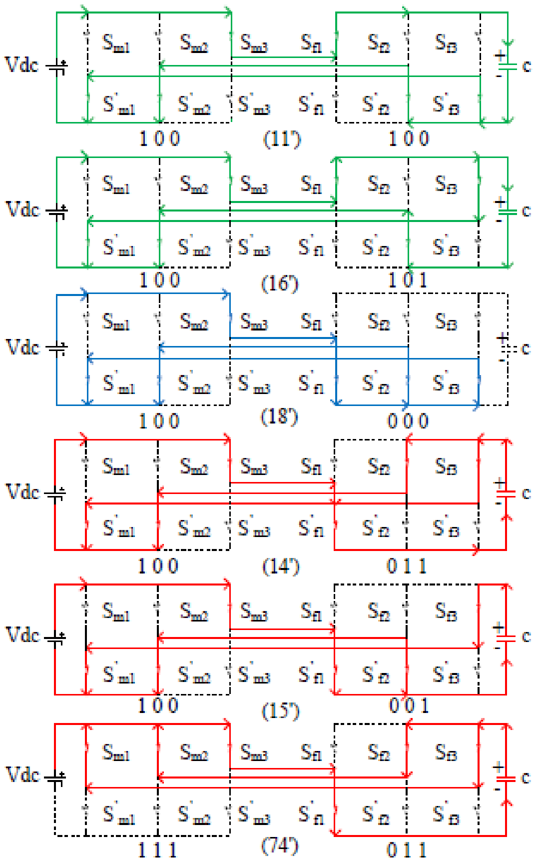


**Figure 5.** current flow for different switching state.

Combinations (14), (15), and (74) will result in a current in the other direction and will, therefore, act to discharge the capacitor. Combinations ending with 7 (1 1 1) or 8 (0 0 0) are zero states and will, therefore, have no impact of floating capacitor's voltage. From Figure 4, it is evident that, if the reference voltage is in outer hexagon, then there are only two switching combinations in each sector to charge the floating capacitor.

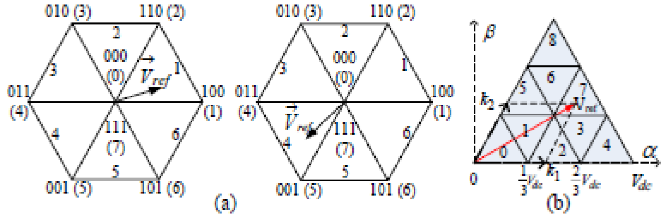


**Figure 6.(a)** Space vector diagram of individual converter (not in scale). (b) Space vector diagram of the dual-inverter system with source ratio of 2:1.

During inductive load operation, capacitor discharge rate will be slower and will cause over charging if the reference voltage lies in outer hexagon. Also, due to lack of charging states, the floating capacitor will discharge if the machine is drawing active power. To avoid these two phenomena, a restriction has to be imposed on modulation index. As a result, the maximum useable number of voltage levels across the load will be reduced to nine (13 for isolated sources) along with a slightly lower than ideal dc bus voltage utilization. Therefore, the floating capacitor can charge to half of the main dc-link capacitor voltage only if the modulation index (m) is limited i.e., m =0 .66.

This is 33% reduction of dc bus utilization in contrast with a dual inverter supplied by two isolated sources. The dual inverter with a zero sequence elimination technique also uses single supply with 15% reduction in dc bus utilization and can achieve five-level voltage across the load.

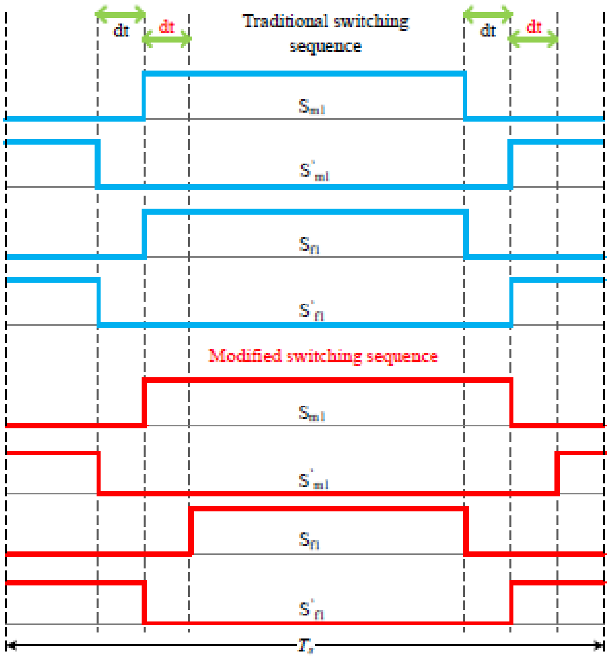


**Figure 7.** Delayed dead-time intervals in both converters when current direction is positive.

## 3.Modulation Strategy

Space Vector PWM (SVPWM) is a more sophisticated technique for generating a fundamental sine wave that provides a higher voltage to the motor and lower total harmonic distortion (THD). It is also compatible for use in vector control (Field orientation) of AC motors. A three-phase voltage vector is transformed into a vector in the stationary d-q coordinate frame which represents the spatial vector sum of the three-phase voltage. Voltage equations in d-q co-ordinate frame are as follows:

$V_d = V_{an} - V_{bn}\cos 60 - V_{cn}\cos 60$

$= V_{an} - V_{bn}/2 - V_{cn}/2$

$V_q = 0 + V_{bn}\cos 30 - V_{cn}\cos 30$

$= \sqrt{3}(V_{bn} - V_{cn})/2$

$$\begin{bmatrix} Vd \\ Vq \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Van \\ Vbn \\ Vcn \end{bmatrix}$$

$$|V_{ref}| = (V_d^2 + V_q^2)^{1/2}$$

$$\alpha = \tan^{-1}\left(\frac{Vq}{Vd}\right) = \omega t = 2\pi f t$$

Where, f is fundamental frequency.

SVPWM has been used for this dual-inverter floating bridge topology. Switching combinations are selected in such a way that the average generated voltage for each of the converters is 180° phase shifted from the other[seeFigure 6(a)]. These voltages will then add up at load terminal to match overall voltage reference [see Figure 6(b)]. To achieve better results, the output switching sequences are modified. The modification of the pulses is necessary to minimize the unwanted voltage levels due to dead-time intervals in each phase leg.

For an example, consider phase legs inside the green dotted line in Figure 3 for positive load current (current flowing from main to floating converter). If the top switches of the legs (Sm1 and Sf1) are ON, then the load current will go through switch Sm1 and diode Df1. Now, if both legs go to its dead time at the same time, the load current will change direction and will go through diode Dm1 and diode Df1. Finally, when both the converter leg bottom switches (Sm1 and Sf1) turned ON, current will go through diode Dm1 and switch Sf1. It is clear that during dead-time interval, the voltage level is different from the voltage levels before and after the dead-time interval. To avoid this unwanted voltage level, in this scenario, the main converter leg will go into its dead-time first, and then, second converter will go to its dead-time interval(as shown in figure 7) as soon as the main converter passes its dead-time interval.

**Table 1.** Delay depending on current direction time

| | **Inv-1 Top** | **Inv-1 Bot** | **Inv-2 Top** | **Inv-2 Bot** |
|---|---|---|---|---|
| **I > 0** | Turn off | Turn on | Turn on | Turn off |
| **I < 0** | Turn on | Turn off | Turn off | Turn on |

Table 1. shows the generalized solution for positive and negative load currents to avoid the unwanted voltage levels. Due to the modified switching sequences, the current direction does not change

during the dead-time. The state of the floating capacitor will depend on the current just before the occurrence of dead-time interval. As an example, if the capacitor was charging, then it will keep charging when the converter is in dead-time period. The value of dead-time is too small for any overcharge or discharge to change the capacitor voltage drastically.

**4. OEWIM**

Open-end winding induction machines fed from two standard two-level voltage source inverters (VSI) provide an attractive arrangement for AC drives.

An open-end winding induction machine, fed by two 2-level VSIs, offers several advantages when compared to a standard wye or delta connected induction machine drive. The main features of an open-end winding induction machine drive can be summarized as: equal power input from both sides of each winding, thus each VSI is rated at half the machine power rating; each phase stator current can be controlled independently; possibility to have twice the effective switching frequency (depending on the modulation strategy); extensibility to more phases, therefore multiphase induction machines can be considered if current reduction is required; possibility of reducing common-mode voltage; and certain degree of fault tolerance, as there is voltage space vector redundancy.

To supply energy to an open-end winding machine, different power converter topologies have been developed; present a topology based on two 2-level VSIs fed by a single DC source.

**5. Field Oriented Control(FOC)**

The electrical drive controls become more accurate in the sense that not only are the DC current and voltage controlled but also the three phase currents and voltages are managed by so-called vector controls. The most efficient form of vector control scheme is the Field Orientated Control. The only input over which control is possible is the input current supplied to the stator. The actual stator current is the vector sum of two current vectors, the inductive (*phase delayed*) magnetising current vector producing the flux in the air gap and the *in phase*, torque producing, current. To change the torque we need to change the *in phase*, torque producing, current but because we want the air gap flux to remain constant at its optimum level, the magnetising current should also remain unchanged when the torque changes.

For many applications vector control is not necessary, but for precision control, optimum efficiency and fast response, control over the rotor field is needed and alternative methods of indirect control have been developed.

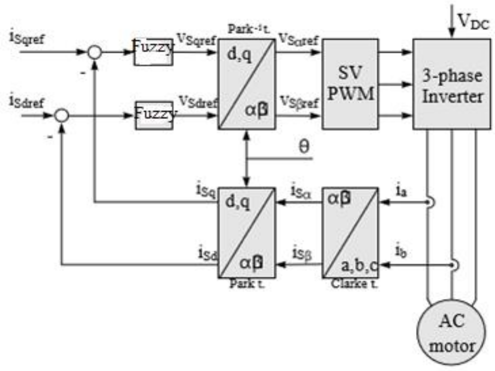


**Figure 8.** Block diagram of FOC

Because of the low cost of computing power, vector control is being used in more and more motor applications. FOC *activates* a pulse width modulated (PWM) inverter providing power to the motor. *Produces* Stator input voltage waveforms of the correct amplitude and frequency.

## III. FUZZY LOGIC CONTROLLER

Fuzzy logic is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables. Figure 9 shows the basic block diagram of fuzzy logic controller. Fuzzy logic is able to give results in the form of recommendation for a specific interval of output state.

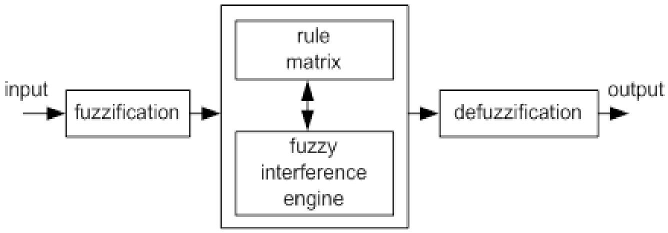


**Figure 9.** Block diagram of FLC

Fuzzy logic allows to lower complexity by allowing the use of imperfect information in sensible way. It can be implemented in hardware, software, or a combination of both. The Fuzzy logic investigation and control techniques appeared in Figure can be depicted as:

Receiving one or vast number of estimations or other appraisal of conditions existing in some framework that will be broke down or controlled.

Processing every got contribution as per human based, Fuzzy "assuming at that point" rules, which can be communicated in straightforward dialect words, and joined with conventional non-Fuzzy handling.

**Membership functions:**

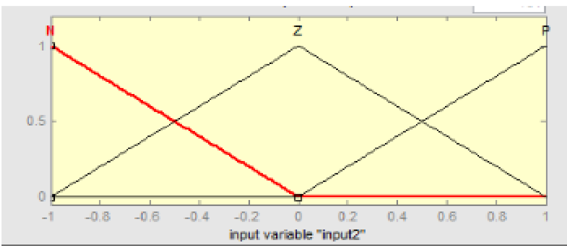


**Figure 10.** Input1 membership function

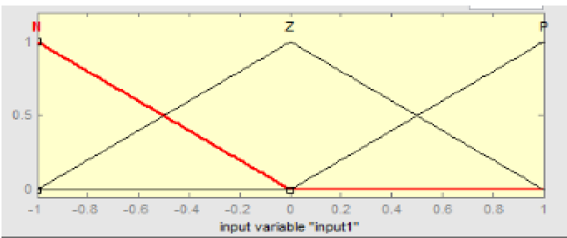


**Figure 11.** Input2 membership function

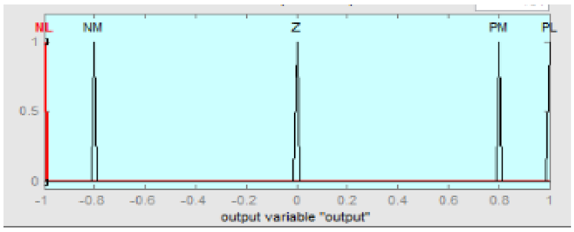


**Figure 12.** Output membership function

**Table 2.** Rule base for three Membership function:

| Change in Error($\frac{dV}{dt}$) | Error (Voltage) | | |
|---|---|---|---|
| | N | Z | P |
| N | NL | NM | Z |
| Z | NM | Z | PM |
| P | Z | PM | PL |

The FLC involves three sections: fuzzification, obstruction motor and defuzzification. The FC is portrayed as I. seven fuzzy sets for each info and yield. ii. Triangular enrollment capacities for effortlessness. iii. Fuzzification utilizing nonstop universe of talk. iv. Suggestion utilizing Mamdani's, "min" administrator. v. Defuzzification utilizing the tallness technique.

## IV. SIMULATION RESULTS

### SIMULINK MODEL OF OEWIM WITH FLOATING BRIDGE MULTILEVEL CONVERTER:

The open ended winding induction motor drive with a floating bridge multilevel converter using PI controller and Fuzzy logic controller has been simulated using SIMULINK. Results from the converter operating as an open-loop v/f motor drive are presented to show the converter operation.

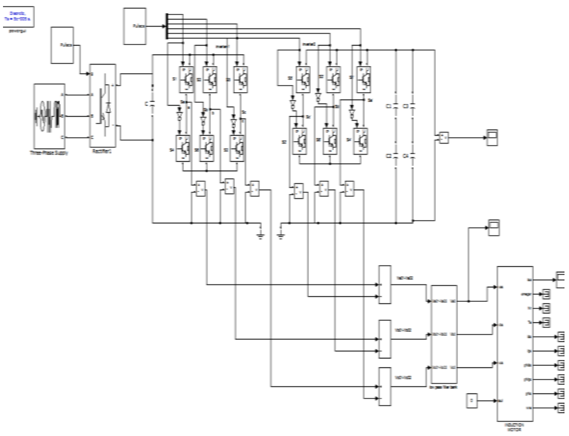

**Figure 13.** Simulink Model of Open loop v/f control OEWIM drive with a floating bridge multilevel converter

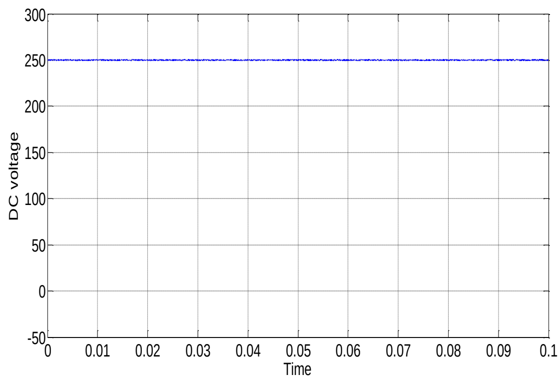


**Figure 14.** Floating DC link Voltage of Open loop v/f control OEWIM drive with a floating bridge multilevel converter

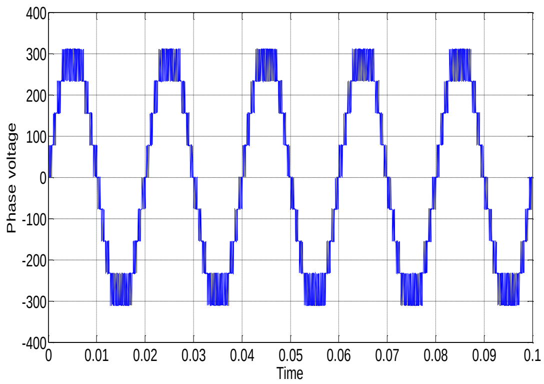


**Figure 15.** Phase Voltage of Open loop v/f control OEWIM drive with a floating bridge multilevel converter

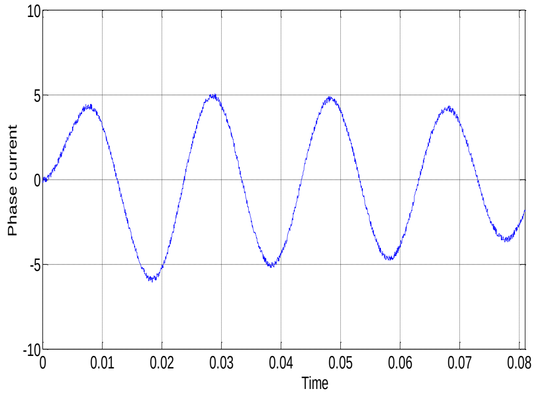


**Figure 16.** Phase current of Open loop v/f control OEWIM drive with a floating bridge multilevel converter

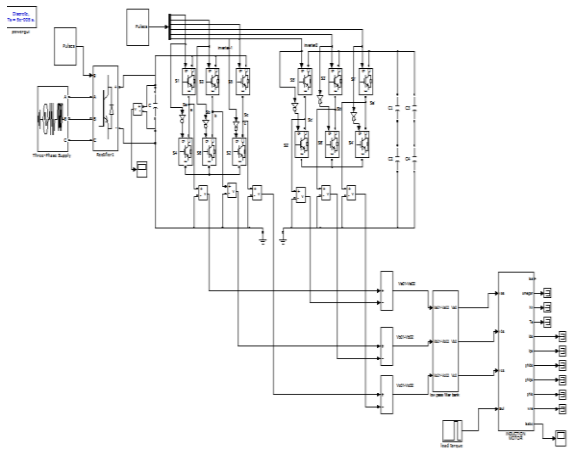

**Figure 17.** Simulink Model of Open loop v/f control OEWIM drive with a floating bridge multilevel converter under load

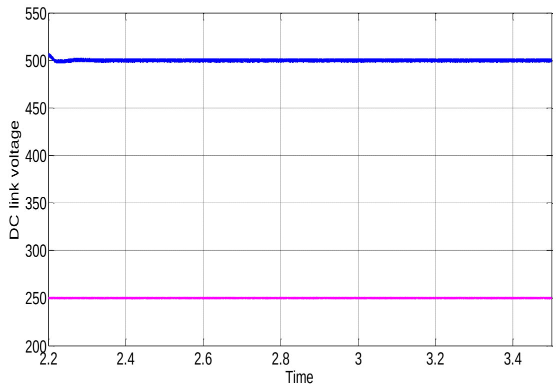


**Figure 18** Open loop v/f control of OEWIM drive with a floating bridge multilevel converter: Main DC link Voltage (Blue) and Floating Dc Link voltage (pink)

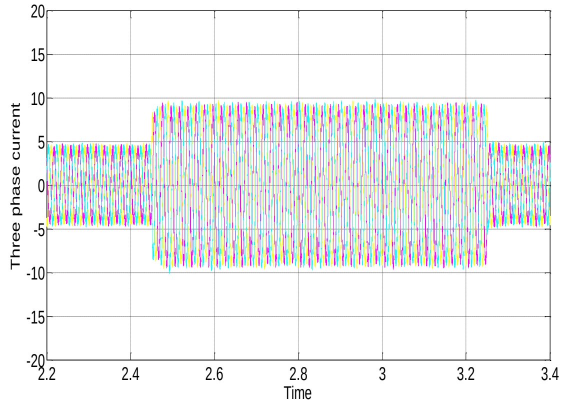


**Figure 19.** Three Phase current of Open loop v/f control OEWIM drive with a floating bridge multilevel converter

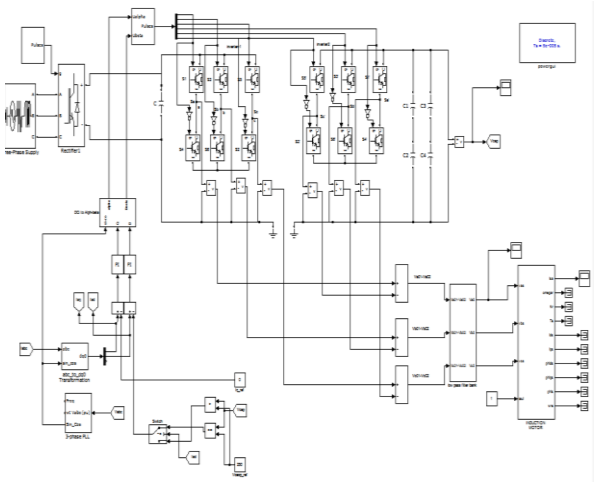

**Figure 20.** Simulink Model of closed loop control OEWIM drive with a floating bridge multilevel converter under load

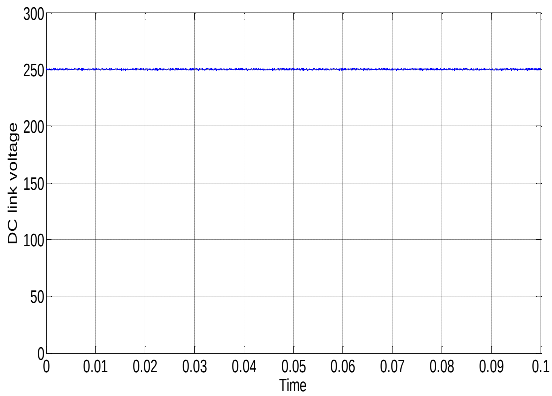


**Figure 21.** Floating DC link Voltage of closed loop control OEWIM drive with a floating bridge multilevel converter under load

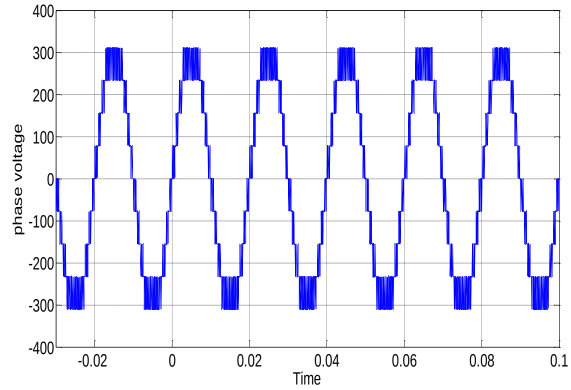


**Figure 22**. Closed loop control of OEWIM drive with a floating bridge multilevel converter under load: Phase Voltage

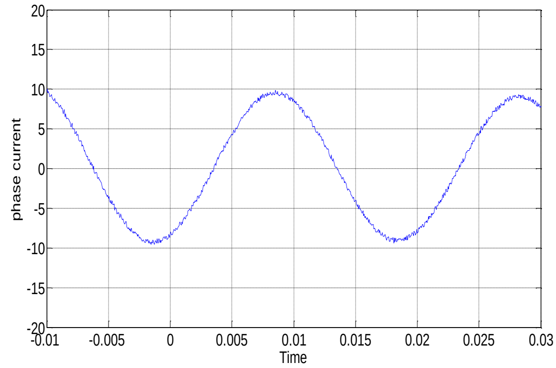


**Figure 23.** Closed loop control of OEWIM drive with a floating bridge multilevel converter under load: Phase current

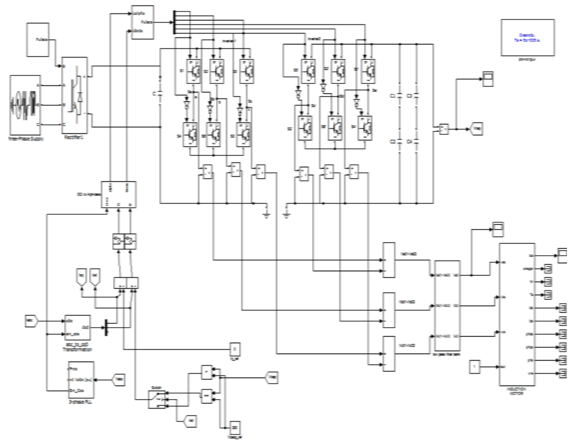

**Figure 24.** Simulink Model of OEWIM with a floating bridge multilevel converter using FLC

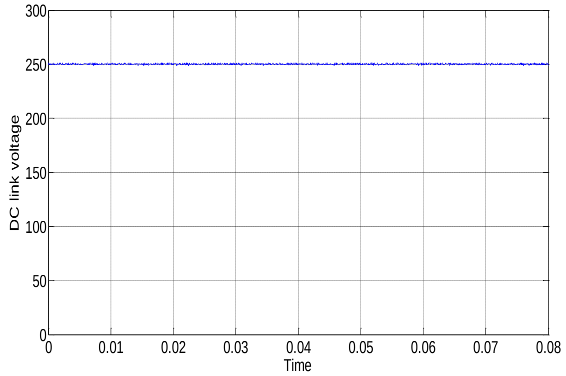


**Figure 25.** Closed loop control of OEWIM drive with a floating bridge multilevel converter using FLC: Floating DC link Voltage

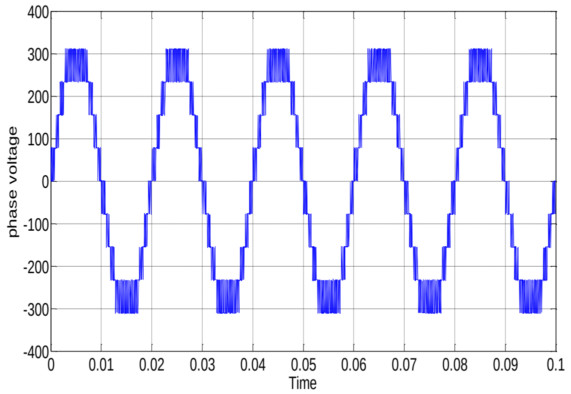


**Figure 26**. Phase Voltage of OEWIM with a floating bridge multilevel converter using FLC

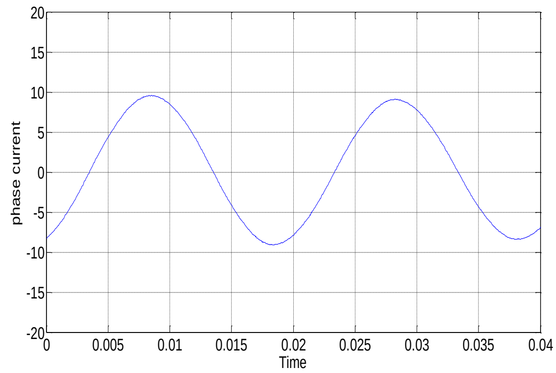


**Figure 27.** Phase current of OEWIM with a floating bridge multilevel converter using FLC

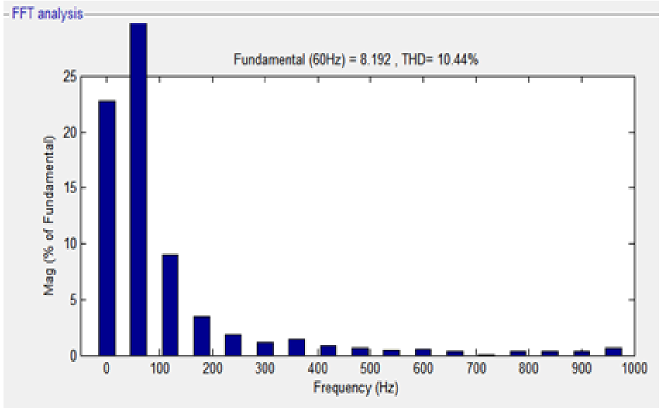


**Figure 28.** THD of Current Is (using PI)

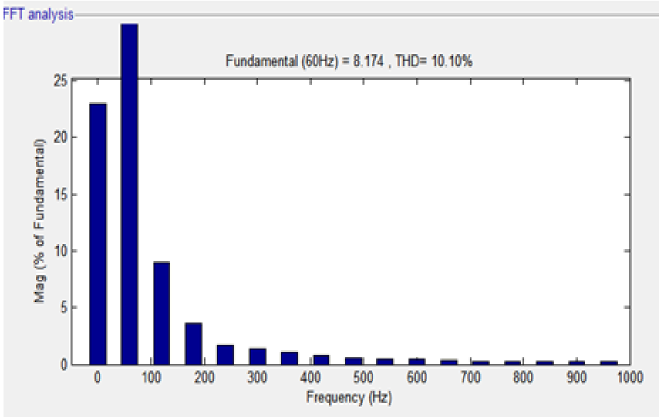


**Figure 29.** THD of Current Is (using FLC)

## V. CONCLUSION

In this paper, a floating capacitor bridge inverter using PI and FLC are shown. A changed space vector modulation methodology is embraced to dispose of the undesirable voltage levels during the dead-time interims, in this manner enhanced the waveform quality for this floating bridge topology. An open loop v/f control drive was executed to approve the execution of the capacitor control. At last, execution of the proposed system was assessed utilizing loop field oriented controlled motor drive, the outcomes demonstrated that the proposed topology accomplishes multi-level output voltage waveforms. Phase current, phase voltage, dc link and floating capacitor voltages of Open loop v/f control and closed loop control of open ended winding induction motor drive with a floating bridge multilevel converter using PI and FLC are obtained. Total harmonic distortion is reduced by using FLC compared to that of PI controller.

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