FUZZY LOGIC CONTROLLER FOR CASCADED H-BRIDGE MULTI LEVEL INVERTER

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Abstract- This paper describes the design of a rule based Fuzzy Logic Controller (FLC) for multilevel inverter. A multilevel inverter is controlled by varying the modulation index of the inverter by keeping the DC link voltage constant. The nine level Cascaded H Bridge multilevel inverter topology is designed as the test system for the design of fuzzy logic controller after a thorough evaluation of its advantages. The conventional control methods are mainly restricted to the direct and indirect control of the inverter. The proposed fuzzy logic controller shows improved functionalities in the simulative experimental studies. The Fuzzy Associative Memory (FAM) table is derived after a thorough research of the characteristics and compared with the conventional controller for harmonic disturbance, voltage profile and other system parameters.

Keywords— Cascaded H – Bridge inverter, Fuzzy logic Controller, PI controller

1. Introduction

Nowadays Multi-level inverters take an upper hand over the conventional Pulse Width Modulation (PWM) inverters [1]. The advantages of the multilevel inverters (MLI) include: 1) they provide even voltage sharing, both statically and dynamically 2) substantial reduction in size and volume is possible due to the elimination of the bulky coupling transformers or inductors and 3) multilevel inverters can offer better voltage waveforms with less harmonic content and, thus, can significantly reduce the size and weight of passive filter components[2]. There are three types of multilevel topologies, flying capacitor multilevel inverters, diode clamped and cascaded multi-level inverters.

For utility applications such as voltage regulation, Static VAR compensation,[3] etc the cascaded MLI has been employed widely. In such cases the performance of the inverter degrades with non linear loads. With rapid growth in the use of high efficiency power converters, more and more electrical loads are nonlinear and generate harmonics[4]. This demands a suitable controller to ensure satisfactory performance under dynamic load conditions.

Conventional closed loop control scheme employs PID controller to achieve the desired output. The PID controller requires quite a large bit of tuning to obtain fast and dynamically acceptable response. The design of the controller parameters requires the complete mathematical model of the system, which includes linearization over a limited operating region.

Recently, fuzzy logic controllers are gaining momentum in many applications. In this paper, a controller based on fuzzy set theory [6] is proposed. Unlike its counterpart, the PID controller no detailed mathematical model or linearization about an operating point is required by the fuzzy logic controller. Also, each rule addresses a wider scenario of operating conditions and ensures the same performance even with change in temperature, variation in system parameter with aging or with change in operating conditions.

2. Cascaded H - Bridge Multilevel Inverter

The structure of single cell of multilevel-cascaded H - bridge configuration is shown in the Fig.1[9]. The output of this cell will have three levels namely +V, 0 and –V. Using one single H-bridge, a three level inverter can be realized. This circuit requires about four switching devices. To realize higher levels of output voltage, the H- bridge circuits are cascaded. The circuit has many advantages like simple, modular, improved waveform which results in reduced total harmonic distortion.
The Cascaded multi-level inverter circuit provides high quality output when the number of levels in the output increases and also this reduces the filter components size and cost. Fig. 2 shows a fifteen level cascaded inverter and it requires about 28 switching devices and separate DC source for each module[7].

3. Cascaded Multilevel Inverter With Fuzzy Logic Controller

The fuzzy logic controller (FLC) unlike conventional controllers does not require a mathematical model of the system being controlled. However, an understanding of the system and the control requirements is necessary. The fuzzy controller designer must define what information flows into the system, now the information is processed, and what information flows out of the system. The fuzzy logic controller consists of three basic blocks. i) Fuzzifier; ii) Inference Engine; iii Defuzzifier. [5]
3. 1. Fuzzifier:

The fuzzy logic controller requires that each control variable which defines the control surface be expressed in fuzzy set notations using linguistic labels. Seven classes of linguistic labels ((Large Positive) LP, (Medium Positive) MP, (Small Positive) SP, (Very Small) VS, (Small Negative) SN, (Medium Negative) MN, (Large Negative) LN) characterized by membership grade are used to decompose each system variable into fuzzy regions. The membership grade denotes the extent to which a variable belongs to a particular class/label. This process of converting input/output variable to linguistic labels is termed as fuzzification. It is executed using reference fuzzy sets shown in Fig. 4 and used to create a fuzzy set that semantically represents the concept associated with the label. To have a smooth, stable control surface, an overlap between adjacent labels is provided such that the sum of the vertical points of the overlap should never be greater than one. In the proposed controller, the error in voltage $e = (V_{re}, - V_o)$ and its rate of change are normalized, fuzzified, and expressed as fuzzy sets.

3. 2. Inference Engine:

The behavior of the control surface which relates the input and output variables of the system is governed by a set of rules. The set of rules for the fuzzy controller are based on MacVicar-Whelam’s decision table shown in Table I, which proposes a definite control action for a given error $e$ and its rate of change. As for example If $(e \text{ is } \text{LP}) \text{ AND } (\frac{de}{dt} \text{ is } \text{LP})$, then $(\text{the controller output } U \text{ is } \text{LP})$. Thus, each entry in the table is a rule and there are 49 rules that form the knowledge repository of the fuzzy logic controller. These rules are used to decide the appropriate control action. When a set of input variables are read, each of the rule that has any degree of truth (a nonzero value of membership grade) in its premises is fired and contributes to the forming of the control surface by appropriately modifying it. When all the rules are fired, the resulting control surface is expressed as a fuzzy set (using linguistic labels characterized by membership grades) to represent the controller’s output.

<table>
<thead>
<tr>
<th>Error</th>
<th>Rate of change of Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP</td>
<td>LP MP SP ZZ SN MN LN</td>
</tr>
<tr>
<td>MP</td>
<td>MP SP ZZ SN MN LN</td>
</tr>
<tr>
<td>SP</td>
<td>SP ZZ SN MN LN</td>
</tr>
<tr>
<td>ZZ</td>
<td>ZZ SN MN LN</td>
</tr>
<tr>
<td>SN</td>
<td>SN MN LN</td>
</tr>
<tr>
<td>MN</td>
<td>MN LN LN</td>
</tr>
<tr>
<td>LN</td>
<td>LN</td>
</tr>
</tbody>
</table>

Table I: Mac Vicar Whelam’s Decision Matrix
3.3 Defuzzifier:
The fuzzy set representing the controller output in linguistic labels has to be converted into a crisp solution variable before it can be used to control the system. This is achieved by using a defuzzifier. Several methods of defuzzification are available. Of these, the most commonly used methods are i) Mean of Maxima (MOM) and ii) Center of Area (COA). Most control applications use the COA method. This method computes the centre of gravity of the final fuzzy space (control surface) and produces a result which is sensitive to all the rules executed. Hence, the results tend to move smoothly across the control surface.

A rule-based fuzzy logic controller is used as shown in Fig. 3, to track the reference voltage for any load condition. The inputs for the fuzzy logic controller are error and rate of change in error. The controller and the inverter are system are completely built in Matlab / Simulink environment.

4. Cascaded Multilevel Inverter With Pi Controller
To investigate the system behavior a PI controller is built for MLI. The controller is designed for optimum loading condition. Hence whenever the load is non linear the distortion in the output is more. The Multilevel inverter PI controller is shown in Fig. 5.

![Fig. 5. Cascaded MLI with PI Controller](image)

The performance of the inverter with the PI controller is analysed.

5. Simulation Results

5.1. Cascaded H-Bridge Multi Level Inverter:
The Cascaded H-bridge Multilevel Inverter circuit with nine levels is built for utility applications. Sinusoidal pulse with modulation (SPWM) is employed. The inverter operates with an input voltage of 120V dc source for each cell and at a switching frequency of 20 kHz. The simulated results of cascaded H-bridge inverter is presented in Fig. 6.
Fig. 6(a) shows the carrier waveforms used to generate switching signals. The modulated gate pulses are presented in Fig. 6(b). The output voltage waveform for the nine level inverter circuit without filter is shown in Fig. 6(c) and output voltage with filter is given in Fig. 6(d).

5.2. Cascaded MLI with PI Controller (Resistive load)

The Cascaded H-bridge MLI with PI controller has been designed and simulated. The results are observed with both linear and nonlinear loads. This offers satisfactory performance under steady state but still the dynamic performance is substandard.

The results of the PI controlled cascaded H-bridge inverter with a resistive load of 20Ω are presented in Fig 7. The Sinusoidal pulse width modulated switching signals is given in Fig 7(a). The response of the MLI with PI controller is
satisfactory and it can be observed from Fig. 7(b) wherein the reference voltage and the output voltage of the MLI are presented. The load current is given in Fig. 7(c). The Total Harmonic Distortion waveform is shown in Fig. 7(d).

It is observed from the results that the peak overshoot in the output voltage is 16.6% and the total harmonic distortion is 3.21%.
5.3. Cascaded MLI with Fuzzy Logic Controller (Resistive load)

Fuzzy logic provides a better alternative as it does not require any mathematical model of the system. The rule based fuzzy logic controller is built in Matlab / Simulink based on the information collected from the system. The results of the cascaded MLI with fuzzy logic controller are presented in Fig.8 for a resistive load of 20Ω. From the results it can be observed that the performance of the cascaded MLI with Fuzzy controller is found to be superior.

![Graph of 9-level MLI with Fuzzy controller for a resistive load of 20Ω](image)

(a) Reference and output voltage Signals (b) Load voltage and load current (c) THD

The output voltage and reference voltage of the cascaded MLI are shown in Fig. 8(a). From the response it can be observed that the peak overshoot is reduced to a greater extent with fuzzy controller. The load current and load voltage waveforms are shown in Fig. 8(b). From the Fig.8(c) it can be seen that the THD of the output voltage is decreased with the proposed controller.

It is observed from the results that the peak overshoot in the output voltage is 3% and the total harmonic distortion is 2.21%.

5.4. Cascaded MLI with PI Controller (Bridge rectifier load)

The performance of the MLI with PI controller is studied with nonlinear load. Here the bridge rectifier with RC load is used. The output voltage and reference voltage of the cascaded MLI are shown in Fig. 9(a). The load current waveform is shown in Fig. 9(b).
From the results it is examined that the THD and peak overshoot of the output voltage are increased when non linear loads are connected.

5.5. Cascaded MLI with Fuzzy Controller (bridge rectifier load)

The performance of the MLI with Fuzzy controller is studied with nonlinear load. Here the bridge rectifier with RC load is connected at the inverter output. The output voltage and reference voltage of the cascaded MLI are shown in Fig. 10(a). The load current waveform is shown in Fig. 10(b). It can be seen that the THD of the output voltage is comparatively less for non linear load, compared with PI controller.

It is observed from the results that the peak overshoot in the output voltage is 3% and the total harmonic distortion is 2.21%.
6. Performance Comparison of Fuzzy Controller and PI Controller

The above discussed results reveal that the performance of the PI controller degrades under dynamic loading conditions. The simulation results explore that the fuzzy logic controller outperforms the PI controller. The performance of the cascaded MLI with PI and Fuzzy controller has been analyzed and the results are presented in a tabular form. The performance of the system is measured in terms of peak overshoot, settling time and THD.

<table>
<thead>
<tr>
<th>Control Factor</th>
<th>PI</th>
<th>Fuzzy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak over Shoot</td>
<td>16.6%</td>
<td>3%</td>
</tr>
<tr>
<td>Setting Time</td>
<td>0.05 sec</td>
<td>0.009 sec</td>
</tr>
</tbody>
</table>

The performance of the controllers are tabulated in Table II. The quality of output voltage in terms of THD is presented in Table III. Hence it is concluded from the results that the peak overshoot, settling time and THD are reduced in the output voltage with proposed fuzzy controller. Also the dynamic response is superior with the proposed controller which is a high demand issue in utility end.

7. Conclusion

A model of the closed loop system for MLI with PI controller has been developed and simulated to study the system response. With the acquainted knowledge a rule based fuzzy logic controller is developed to enhance the system performance. The simulation results reveal that the fuzzy logic controller outperforms the PI controller. Compared with the PI controller the FLC achieves a smaller overshoot in the output voltage and affords quick settling. It is also seen that the proposed FLC can offer low THD under nonlinear loading condition and good dynamic response under transient loading condition. The MLI with the proposed FLC is found to be suitable for utility applications where the load introduces periodic distortions.

REFERENCES


BIBLIOGRAPHY

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