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Performance Analysis of Three-Phase AC Voltage Controller with Intelligent AI Controller

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Abstract

Three-phase AC voltage controllers are widely used in industrial applications for controlling power delivered to AC loads such as induction motors, heating systems, and renewable energy interfaces. Conventional controllers based on fixed firing angle control suffer from slow response and poor dynamic performance under varying load conditions. This paper presents the performance analysis of a three-phase AC voltage controller using an intelligent Artificial Intelligence Controller. The proposed control method generates optimized switching pulses for semiconductor switches by continuously monitoring the output voltage error and its rate of change. The simulation results demonstrate that the fuzzy-controlled AC voltage controller provides improved stability, faster response, and enhanced voltage control compared with conventional firing angle control techniques. The proposed intelligent control approach is suitable for modern industrial power conversion applications.

Keywords: Three-phase AC controller, Closed Control, Artificial Intelligence, Thyristor switching, Voltage regulation, Power electronics.

1. Introduction:

Power electronic converters play an important role in modern electrical energy conversion systems. Three-phase AC voltage controllers are extensively used for controlling the RMS voltage supplied to electrical loads by varying the firing angle of semiconductor switches. These controllers are commonly applied in industrial motor drives, soft starters, heating control systems, and power conditioning applications.

Traditional phase-angle control methods use fixed mathematical controllers that provide acceptable performance under constant operating conditions. However, nonlinear loads, sudden load variations, and parameter uncertainties reduce the controller performance and increase output voltage distortion.

Artificial Intelligence (AI)-based control techniques have gained significant attention due to their ability to handle nonlinear systems without requiring an exact mathematical model. Among various AI techniques, the Fuzzy Logic Controller (FLC) provides improved robustness, faster dynamic response, and better adaptability.

In this research work, a three-phase AC voltage controller integrated with a fuzzy logic intelligent controller is developed and analyzed. The fuzzy controller determines the appropriate firing angle by processing voltage error and error variation. A Python simulation model is implemented to study the input voltage, switching pulses, output voltage, and load current characteristics.

II. Analysis of the AI-Controlled Three Phase Controller

A three-phase AC voltage controller consists of three pairs of bidirectional semiconductor switches, generally implemented using thyristors connected in anti-parallel configuration.
The output voltage is controlled by changing the firing angle (α) of the thyristors.
The RMS output voltage is given by:

$$V_o = V_s \sqrt{\frac{1}{\pi}\left(\pi - \alpha + \frac{1}{2} sin(2\alpha)\right)}$$

where:

- V_o= Output voltage
- V_s= Supply voltage
- α = Firing angle

Increasing the firing angle reduces the conduction period and decreases output voltage.

The three phase AC voltage controller is as shown in Fig.1.

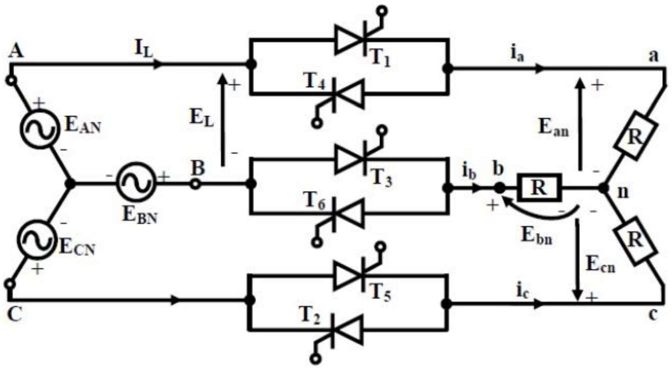

Fig.1 Three Phase AC Voltage Controller

The key waveforms of the circuit is as shown in Fig.2.

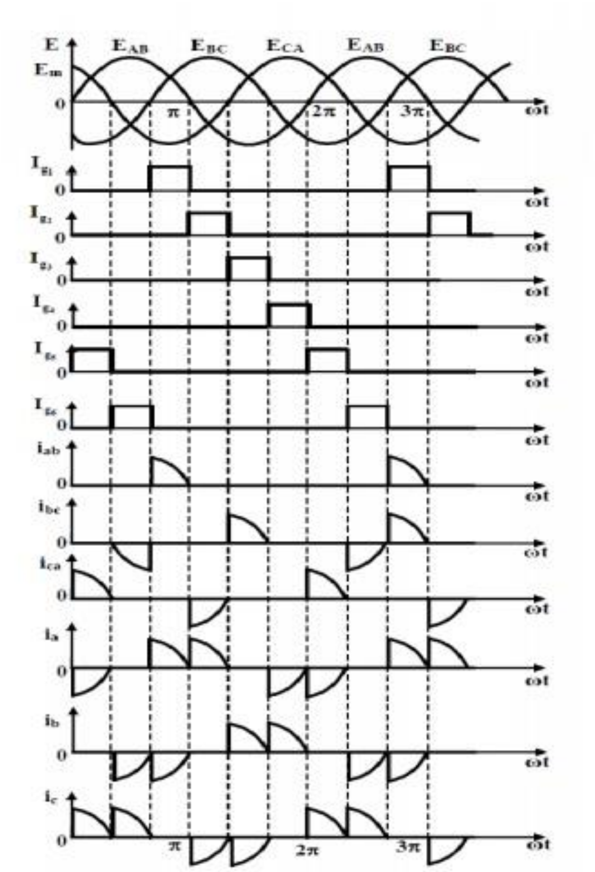

Fig.2 Key Waveforms of Three Phase Converter

Intelligent Control Strategy

The proposed controller consists of:

Input Variables

1. Voltage error:

$$e(k) = V_{ref} - V_o(k)$$

2. Change in error:

$$\Delta e = e(k) - e(k-1)$$

Output Variable

The fuzzy controller output determines the firing angle variation:

$\Delta\alpha$

Fuzzy Membership Functions

Input variables are classified into:

- Negative Large (NL)
- Negative Medium (NM)
- Zero (ZE)
- Positive Medium (PM)
- Positive Large (PL)

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The fuzzy rules are developed based on expert knowledge.

Error	Change Error	Firing Control
Positive Large	Positive	Increase conduction
Zero	Zero	Maintain firing angle
Negative Large	Negative	Reduce conduction

The python program code for this is as shown in Fig.3

```
import numpy as np
import matplotlib.pyplot as plt

# Simulation parameters
f = 50
Vm = 325
t = np.linspace(0,0.04,2000)

# Three phase input voltages

Va = Vm*np.sin(2*np.pi*f*t)

Vb = Vm*np.sin(2*np.pi*f*t-2*np.pi/3)

Vc = Vm*np.sin(2*np.pi*f*t+2*np.pi/3)


# Reference voltage

Vref = 200


# Fuzzy Controller Approximation

error = Vref - abs(Va)

delta_error = np.gradient(error)


# Fuzzy control output

alpha = 90 - 0.3*error - 0.2*delta_error


# Limit firing angle

alpha = np.clip(alpha,10,170)


# Switching pulse generation

pulse = np.sin(2*np.pi*f*t-alpha*np.pi/180)

switching = np.where(pulse>0,1,0)


# Output voltage

Vo = Va*switching


# Load current

R=20
Io=Vo/R


# Plot Input Voltage

plt.figure(figsize=(10,4))
plt.plot(t,Va)
plt.title("Three Phase AC Input Voltage")
plt.xlabel("Time (s)")
plt.ylabel("Voltage")
plt.grid()
plt.show()


# Switching waveform

plt.figure(figsize=(10,4))
plt.plot(t,switching)
plt.title("Fuzzy Controller Switching Pulse")
plt.xlabel("Time(s)")
plt.ylabel("Pulse")
plt.grid()
plt.show()


# Output voltage

plt.figure(figsize=(10,4))
plt.plot(t,Vo)
plt.title("Controlled Output Voltage")
plt.xlabel("Time(s)")
plt.ylabel("Voltage")
plt.grid()
plt.show()


# Current waveform

plt.figure(figsize=(10,4))
plt.plot(t,Io)
plt.title("Load Current Waveform")
plt.xlabel("Time(s)")
plt.ylabel("Current")
plt.grid()
plt.show()
```

Fig.3 Program for the Closed control of Converter

The output waveforms are as shown in Fig. 4, Fig.5 and Fig.6

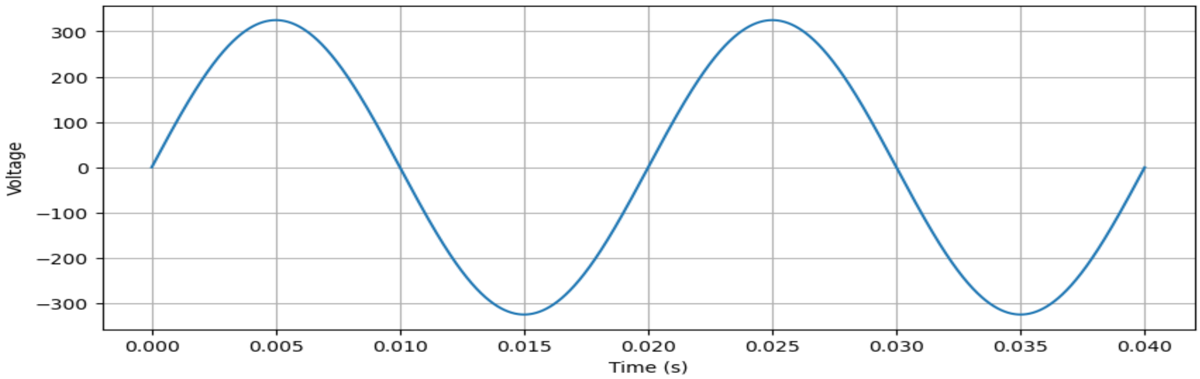

Fig.4 Input Waveform

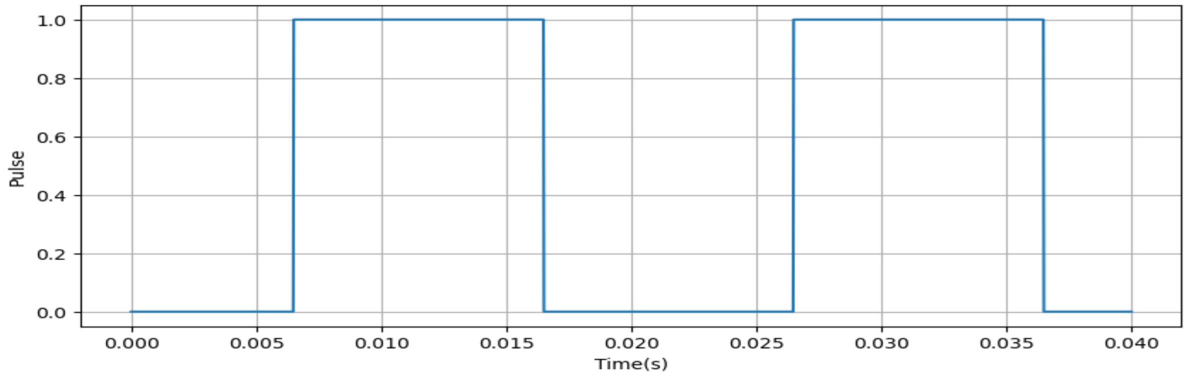

Fig.5 Switching Pulse

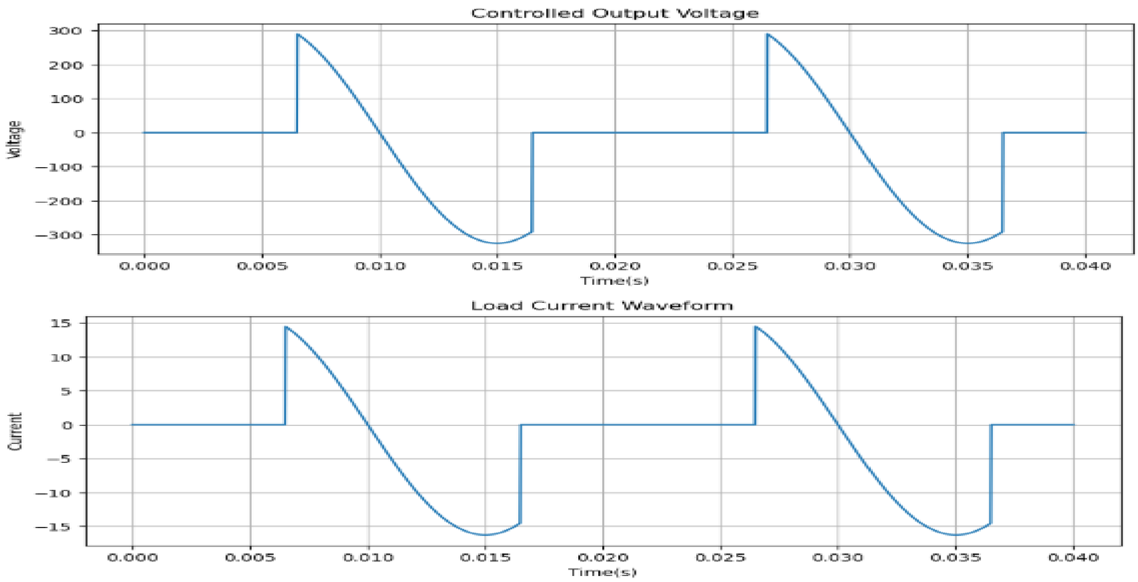

Fig.6. AI controlled Output Voltage and Current

Conclusion

A three-phase AC voltage controller with an intelligent fuzzy logic control technique has been developed and analyzed. The proposed AI-based controller provides adaptive firing angle control by processing voltage error and error variation. A Python simulation model was developed to evaluate input voltage, switching pulses, output voltage, and load current characteristics. The results demonstrate that closed control improves voltage regulation, transient response, and system stability compared with conventional phase-angle control methods. The intelligent controller effectively handles nonlinear operating conditions and load variations, making it suitable for industrial power electronic applications such as motor drives, heating systems, and renewable energy conversion systems.

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