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Simulation Analysis of WYE connected DC-DC Converter with AI controlled for Solar Applications

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Abstract

The integration of renewable energy sources with advanced power electronic converters has become essential for improving the efficiency and reliability of solar photovoltaic (PV) systems. This paper presents a simulation analysis of a WYE-connected DC–DC converter with an Artificial Intelligence (AI)-based control strategy for solar applications. The proposed converter topology enhances voltage conversion capability, reduces current ripple, and improves power transfer efficiency compared with conventional DC–DC converter configurations. Due to the nonlinear characteristics of PV systems and variations in solar irradiation and temperature, conventional maximum power point tracking (MPPT) techniques may experience slow response and reduced tracking accuracy. To overcome these limitations, an AI-based controller is developed to generate optimized switching signals for achieving effective MPPT operation. The proposed system includes a PV source, WYE-connected DC–DC converter, AI controller, switching circuit, and DC load.

Keywords: Solar PV, WYE-connected DC–DC converter, Artificial Intelligence, MPPT, MATLAB/Simulink, Renewable Energy.

1. Introduction

The rapid growth of renewable energy technologies, particularly solar photovoltaic (PV) systems, has created a significant demand for efficient, reliable, and intelligent power conversion systems. Solar energy is considered one of the most promising solutions for reducing dependency on conventional fossil fuel-based power generation due to its clean, sustainable, and widely available nature. However, the intermittent characteristics of solar irradiation, temperature variations, and partial shading conditions introduce significant challenges in extracting maximum available power from photovoltaic sources. Therefore, advanced power electronic converters with intelligent control techniques are essential to improve the performance, stability, and efficiency of solar energy conversion systems.

DC–DC converters play a vital role in photovoltaic applications by providing voltage regulation, maximum power point tracking (MPPT), and efficient energy transfer between the PV source and the load or energy storage system. Conventional DC–DC converters such as buck, boost, buck–boost, and interleaved converters are widely used in solar applications; however, they suffer from limitations including high switching stress, increased current ripple, limited voltage conversion ratio, and reduced efficiency under dynamic operating conditions. To overcome these limitations, advanced converter topologies with improved voltage gain, reduced losses, and better power density are continuously being investigated.

The WYE-connected DC–DC converter is an emerging high-performance topology that provides enhanced voltage conversion capability and improved current distribution compared with conventional converter structures. The WYE configuration enables multiple converter branches to operate in a coordinated manner, resulting in reduced input current ripple, lower semiconductor stress, and improved overall efficiency. Such characteristics make it suitable for high-power photovoltaic applications where maintaining stable DC output voltage under rapidly changing environmental conditions is a major requirement.

In conventional solar power systems, MPPT controllers are commonly implemented using perturb and observe (P&O) and incremental conductance (INC) algorithms. Although these techniques are simple and cost-effective, their performance deteriorates during fast changes in solar irradiation and temperature conditions. They may exhibit slow tracking speed, oscillations around the maximum power point, and reduced energy harvesting capability under partial shading conditions. Hence, intelligent control approaches based on artificial intelligence (AI) techniques have gained significant attention for improving the dynamic response and optimization capability of renewable energy conversion systems.

Artificial intelligence-based controllers, including artificial neural networks (ANN), fuzzy logic controllers (FLC), adaptive neuro-fuzzy inference systems (ANFIS), and machine learning-based optimization algorithms, provide improved decision-making capability without requiring an exact mathematical model of the system. These controllers can learn nonlinear relationships between PV parameters such as voltage, current, irradiation level, and temperature, enabling accurate prediction of the optimum operating point. AI-based MPPT techniques can achieve faster convergence, reduced steady-state oscillations, and higher energy extraction compared with conventional approaches.

Analysis of WYE connected DC-DC Converter:

The wye connected converter is as shown in Fig.1. When the switch SW is turned ON, D_1 gets reverse-biased, and hence it is replaced by an open-circuit in series with the source.

By applying KVL, we have,

$$V_L = V_{C1}\left(\frac{N_1}{N_3 - N_2}\right) \tag{1}$$

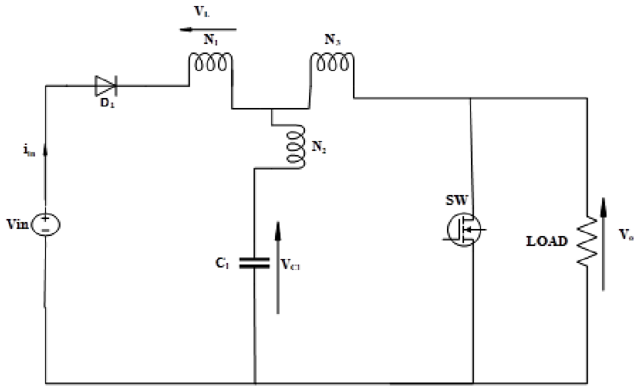

Fig.1 Wye connected DC-DC converter

When the switch is turned OFF, the diode D_1 now conducts linking the source with the impedance network.

$$V_L = (V_{in} - V_{C1})\left(\frac{N_1}{N_1+N_2}\right) \tag{2}$$

The key waveforms are as shown in Fig.2. and are expected from the Y-source boost DC/DC converter in response to the applied gate voltage VGS to switch SW. This causes diodes D1 and D2 to become reverse-biased, and their voltages VD1 and VD2 to increase. The input current Iin, which is also the current ID1 through D1, then reduces to zero during this interval.

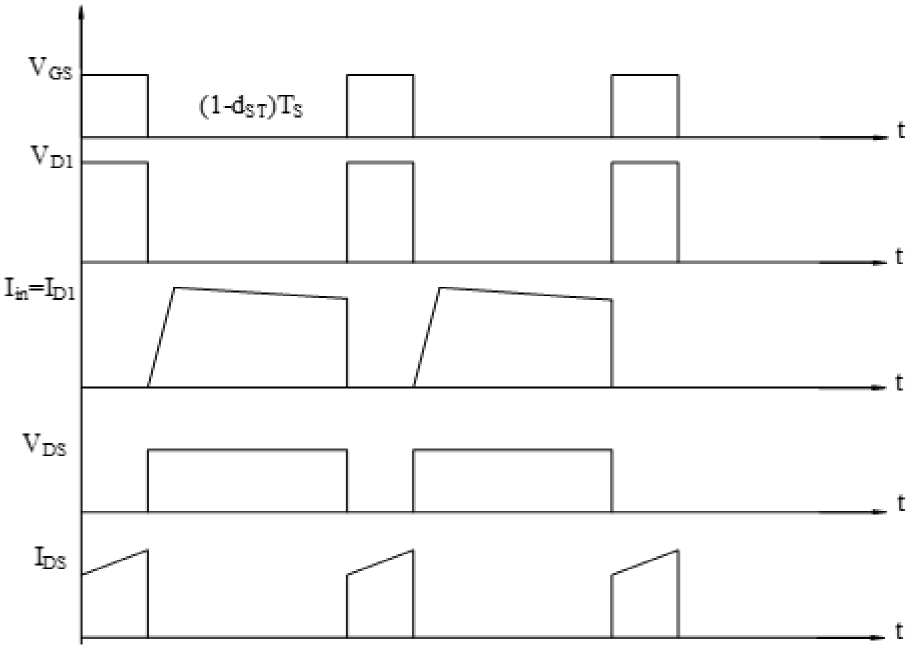

Fig.2. Key waveforms of wye connected DC-DC converter.

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AI integration of Wye connected Converter:

The integration of Artificial Intelligence (AI) with a WYE-connected DC–DC converter provides an intelligent control mechanism that improves the performance, efficiency, and adaptability of solar photovoltaic (PV) energy conversion systems. A conventional DC–DC converter operates using fixed or manually tuned control parameters, which may not provide optimum performance under rapidly changing solar irradiation, temperature variations, and load disturbances.

In an AI-controlled WYE converter, the conventional feedback controller is replaced or enhanced by an intelligent algorithm such as an Artificial Neural Network (ANN), Fuzzy Logic Controller (FLC), Adaptive Neuro-Fuzzy Inference System (ANFIS), or Reinforcement Learning (RL). The AI controller continuously analyzes PV system parameters and generates an optimized switching duty cycle for the converter switches.
Programme for this converter is as give below as screen shots

```
# ===============================================================
# ANN Based MPPT Controller for WYE Connected DC-DC Converter
# Solar PV Application
# ===============================================================
import numpy as np
import matplotlib.pyplot as plt

from sklearn.neural_network import MLPRegressor
from sklearn.preprocessing import StandardScaler
# ---------------------------------------------------------------
# 1. Generate Solar PV Training Data
# ---------------------------------------------------------------
# PV voltage range (V)
Vpv = np.linspace(20, 45, 100)
# PV current model (A)
Ipv = 5.5 - 0.05*(Vpv-20)
# PV Power
Ppv = Vpv * Ipv
# ANN Inputs
X = np.column_stack((Vpv, Ipv))
# ANN Output
Y = Ppv
# ---------------------------------------------------------------
# 2. Data Normalization
# ---------------------------------------------------------------
scaler = StandardScaler()
X_scaled = scaler.fit_transform(X)
# ---------------------------------------------------------------
# 3. Create ANN MPPT Controller
# ---------------------------------------------------------------
ANN_MPPT = MLPRegressor(
    hidden_layer_sizes=(10,10),
    activation='relu',
    solver='adam',
    learning_rate_init=0.001,
    max_iter=2000,
    random_state=1
)
# Training ANN
ANN_MPPT.fit(X_scaled,Y)
print("ANN Training Completed")
# ---------------------------------------------------------------
# 4. Test ANN Controller
# ---------------------------------------------------------------
V_test = 36        # PV voltage
I_test = 5.2       # PV current
input_data = scaler.transform(
    [[V_test,I_test]]
)
Predicted_power = ANN_MPPT.predict(input_data)
print("--------------------------------")
print("PV Voltage =",V_test,"V")
print("PV Current =",I_test,"A")
print("Maximum Power =",round(Predicted_power[0],2),"W")
```

```
Predicted_power = ANN_MPPT.predict(input_data)
print("--------------------------------")
print("PV Voltage =",V_test,"V")
print("PV Current =",I_test,"A")
print("Maximum Power =",round(Predicted_power[0],2),"W")
# ---------------------------------------------------------------
# 5. Duty Cycle Calculation
# WYE DC-DC Converter
# Boost Mode Operation
# ---------------------------------------------------------------
Vin = V_test
Vout = 100
Duty_cycle = 1 - (Vin/Vout)
print("Optimized Duty Cycle =",
      round(Duty_cycle,3))
# ---------------------------------------------------------------
# 6. PWM Generation
# ---------------------------------------------------------------
Fs = 20000         # Switching frequency
time = np.linspace(0,0.002,1000)


carrier = np.mod(time*Fs,1)

PWM = carrier < Duty_cycle


# ---------------------------------------------------------------
# 7. Plot PWM Signal
# ---------------------------------------------------------------

plt.figure(figsize=(8,3))

plt.plot(time,PWM)

plt.xlabel("Time (s)")
plt.ylabel("Gate Pulse")

plt.title("ANN Generated PWM Signal")

plt.grid()

plt.show()


# ---------------------------------------------------------------
# 8. PV P-V Characteristic
# ---------------------------------------------------------------

plt.figure(figsize=(7,4))

plt.plot(Vpv,Ppv)
```

```
# ---------------------------------------------------------------
# 8. PV P-V Characteristic
# ---------------------------------------------------------------

plt.figure(figsize=(7,4))

plt.plot(Vpv,Ppv)

plt.xlabel("PV Voltage (V)")
plt.ylabel("PV Power (W)")

plt.title("Solar PV Maximum Power Curve")

plt.grid()

plt.show()


# ---------------------------------------------------------------
# 9. ANN Performance Test
# ---------------------------------------------------------------

Predicted = ANN_MPPT.predict(X_scaled)


plt.figure(figsize=(7,4))

plt.plot(Ppv,label="Actual PV Power")

plt.plot(Predicted,
         '--',
         label="ANN Prediction")


plt.xlabel("Sample")

plt.ylabel("Power (W)")

plt.title("ANN MPPT Prediction Performance")

plt.legend()

plt.grid()

plt.show()
ANN Training Completed
```

Fig.3 Screen shots of programme

The pulse waveform for the switches of the converter is as shown in Fig.4

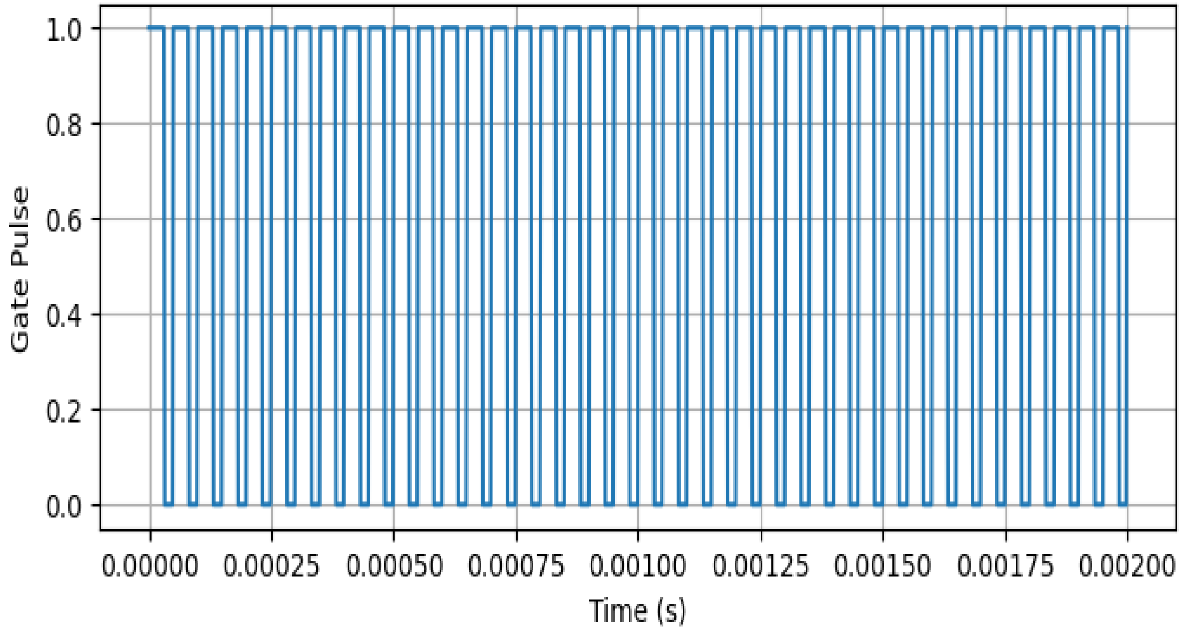

Fig.4 Pulse waveform

The solar PV maximum curve is as shown Fig.5

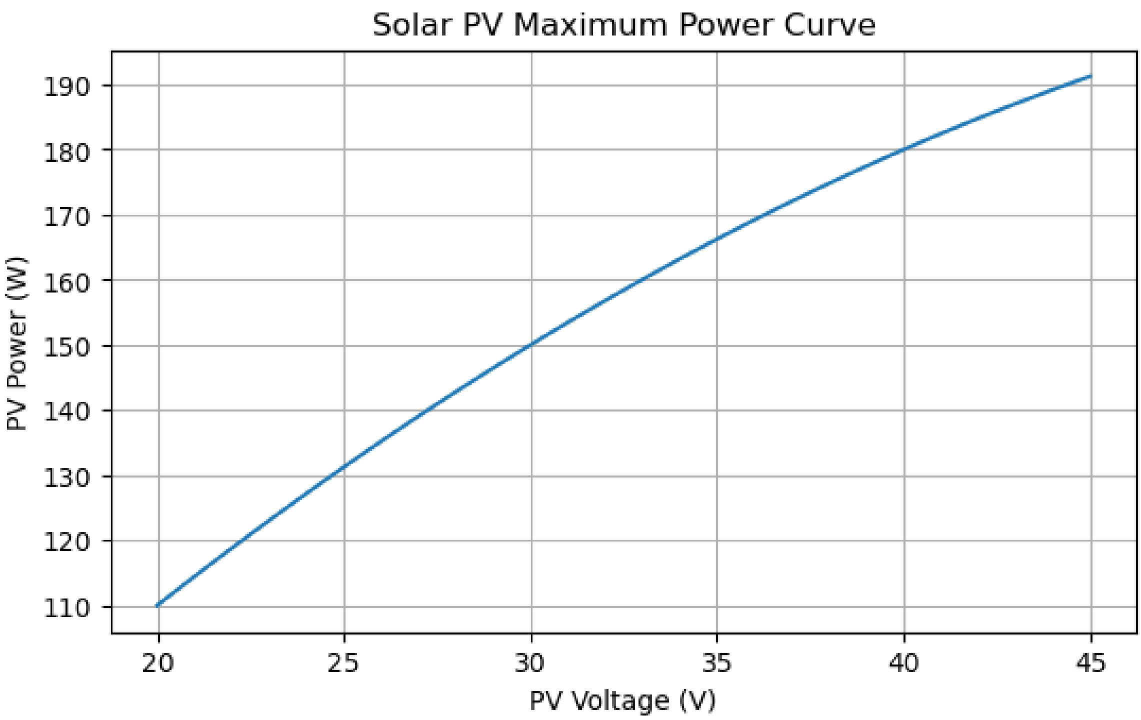

Fig.5 Solar PV maximum Power Curve

The ANN MPPT performance prediction is as shown Fig.6.

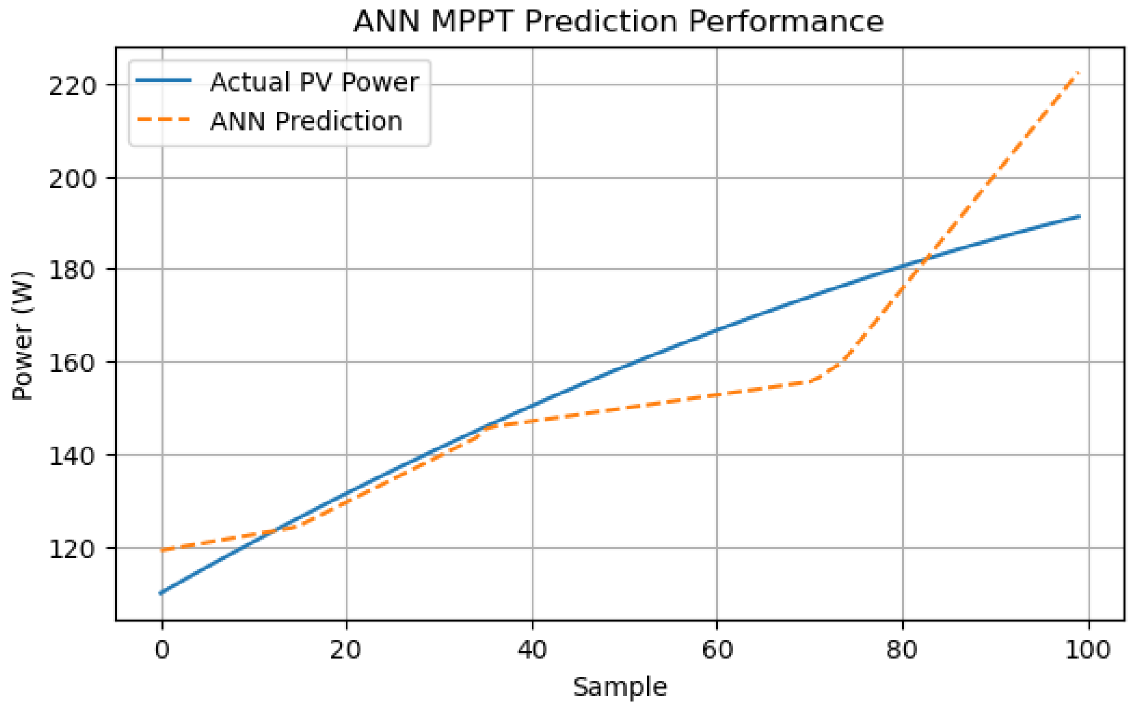

Fig.6 ANN MPPT Prediction Performance

Conclusion

This research presented the simulation analysis and AI integration of a WYE-connected DC–DC converter for solar photovoltaic applications using Python-based artificial intelligence techniques. The developed ANN-based MPPT controller effectively predicts the maximum power point and generates an optimized duty cycle for converter switching operation. The Python implementation demonstrates the capability of AI algorithms to handle nonlinear PV characteristics and improve converter performance under varying operating conditions. The integration of AI control with the WYE-connected converter enhances voltage regulation, power extraction efficiency, and dynamic response while reducing tracking errors and power fluctuations. The proposed approach provides a flexible and intelligent solution for renewable energy conversion systems. The developed Python-based model can be further extended with real-time data acquisition, deep learning algorithms, and hardware implementation for advanced solar energy management systems, microgrids, and smart power applications.

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