Sensorless Current Prediction of a Three-Phase Inverter Using Machine Learning Algorithms

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Abstract. The inverter is a crucial component and. Its design can be customized to generate single-phase, three-phase, or multiphase outputs, which enables easy adjustments of output voltage and frequency to meet the diverse needs of different loads. Despite the benefits of inverters, practical conditions can lead to imperfect output waves due to various losses. The refinement of the pure sinusoidal output wave is essential for reducing harmonic distortion and improving overall power quality. Inverters have significant importance in industrial applications, with the sinusoidal pulse width modulation (SPWM) technique being a widely employed form of control the output voltage. However, inverter performance can be further improved by applying machine learning algorithms. Machine learning algorithms have made it feasible to develop accurate and efficient methods for improving inverter performance, which in turn enhances overall efficiency and reliability in power systems applications. In this paper, a dataset was generated using MATLAB for a Resistive and Inductive load three-phase inverter, and machine learning algorithms such as Multi-Linear Regression (MLR), Support Vector Machine (SVM), and K-Nearest Neighbors (KNN) were applied to estimate output current and predict power losses. These algorithms offer precise solutions for output current estimation and power loss prediction, this removes the requirement for external inverter sensors.

Keywords: Three-phase inverter · Machine Learning Algorithms (MLA) · Multilinear Regression · Support Vector Machine · K-Nearest neighbor

1 Introduction

Inverters are used in industrial applications to regulate various types of motors and power systems. Pulse Width Modulation (PWM) is used to regulate the gate signal of switching components of the inverter control signal in the industry. However, PWM has its limitations, and many PWM approaches have been developed in recent years. Sinusoidal Pulse Width Modulation (SPWM) has become more popular than traditional PWM due to its low total harmonic distortion, variable output voltage, and low current ripple. The SPWM method is favored in producing variable voltage levels due to its ease of usage, low Total Harmonic Distortion (THD), and low cost [1, 2]. It is employed as a control signal in circuit topology used to balance network voltages and in Uninterruptible Power Supplies (UPS) to provide emergency power to critical loads during a power outage.

B. Raj et al. (Eds.): ICETE 2023, AER 223, pp. 653–661, 2023.
https://doi.org/10.2991/978-94-6463-252-1_66

Machine-learning techniques have been developed for closed-loop systems, providing more pragmatic and accurate answers in mathematical computations that are hard to quantify. In this paper, the parametric simulation for a three-phase inverter was carried out using the SPWM [3–9] control approach in MATLAB software, and the output inverter current was predicted using Machine Learning Algorithms (MLA) without any sensor [10]. This technology can be adopted in industrial applications because of its simple construction, an output voltage that resembles dependability and pure sinusoidal, and low cost.

2 Python Modules

Python is a popular programming language that provides a versatile environment for scientific computing. One of the primary advantages of Python is to handle computing operations of various scales, from small to massively high-performance, without any additional cost to the user. Python's high-level code nature makes it simple to learn and comprehend even for those with basic programming syntax knowledge. The Python programming language offers a range of powerful modules for data analysis, including NumPy, Pandas, Matplotlib, Scikit-learn, Keras, and Seaborn. NumPy is a library used for numerical computing that provides support for multi-dimensional arrays and a vast array of mathematical functions. Pandas is a data modelling and function package for handling structured data such as tabular data stored in spreadsheets or CSV files. Matplotlib is a data visualisation package that includes 2D plots, histograms, and scatter charts. Scikit-learn is a popular library that provides a wide range of machine learning algorithms, such as linear regression, decision trees, and support vector machines [11–16], as well as tools for feature selection and model evaluation. Keras is a high-level neural networks API that can run on top of TensorFlow, allowing users to build and train neural networks with ease. Finally, Seaborn is a data visualization library based on Matplotlib, providing a high-level interface for creating attractive and informative statistical graphics. While these are some of the most popular and commonly used libraries for machine learning and data analysis in Python, there are many others. Each library provides different functionality, as a result, it is critical to select the ones that best meet your requirements.

Python's flexibility, along with its extensive library support, makes it an excellent choice for data analysis and machine learning tasks.

3 Simulation Model of Proposed Three Phase Inverter

A three-phase six pulse inverter circuit converts the DC power into three separate and distinct AC waveforms that are 120 degrees out of phase with each other. These three waveforms are then combined to form a balanced three-phase AC output. The MATLAB model of a three-phase inverter circuit diagram provides a virtual representation of the physical components of the circuit, including the DC power source, the inverter circuit, and the three-phase AC output. This model can be used to simulate the behaviour of the circuit, including how it responds to changes in input power, load conditions, and component failures. It can also be a useful tool for designing, testing, and optimizing

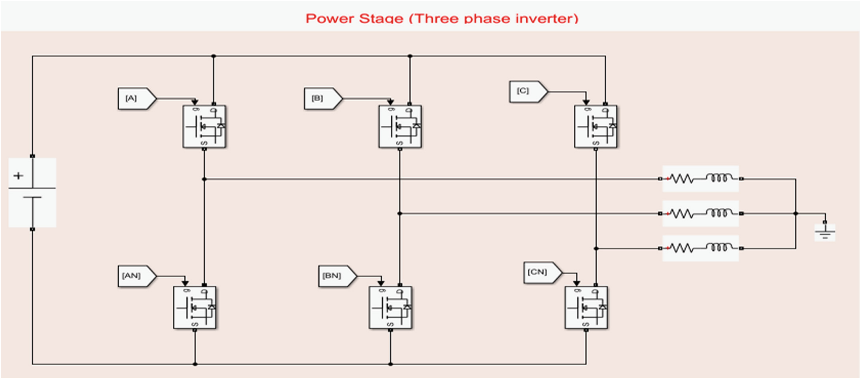

Fig. 1. Proposed Three-phase Inverter Model

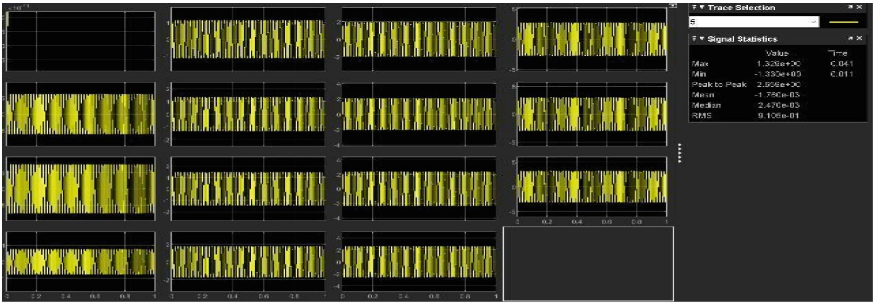

Fig. 2. Output currents of the three-phase inverter

three-phase inverter circuits. By running simulations in a virtual environment, engineers can experiment with different circuit configurations and component values to determine the best design for their application. Additionally, the model can be used to visualize the waveforms generated by the inverter, which can help engineers understand the behaviour of the circuit and identify potential issues.

Multiple Three-phase inverter models are made in a single environment, the Fig. 1 is a simulation model of a three-phase inverter circuit, in Fig. 2 shows the currents of the three-phase inverter with modulation index of 0.4 with voltage of 100V with resistance of 10 ohms and inductance of 10mH, and the output current is noted 1.32A, similarly for different modulation index, resistance, inductance and voltage the output current is noted.

4 The Machine Learning Algorithm and Simulation Results

The algorithms for the prediction used are Multilinear regression, Support vector machine, and k-nearest neighbour. Multilinear regression aims to find the best-fit line that minimizes the sum of the squared differences between the observed values and the values predicted by the model. The line is represented by a linear equation, where the

```
 Test and Predicted current
The r2 error is: 0.8809411666787195
The mean_absolute_error is: 0.6392669961067139
The mean_squared_error is: 0.7844468048757123
The explained_variance_score is: 0.8837324361452591
 Test and Predicted Power Loss
The r2 error is: 0.8353262461006488
The mean_absolute_error is: 1.6191095899784975
The mean_squared_error  is: 14.498571167152766
The Variance Score is: 0.8463281479459415
```

Fig. 3. Multi linear regression output

coefficients represent the effect of each independent variable on the dependent variable. All of the three algorithms are used for prediction purposes. The selection of an algorithm depends on the nature of the problem and the characteristics of the dataset. All algorithms are effective methods for analysing and predicting data. Each algorithm has its own strengths and weaknesses, and the choice of an algorithm depends on the nature of the problem and the characteristics of the dataset.

Pseudocode:

Step 1: Import the required Libraries

Step 2: Load the Dataset from the system

Step 3: Shape the required Dataset as required

Step 4: Select the Dependent variable column from the data set

Step 5: Initialize other columns of the dataset as independent variables

Step 6: Split the dataset into Test and Train of size between 0 to 1

step 7: Fit the dataset using Scaler function to fit the data

Step 8: Fit the training data and testing data "to the required algorithm"

Step 9: Predict the output current of testing data from step 8 by using testing data

Step 10: Compare the predicted output current and actual output current

Step11: Calculate different scores to check the accuracy of the data by using mean_absolute_error, mean_squared_error, r2_score, explained_variance_score

Step 12: Calculate the I^2*R loss by using the actual current and predicted output current

Step 13: Repeating step 11 for step 12

4.1 Training of Dataset Using Multilinear Regression

For Multi linear regression, in the pseudocode step 8 use Linear Regressor() method, to execute accordingly.

For the corresponding input values the output current actual and predicted is displayed in Fig. 4. The best-fit line of Fig. 5 is made with the help of Fig. 4, where the line is made in such a way that it maintains the minimum distance between all the points (Fig. 3).

4.2 Training of Dataset Using Support Vector Machine (SVM)

For Support vector machine, in the pseudocode step 8 use svm.SCR() method to execute accordingly.

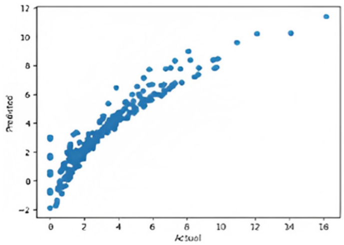

Fig. 4. Actual current and predicted current.

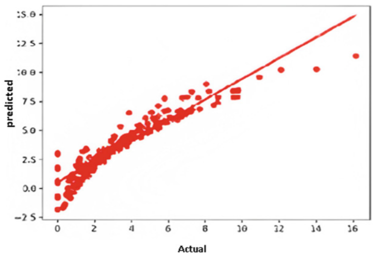

Fig. 5. Best fit Line For MLR

```
 Test and Predicted current
The r2 error is: 0.1232160751710134
The mean_absolute_error is: 1.874416476612556
The mean_squared_error is: 6.478095704668619
The explained_variance_score is: 0.15330646894405353
 Test and Predicted Power Loss
The r2 error is: -0.03756895450732167
The mean_absolute_error is: 205.07648169515147
The mean_squared_error  is: 142809.27843523028
The Variance Score is: 0.05758428502300983
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Fig. 6. Support Vector Output

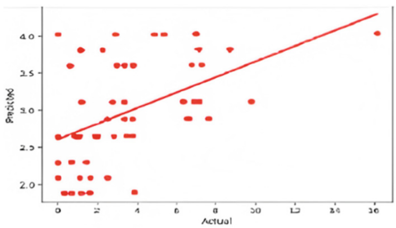

Fig. 7. Best Fit Line for SVM

The approach aims to decrease the number of variables in the dataset, which allows the identification of an optimal feature subset for constructing models. This, in turn, results in dependable model parameters and performance because the model utilizes the

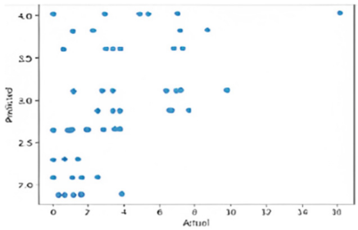

Fig. 8. Actual current and predicted current.

best possible features selected via feature selection techniques. Figure 7 is the comparison with the actual and predicted current from the data using the SVM algorithm with the best-fit line present in it. The best-fit line is made in such a way that it maintains the minimum distance between all the points (Figs. 6 and 8).

4.3 Training of Dataset Using K Nearest Neighbor (KNN)

For Support vector machine, in the pseudocode step 8 use K-Neighbor Regressor() method to execute accordingly.

For the corresponding input values the output current actual and predicted is displayed in Fig. 9.

The best-fit line of Fig. 10 is made with the help of Fig. 9, where the lines are made in such a way that it maintains the minimum distance between all the point (Fig. 11).

```
 Test and Predicted current
The r2 error is: 0.9188818311391389
The mean_absolute_error is: 0.4819464085297419
The mean_squared_error is: 0.599339525266294
The explained_variance_score is: 0.9195436308147333
 Test and Predicted Power Loss
The r2 error is: 0.822825361816454З
The mean_absolute_error is: 58.703825978576184
The mean_squared_error  is: 24386.024780424963
The Variance Score is: 0.8355420063832664
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Fig. 9. Output Values

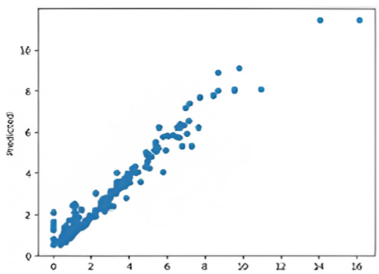

Fig. 10. Actual current and predicted current

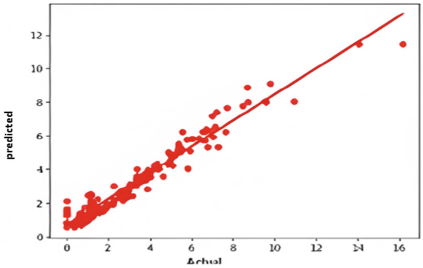

Fig. 11. Best fit line

5 Results

From the above three regression models worked on the six stepped three-phase inverter circuit, the output parameter is concerned with R2 error, mean absolute error, Mean squared error, and Variance score.

Table 1 is the comparison of all three different algorithms' predictions on the basis current. Table 2 is the comparison of all three different algorithms' predictions based on power loss.

For predicting current, the K nearest neighbor algorithm performs the best, with the highest R2 error, lowest mean absolute error, and lowest mean square error.

For predicting power loss, the multi-linear regression algorithm performs the best, with the highest R2 error and variance score. However, the K nearest neighbor algorithm has a lower mean absolute error and mean square error, indicating it may perform better in practical use.

Table 1. Comparison of current prediction using different algorithms.

	Multi linear regression	Support vector model	K nearest neighbor
R2 error	0.8809	0.1232	0.9188
Mean Absolute error	0.6392	1.874	0.4819
Mean square error	0.7844	6.47	0.5933
Variance Score	0.8837	0.1533	0.9195

Table 2. Comparison of power loss prediction using different algorithms.

	Multi linear regression	Support vector model	K nearest neighbor
R2 error	0.835	0.037	0.822
Mean Absolute error	1.619	205.067	58.703
Mean square error	14.4	142809.27	24386.02
Variance Score	0.84	0.0575	0.8355

The support vector model algorithm performs the worst in both tasks, with the lowest R2 error, highest mean absolute error and mean square error and lowest variance score.

6 Conclusion

Machine learning algorithms have proven to be a practical solution for optimizing inverter performance in closed-loop systems. In this paper, a three-phase inverter was developed using machine learning algorithms on a data set obtained from a MATLAB simulation. Python modules such as Pandas, Numpy, Matplotlib, Keras, and seaborn were used to handle data sets and visualize the training and testing results. The MATLAB simulation model was efficient and created a perfect data set for training the models. The trained models showed good correlation with actual values, demonstrating their accuracy and reliability. The machine learning algorithms optimize inverter performance, improve efficiency and reliability in power systems applications. In the future, researchers could investigate the possibility of utilizing other machine learning algorithms and improving their hyperparameters to further improve prediction model.

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