

# Machine Learning Based Sensorless Current Prediction of a Multilevel Inverter

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**Abstract:** Renewable energy, transportation, and the power industry have all shown a great deal of interest in multilevel inverters. The inverter's power rating can be increased without necessitating higher ratings on individual devices by increasing the number of voltage levels it has. This reduction in harmonic distortion increases as the number of voltage levels increases and becomes more significant. However, in practice, there are variations that are inflicted on the output waveform and these distort the waveform as well as the poor power quality. This paper shows that it is possible to enhance the functionality of multilevel inverters by using machine learning algorithms. Because of these algorithms one could have accurate and effectual ways of enhancing the efficiency of the inverter. In this paper, machine learning algorithms which includes Support Vector Machine (SVM), K-Nearest Neighbors (KNN), and MultiLinear Regression (MLR) were applied to the MATLAB data set of a three-phase, three-level diode clamped multilevel inverter with RL Load. In contrast, multilevel inverters are much more advanced power conversion instruments than the conventional inverters and these are capable of providing more flexibility in controlling the process of conversion of DC into AC. Multilevel inverters facilitate generation of an AC waveform which can be a sine wave or steady wave and the standard inverters allow only for a square wave or pulse wave. This is achieved through the use of many DC voltage levels available in the device, which minimize distortion or what could be referred to as harmonics and improve the quality of the power delivered.

**Keywords:** Machine learning, K-nearest neighbour (KNN), support vector machine (SVM), diode clamped multilevel inverter, multilinear regression (MLR).

## 1. Introduction

Multilevel inverters are generally complex power conversion systems compared to normal inverters as they provide more control over the process of conversion of direct current to an alternating current. Traditional inverters are able to produce only an inverted square wave or just pulsing AC waveform while multilevel inverters may provide an output which looks like a stepped waveform or sine wave. This is achieved through the utilization of multiple DC voltage levels of the device since this reduces the amount of distortion or harmonics thus providing cleaner power. Because of these advantages such as improved power control and efficiency, multilevel inverters are being employed in industrial motors, electric vehicles, and renewable energy sources. There are many different designs of these devices; some popular types are capacitor-clamped inverters, diode-clamped inverters, and cascaded H-bridge

inverters. As for me, everybody has advantages and, yes, you got it, disadvantages.

Of the gate signals, the most common method to control switching devices in industrial applications is through the Pulse Width Modulation (PWM). Some of the traditional methods for implementing PWM are still quite commonly in use, but they do not always work well. As it can generate output voltages that appear like pure sinusoidal waves, lower total harmonic distortion (THD), and minimize the current variation (ripple), sinusoidal pulse width modulation (SPWM) is gradually gaining more popularity. Due to its high output, reliability, and ease of use, SPWM is more suitable to be used in industries than the other two topologies.

Due to the advantages of SPWM, it is suitable for applications like wind turbines and UPS (uninterruptible power supplies) that require the voltage level to be variable. In wind energy systems,

SPWM is a control mechanism that is applied to ensure stable grid voltage regulation. It supplies clean power to UPS systems during power outages. Previous studies comparing PWM and SPWM in various applications have highlighted the superiority of the SPWM technique which includes less energy loss during switching and better motor characteristics.

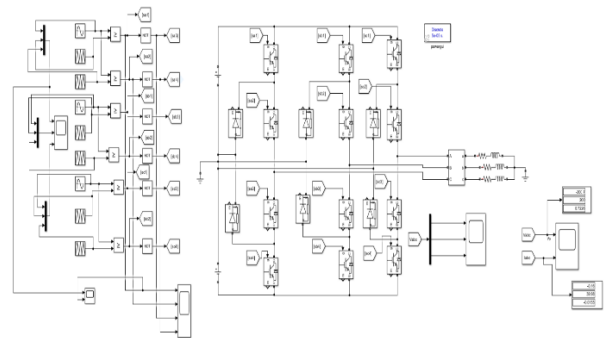
The output current of an inverter was previously sensed by some physical sensors which created a complication of circuit components. However, with the above extra sensors not being necessary in closed-loop systems, the current can now be estimated using machine learning. Artificial neural networks can be considered a practical and accurate approach to control complex calculations and solve such challenging-to-quantify problems as those in inverters.

Some of the research conducted to explore the simulation of three-phase inverters with SPWM control using MATLAB software is as follows: These simulations were designed to try and predict the inverter's output current using machine learning algorithms despite the lack of sensors. Due to its high reliability and productivity, this machine-learning method of current estimation has gradually evolved into more widely used.

As discussed earlier, there are many advantages of using machine learning algorithms in controlling multilevel inverters over conventional methods. Firstly, it simplifies the circuit design by eliminating the need for costly and time-consuming physical current sensing. Second, by providing output current data, it improves the control system precision in real-time. Finally, it allows for the use of historical operation data in setting the optimum performance parameters of inverters.

A general enhancement of reliability, and productivity across various industrial applications through an integration of machine learning and inverter control. Further and superior control systems for the whole power electronics industry including inverters are expected as machine learning evolves.

## 2. Three - Phase, Three - Level, Diode - Clamped Multilevel Inverter



**Figure 1: Three level - diode clamped inverter**

There are three primary components that make up the 3-level diode-clamped inverter:

**DC Bus:** The DC voltage is split into three separate levels in this section by means of 2 capacitors connected in series: positive, zero, and negative.

**Switching Devices:** Four switching devices (such as MOSFETs or IGBTs) and four diodes are present in each leg that is in charge of a single phase. These gadgets are essential for producing different voltage levels.

**Clamping Diodes:** These diodes clamp the voltage to predetermined levels, as their name implies. Ensuring that each switching device's voltage stress is limited to the voltage of a single capacitor, enhances the system's overall health.

This inverter utilizes PWM, which replaces the capacitors with two voltage sources sharing the same ground. To achieve that, listed below is a detailed elaboration that will help shed more light on the mentioned particular approach.

1. **Voltage Sources:** This inverter employs two separate DC sources which are  $V_{dc}/2$  in place of the conventional capacitors as shown below. Thus, there is a connection between the negative terminals of these sources. Three separate voltage levels are produced by this configuration: The signals that are generated are the positive half of the voltage supply ( $V_{dc}/2$ ), the negative half of the voltage supply ( $-V_{dc}/2$ ), and zero or ground.

2. **Switching Devices and Diodes:** The three sections of the inverter that produce one phase have two more diodes and four more controlled switches (MOSFETs or IGBTs). The described configuration enables to regulation of the current in the required manner and, therefore, generates the required levels of AC voltage at the output.

3. Pulse Width Modulation: To regulate the switching components that might be IGBTs or MOSFETs in the inverter, what is used is the pulse width modulation or PWM. Specifically, two triangular carrier signals and a sine wave reference signal, which represents the desired AC signal, are compared. These comparisons lead to the switching on or off of the switches and consequently influence the output voltage of the AC.

4. Generating Voltage Levels:

- Positive Voltage (+Vdc/2): In a single phase leg, both top switches are engaged to produce the maximum positive voltage level at the output. By doing this, the output is immediately connected to the positive voltage source (Vdc/2). On the other hand, the two lower switches remain deactivated (OFF).

- Zero Voltage (0 V): Either the middle 2 switches are turned ON, establishing a direct connection to ground for zero voltage, or the outer 2 switches are turned ON, indirectly connecting the output to ground through the diodes.

- Negative Voltage (-Vdc/2): The inverter flips the switch configuration from the highest positive level to the most negative voltage level at the output. The two bottom switches in a single-phase leg are engaged (turned ON) in this situation. By doing this, the output is immediately connected to the source of negative voltage (-Vdc/2). Conversely, the top two switches have been deactivated or turned off.

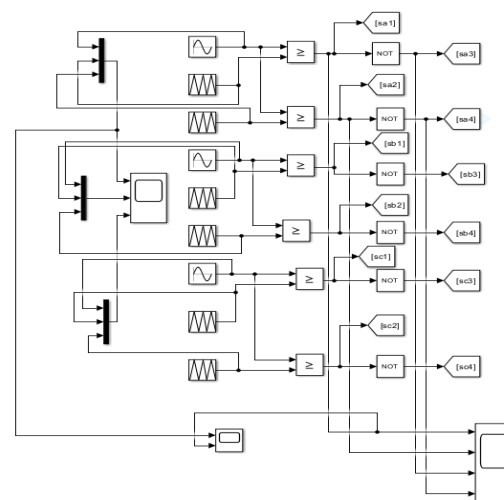
5. Clamping Diodes: These clamping diodes are essential for protecting the switching components. They serve as a safety measure by putting a cap on the voltage that each switch can handle. This way they ensure that no switch is ever forced to block the entire DC voltage (Vdc) and the like. This method protects switches from high voltage stress, thus greatly enhancing the efficiency and reliability of the inverter.

6. Output Waveform: The inverter has the feature of pulse-width modulation with the help of which component switching is controlled. This PWM method changes the time (width) for which the voltage switching is done by the switches. It is High-quality output waveforms that resemble sinusoidal AC voltages are often generated in multilevel inverters through the use of a well-developed method called sinusoidal pulse width modulation, or SPWM. Multilevel inverters are

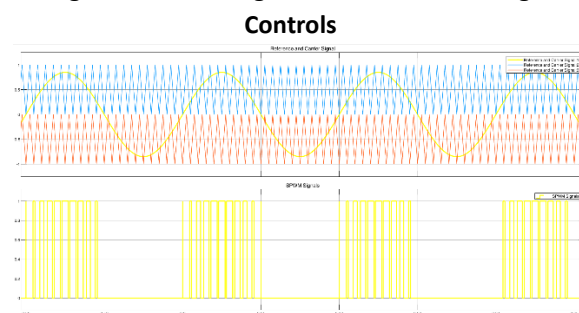
notable that the pulse widths of these pulses can be controlled to generate three different voltage levels in an AC output waveform of the inverter. This method looks very close to a sinusoidal wave which is what AC power is seeking for smoothness. The first benefit of this method is that it can significantly minimize harmonic distortion and generate a better power supply.

7. Phase Shifting for Three-Phase Operation: The inverter in a 3-phase system makes use of reference signals where each of the signals is intentionally phase-shifted by 120 degrees from the other. The deliberate timing of these three output waveforms ensures that they are balanced and in phase as the following three output waveforms clearly indicate. Stable and superior three-phase AC output is produced by this synchronized operation which is crucial in several industrial processes.

**Sinusoidal Pulse Width Modulation**



**Figure 2. Block Diagram of SPWM Switching**



**Figure 3. Multiple Pulses generated from the SPWM technique**

designed with improved performance compared to two-level inverters that produce blocky square waves or their derivatives. They achieve this through the synthesis of stepped waveforms in multiple voltage outputs, which drastically

minimizes harmonic distortion while enhancing the quality of the output voltage. This section provides a detailed discussion of how SPWM works in a multilevel inverter.

This paper outlines the principles of sinusoidal pulse width modulation (SPWM) in multilevel inverters.

**Generation of Reference Signal:** The initial sine wave-patterned reference waveform is generated by SPWM. The intended AC output voltage is, as it were, extracted with the help of this reference signal. Some of the features highlighted consist of phase angle – the position of the waveform in relation to a reference point, frequency – cycles per second, and amplitude – voltage strength. These parameters control the resulting AC waveform's magnitude and shape.

**Generation of Carrier Signal:** A high-frequency waveform carrier signal is introduced by SPWM. This carrier signal is typically triangular and its frequency determines how often the switches of the inverter turn 'on' and 'off' or the switching frequency.

**Comparison Process:** The comparator circuit is an important component of SPWM. This circuit compares the sinusoidal reference signal, the blueprint of the intended output, and the high-frequency triangular carrier signal continuously. The continuous comparison of the two signals also determines when the switching components (IGBTs or MOSFETs) of the multilevel inverter are turned on or off. In effect, this comparison defines the switching pattern that defines the final waveform of the AC output.

**Pulse Generation:** SPWM produces pulses based on the continuous comparison of the carrier and reference signals. The pulse width, or duty cycle, is the important factor in this case. This width isn't arbitrary; rather, it accurately represents the reference signal's amplitude, or strength, in relation to the carrier signal at that particular time. Put more simply, a longer pulse width results from

a high reference signal (positive or negative peak). On the other hand, the pulse width will be smaller when the reference signal is nearer zero. The inverter's ability to replicate the gradual rise and fall of a real sine wave is due to this variation in pulse width.

**Switching Control:** Within the multilevel inverter, each pulse produced by SPWM serves as a control signal for the power components (such as MOSFETs or IGBTs). The amount of time the corresponding power device is kept switched ON during each switching cycle is directly determined by the duration (or width) of each pulse. The inverter can efficiently produce a stepped waveform that closely resembles a smooth sine wave by precisely regulating the ON time of these devices based on the reference signal.

**Output Voltage Generation:** In the end, the sequence of pulses produced by SPWM combines to produce an output voltage waveform that largely resembles the intended form, which is usually a smooth sine wave. This is done purposely by changing each pulse's duty cycle or the portion of the switching cycle where the device is ON. The inverter can adjust the amplitude and frequency of the output voltage since it can regulate the duty cycle based on the given reference signal. As a result, the inverter is able to produce excellent AC power that closely resembles a pure sine wave.

A crucial part of multilevel inverters is SPWM. For the purpose of producing control pulses for the inverter's switches, SPWM effectively compares a high-frequency carrier signal with a desired AC waveform, usually a sine wave. In an intentional attempt to imitate the reference waveform, these pulses' duty cycle (width) is changed.

### **3. Dataset Generation**

MATLAB simulations have been performed by utilizing the SPWM technique to obtain a certain quantity of sample data and the MATLAB simulations are shown in the following fig.4, fig.5.

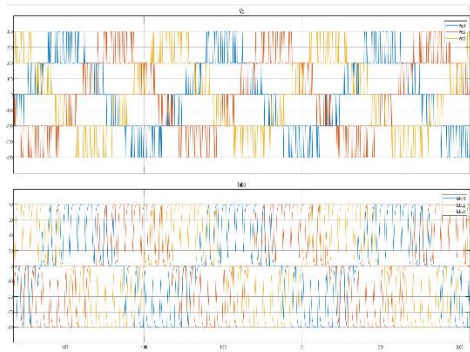


Figure 4. Three-phase voltage and current-generated waveforms

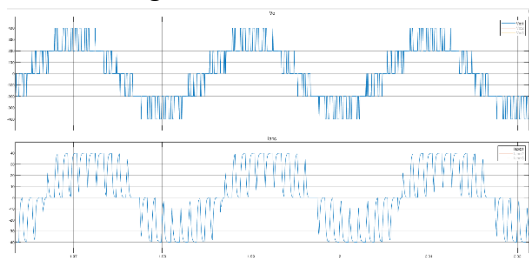


Figure 5. Fig Voltage and Current Waveforms for one phase of 3-phase supply for RL Load

The dataset obtained from the MATLAB simulations explained in the section above, where the output currents corresponded to different parameter values were recorded. A structured table with 534 data points has been created from these recorded values.

The purpose of creating this dataset was to provide future research and analysis with a dependable and organized resource. Every data point in the dataset corresponds to a distinct set of simulation parameters and the output current value that was measured as a result of those settings.

The format used to store the data is CSV (Comma-Separated Values). This format is beneficial in transferring data to different analytical software tools used in statistical analysis, machine learning, and model building. These are easily manageable because the dataset is arranged in tabular form; a glimpse of which is shown in table 6 below. It is used in pattern matching as well as in understanding the changes in the parameters of the simulation and the impact of these changes on the output current. It would be useful to note that the tabular form of the dataset is useful in managing the data and establishing the relationship between the input parameters and the output currents.

Ref Amp	Car Amp	Mod Index	Input Voltage (V)	Resistance( $\Omega$ )	Inductance (mH)	Output Current (A)
0.85	1	0.85	400	5	0.1	36.60
0.8	1	0.8	300	10	0.1	14.94
0.85	1	0.85	200	5	0.15	16.87
0.6	1	0.6	200	10	0.1	9.95
0.85	1	0.85	300	5	0.15	25.24
0.7	1	0.7	200	15	0.3	6.62
0.5	1	0.5	400	10	0.3	19.81
0.4	1	0.4	200	15	0.4	6.61
0.6	1	0.6	150	5	0.4	13.03
0.7	1	0.7	400	10	0.4	19.78
0.8	1	0.8	200	15	0.2	6.59
0.5	1	0.5	300	5	0.2	29.32

Table 1: Sample Dataset

#### 4. Machine Learning Training Python Code

The purpose of this portion is to describe how to utilize the Python machine learning packages to generate predictions about the supplied dataset. The goals encompass identifying the optimal model that matches the provided data and assessing the effectiveness of the available models. To this, several libraries of Python have been imported such as matplotlib, pandas, scikit-learn, and NumPy which assists in training and testing the machine learning classifiers. After preprocessing, the data is now prepared for analysis in this section of the investigation. Numerical and categorical independent variables are added to a variable to be forecasted or explained. This dataset undergoes various models which include: SVM, Random Forest, decision tree, k-nearest Neighbor, and Linear regression. The comparative analysis of these models by training and testing them on this dataset with reference to F1 score, recall, accuracy, and precision. This model is then used to predict the outcome of other new data after being selected. In the process of developing a machine learning model, this section is essential because it helps to assess and select the algorithm that best fits the dataset.

##### Pseudo code:

Add the required library imports.

1. Open the system and load the dataset.
2. As needed, format the dataset.
3. Choose the dataset's dependent variable column.
4. As independent variables, set the remaining columns.
5. Using a ratio of 0 to 1, divide the dataset into training and testing sets.
6. To standardize the data, use the scaler function.

7. Utilizing the training data, train the model and apply data “to the required algorithm”.
8. To estimate the output current, use the testing data.
9. Examine the differences between the actual and anticipated output currents.
10. Determine scores for accuracy, including explained variance, r2, mean squared error and mean absolute error (MAE).
11. With the currents as predicted and as actual, calculate the  $I^2 \cdot R$  loss.

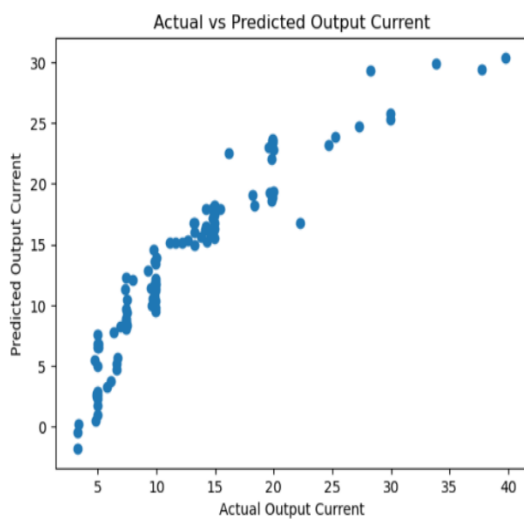
**6.1 Python Implementation for Training the Dataset with Multi-Linear Regression**

Use the Linear Regressor () method in Pseudocode Step 7 to execute the appropriate code for “multilinear regression.

**Output Values:**

Test results and anticipated Current  
 Mean Absolute Error: 2.4458468635258086  
 Mean Squared Error: 8.457522346588066  
 $R^2$  score: 0.8479135502274612  
 Explained Variance Score: 0.8585543784548844  
 $I^2R$  Loss = 8.457522346588066

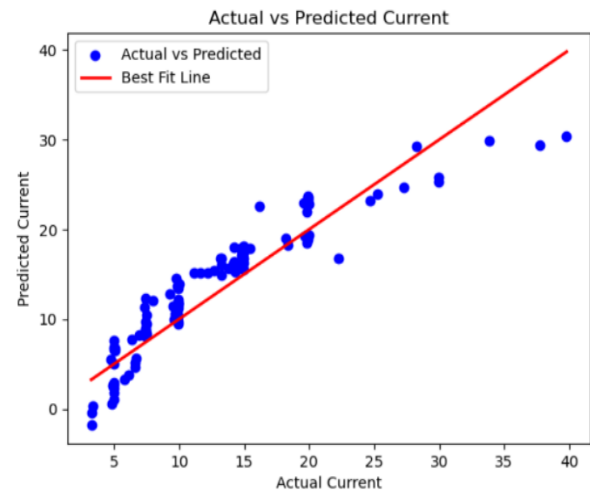
**Actual” vs Predicted Current:**



**Figure 6. Actual vs Predicted output current of MLR**

The relationship between the actual and predicted current values is represented by dots in the graph above, which shows the relationship between the variables. It illustrates how altering one variable has an effect on the other.

**Bestfit line of actual vs predicted current:**



**Figure 7. Best fit line of Actual vs predicted current of MLR**

On the actual vs. predicted graph, the best-fit line is drawn, aiming to reduce the distance between each point.

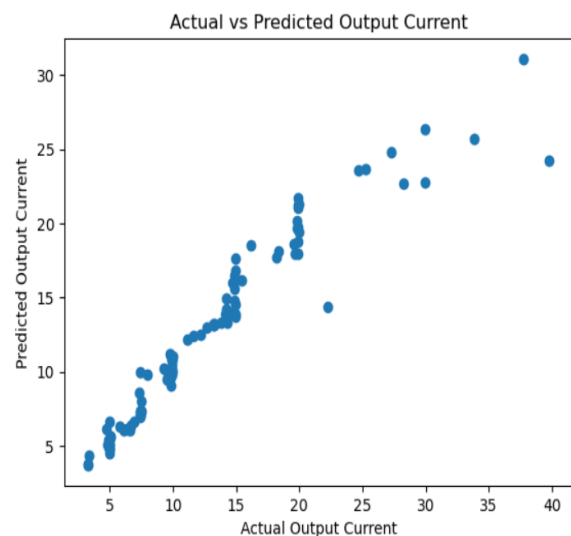
**6.2 PYTHON CODE FOR THE TRAINING OF DATASET USING SUPPORT VECTOR MACHINE**

Use the svm.SCR() method in Pseudocode Step 7 to execute the appropriate code for support vector “machine.

**Output Values:**

Examine and Estimated Current  
 Mean Absolute Error: 1.1585325286994381  
 Mean Squared Error: 5.627896106403859  
 $R^2$  score: 0.8987969876476939  
 Explained Variance Score: 0.9006335737508774  
 $I^2R$  loss = 5.627896106403859

**Actual” vs Predicted Current**



**Figure 8. Actual vs Predicted Current of SVM**

Best Fit line:

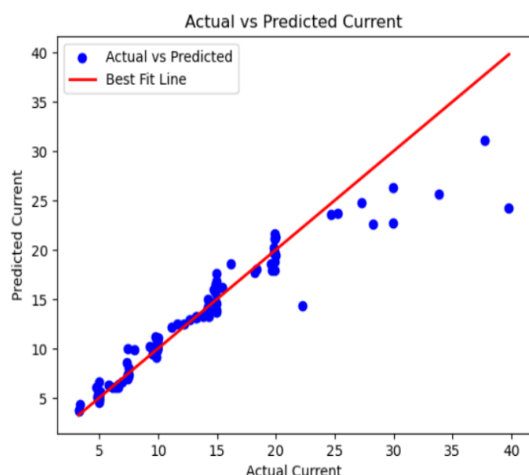


Figure 9. Best fit line of Actual vs Predicted Current of SVM

It employs features selected with feature selection methods to make sure that all the model parameters and their performance are stable.

### 6.3 PYTHON CODE FOR THE TRAINING OF DATASET USING K NEAREST NEIGHBOR

In Pseudocode Step 7, use the K – Nearest Regressor() to run the right code “for K-Nearest Neighbor (KNN).

Output Values:

Test and Predict Current

Mean Absolute Error: 1.1993229471028035

Mean Squared Error: 3.33417141987402

R<sup>2</sup> Score: 0.9400436353104912

Explained Variance Score: 0.9415197986736026

l<sup>2</sup>R Loss = 3.33417141987402

Actual Vs Predicted Current:

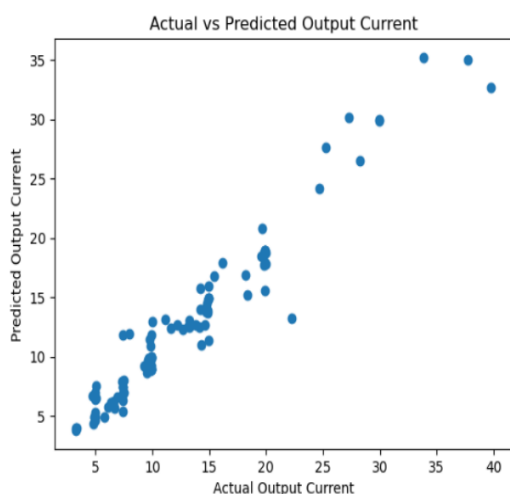


Figure 10. Actual vs Predicted Current of KNN  
Best Fit line:

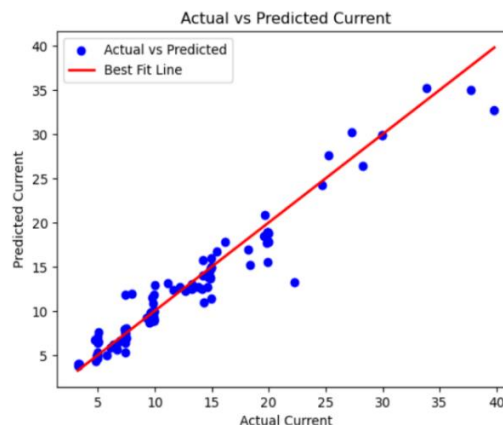


Figure 11. Best Fit line of Actual vs Predicted current of KNN

## 5. Results

This section provides the outcomes obtained from applying several algorithms for current and power loss estimation. The efficiency of the algorithms is analyzed by using factors such as R<sup>2</sup> error, MAE, mean square error (MSE), and variance score. The comparison between the three algorithms: These are some of the methods that have been implemented in this study namely, SVM, KNN, and MLR.

	Multi Linear Regression	Support Vector model	K Nearest Neighbor
R <sup>2</sup> Error	0.847	0.898	0.940
Mean Absolute Error	2.445	1.158	1.199
Mean Square Error	8.457	5.627	3.334
Variance Score	0.858	0.900	0.941

Table 2: Comparison of Current Predictions by Various Algorithms

In the present study, KNN has higher accuracy than the other algorithms such as SVM and MLR since it has the highest R<sup>2</sup> of (0.940) and the variance score of (0.941) to justify the fact that the model has a better fit on the data. It also has a lower MAE which is more desirable as it shows that the model has a better prediction of the true values of house prices. In the case of the SVMs, the variance score is equal to 0.900 and the R<sup>2</sup> error is 0.898, which indicates that the model is well-fitted to the data we have used. In comparing it with the KNN algorithm, the MSE is slightly higher with a value of 1.158 and a mean square error of 5.627 demonstrates a lower accuracy of the model. In comparing the variance score of the multi-linear regression model with SVM and KNN algorithms, the variance score obtained was 0.858 and an R<sup>2</sup> error of 0.847. Comparing it

to the other models, both MAE (2.445) & MSE (8.457) are also quite high, which points towards low levels of prediction precision.

**Power losses by different techniques:-**

Applying MLR, the mean power loss is equal to 8.45.

5.62 is the Average power loss with support vector machines

3.33 is the mean of the power loss when employing the K Nearest Neighbor.

The power losses of the KNN algorithm in question are less, and this fact proves its high predictive performance.

**Conclusion**

Several machine learning algorithms are used to estimate the output current and power losses. According to an analysis of performance metrics, the KNN algorithm performs the best overall in terms of current prediction. It has the lowest MAE, MSE, and highest R2 score. According to this, the KNN algorithm offers the highest level of precision and accuracy for current prediction. Compared to SVM and MLR models, the KNN algorithm performs better in power loss prediction, achieving a lower power loss. When predicting power loss, the KNN algorithm performs with precision and accuracy. Finally, it can be stated that the KNN algorithm is the best choice for predicting both power loss and current.

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