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Short-Circuit Incipient Faults Detection from Single Phase PWM Inverter using Artificial Neural Network

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Abstract

Solar Photovoltaic (PV) system consists of three main parts which are PV array, PV inverter and utility grid. From the three, PV inverter is considered the weakest link in the solar PV system. Insulated Gate Bipolar Transistor (IGBT) is the most critical component in an inverter and is often blamed for the failure of inverters. If the incipient faults of the IGBT can be detected, the breakdown possibility of the solar PV system can be improved. However, before the incipient faults can be detected, it needs to be first generated before further analysis and improvements can be made. This paper proposes a process on how to generate the incipient faults which are caused by the short-circuit fault of a single phase PWM inverter. The single phase PWM inverter consists of four IGBTs and there is a total of six parameters that need to be observed for each IGBT. The parameter that could cause short-circuit fault to the IGBTs is identified by modifying the parameters of IGBT one at a time. The response at the inverter output is observed and recorded after each modification to the parameter value is done. From the results, it shows that parameter Threshold voltage ($V_{ge(th)}$) is identified to be able to generate the short-circuit incipient faults. For the application of detection the incipient faults using neural network, a total of 100 short-circuit incipient faults and one set of normal condition waveform are collected at the output of the single phase PWM inverter. These waveforms are then used to train the feedforward backpropagation neural network. One hidden layer feedforward backpropagation neural network of 7 neurons was trained and MSE of was obtained. It was shown that the trained feedforward backpropagation neural network was able to detect which IGBT component of the single phase PWM inverter produced the short-circuit incipient faults.

Keywords: Incipient Faults, Inverter, Neural Network, Solar PV System, IGBT

1. Introduction

Currently, renewable energy is a trend not only in developed but also in growing countries. This is mainly due to the pollution caused from the combustion of petroleum and coal burning during the generation of electricity. In addition, renewable energy offers a continuous source of energy besides providing a green technology to the ecosystem. Malaysia is committed toward renewable energy as seen in the policies in Renewable Energy Act 2011[1].

According to the research done by[1], there are two types of renewable energy that are suitable to be implemented in Malaysia which are hydropower and solar energy. This is because Malaysia geographical has many rivers and received plenty of sunlight. According to[2], Malaysia receives between 4.21 kWh/m[2] to 5.56 kWh/m[2] annual average daily solar irradiation. This makes Malaysia a very suitable place for solar system implementation and probably is the highest country among worldwide for electrical-producing using the solar PV

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systems[2]. With the increasing usage of solar PV system in Malaysia, the safety aspect of solar PV system needs to be taken seriously. According to[3], the electrical faults in PV system can cause a fire risk, therefore a detection of faults in PV system is very important and worthy of attention. Solar PV systems consist of three main parts which are PV array, inverter and utility grid as shown in Figure 1. The PV inverter is considered the weakest link in any PV systems according to[4]. There are three major categories that lead to failure in inverter which are manufacturing and quality control, inadequate design, and electrical component failure. Several research studies have been carried out on faults in PV system[5–10], however, none of these studies focused on studying the faults in PV inverter. Although there is a research that has been carried out by[11] that focused on the faults in the inverter system, but the research didn't discuss in details on what is the source of the faults and how the faults of the inverter were generated. Therefore, this paper will discuss on the source of fault in the inverter system.

Bonn and Russell H. also mentioned that Insulated Gate Bipolar Transistor (IGBT) is often blamed for the fault of inverter system. This is confirmed through a research done by[12] that proved the IGBT is the most critical components in the inverter using thermal analysis. There are many factors that can lead to IGBT failure and one of the factors is when the IGBT operate in extremely high temperature[13]. Second law of thermodynamics state that in a natural thermodynamic process, all things will become old and eventually fall apart and rots[14]. The same thing will happen to the IGBT components, as the time increases the components become older and damage due to aging process. Chow et. al mentioned in[15] that the faults are usually reflected through changes in the parameter values and according to[16], faults may lead to catastrophic events.

In[17] defined the degradation in a system component as incipient fault and the incipient fault is slowly evolved. The incipient fault can affect the performance of inverter [15], therefore, the detection of incipient fault at earliest stage is very important in order to prevent any external faults as mentioned by[18]. The detection of incipient fault detection is also important in order to avoid the extended period of down-time caused by inverter failure[19]. Furthermore, when the incipient fault is detected, a preventive maintenance can be scheduled and the cost for maintenance or repair can be reduced and this will increase the reliability of the inverter system. Some studies in[20–22] have been carried out in detecting faults in PV inverter system, but the studies only focused on the hard failure of PV inverter which is the fault that has already happen and not the incipient fault at the earlier stage.Therefore, this paper aims to show how can the incipient faults of the single phase PWM inverter generated and then use the feedforward backpropagation neural network to detect the possible IGBT component in the single phase PWM inverter that produce the incipient faults. According to[23], the faults of the IGBT inverter can be divided into two groups which are open circuit fault and short circuit fault. However, this paper only focuses on the short-circuit faultdue to the high magnitude-current generated during the short-circuit event that can quickly lead to fire risk and major failure. To generate the short circuit incipient faults, the parameter that are responsible for the short-circuit fault need to be first identified first. Once the parameter that could cause the short-circuit fault is identified, the incipient faults of the IGBT inverter can be generated by modifying the parameter values. Note that the process of generating the faults is done using Matlab Simulink simulation tool.

Once the short-circuit incipient faults are generated, the neural network will be implemented for classifying all generated faults. The neural network is chosen over other classifier system because it's advantages such as robust to input and system noises. Furthermore, neural network has learning capabilities of computing the answer quickly based on previous learning experience[17] and neural network can provide the correct input-output fault detection relation[18]. In addition, a larger number of input variables can be simultaneously fed into a multi-input neural network and it does not affect the computational time since the neural network perform parallel processing[19]. Besides, the internal structure of neural network can be easily changed if modification needs to be made[19]. In short, the main contribution of this paper is not only showing the methodology to generate the incipient faults but also using the feedforward backpropagation neural network to identify the possible IGBT component of the single phase PWM inverter that produce the short-circuit incipient faults.

2. Experiment Setup to Generate the IGBT Short-Circuit Fault

IGBT acts as power switches in inverter system and its role is to change Direct Current (DC) voltage into Alternating

Voltage (AC) by closing and opening the power switches at appropriate sequence[24]. As discussed earlier, there are many factors that can contribute to the faulty in IGBT component such as operating at high temperature, aging problem, open-circuit and short circuit fault. Recall that this paper only concentrated on the short circuit fault.

A simulation experiment is conducted using Matlab Simulink simulation tool. The parameters values of the IGBT from Simscape Electronics™ library are modified in order to make the IGBT component become faulty. The main objective under this topic is to find the parameters that correspond to short-circuit fault so that the short-circuit incipient faults can be generated. Figure 1 shows the electric circuit diagram used to generate the short-circuit fault.

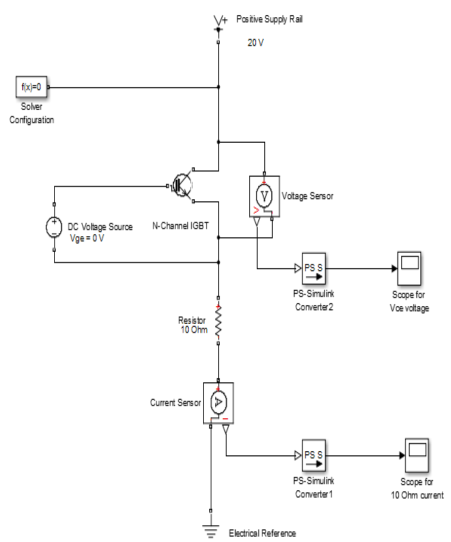

Figure 1. Setup for generating the short-circuit fault.

In the simulation, the power supply voltage is set to 20 V while the Gate-Emitter voltage (V_{ge}) are set with two different values which are 0 V and 15 V that represent the "off-state" and "on-state" of the IGBT respectively. Note that the 15 V is the typical voltage to switch on the IGBT according to the manufacturer datasheet. To measure the voltage across the Collector and Emitter (V_{ce}), a voltage sensor is placed across the Collector and Emitter of IGBT. To measure the current through the 10 Ω resistor ($I_{10\Omega}$) a current sensor is placed between the 10 Ω resistor and ground.

There are six parameters in the IGBT that are available for modifications which are *Zero gate voltage collector current, voltage at which I_{ces} is defined (I_{ces}), gate-emitter threshold voltage $V_{ge(th)}$, collector-emitter saturation voltage, collector current at which $V_{ce\,(sat)}$ is defined and gate-emitter voltage at which V_{ce} is defined.* Note that all the parameters are set according to the manufacturer datasheet values obtained from[25] where these values represent the normal condition of the IGBT. Equation (1) and Equation (2) show the V_{ce} and $I_{10\Omega}$ values under the respective normal conditions i.e., off-state and on-state.

$$V_{ge} = 0\text{ V (off-state)} \rightarrow V_{ce} = 20\text{ V and } I_{10\Omega} = 0\text{ A} \quad (1)$$

$$V_{ge} = 15\text{ V (on-state)} \rightarrow V_{ce} = 0.34\text{ V and } I_{10\Omega} = 1.98\text{ A} \quad (2)$$

For the IGBT to be under short-circuit fault, it is expected that the IGBT to be always in on-state condition regardless of the voltage applied to V_{ge}. In order for the IGBT to be always under on-state condition, the V_{ce} must always approximately equal to 0.34 V regardless whether the V_{ge} equal to 0 V or 15 V.

Once the circuit in Figure 1 is all set, the circuit is then ready to be experimented to generate the short-circuit fault by using the trial and error method. The following section explain the procedure of identifying which parameter in IGBT that could cause the short-circuit fault.

2.1 Generating IGBT Short-Circuit Fault

From the Equation (2) when V_{ge} is equal to 15 V, the V_{ce} will equal to 0.34 V which is in on-state condition. Since the IGBT is already in on-state mode at V_{ge} equal to 15 V, the focus now is when the V_{ge} is equal to 0 V. Under normal condition, when the V_{ge} is equal to 0 V, the IGBT is in off-state condition and the V_{ce} is equal to 20 V. For the short-circuit fault to happen, the V_{ce} must approximately equal to 0.34 V when V_{ge} is equal to 0 V. So, the objective under this topic is to get V_{ce} approximately equal to 0.34 V when V_{ge} is equal to 0 V. Note that the V_{ge} in the circuit in Figure 1 is always set to 0 V.

Before the short-circuit fault can be generated, the specific parameter that could cause the short-circuit fault to IGBT need to be identified first. To do this, all the six parameters mentioned in Section 2 of this paper need to be modified in order to identify the parameter that could cause the short-circuit fault to the IGBT. Recall the six parameters which are *Zero gate voltage collector current (I_{ces}), voltage at which I_{ces} is defined, gate-emitter threshold voltage $V_{ge(th)}$, collector-emitter saturation voltage, collector current at which $V_{ce\,(sat)}$ is defined and gate-emitter voltage at* *which* V_{ce} *is defined*, will be called as Parameter 1, Parameter 2, Parameter 3, Parameter 4, Parameter 5, and Parameter 6, respectively, from now onwards. Before the process of identifying the short-circuit parameter is undertaken, all the parameters are first set according to the manufacturer data sheet value that represents the normal condition. Figure 2 shows the flowchart of identifying the parameter that could cause short-circuit fault to the IGBT.

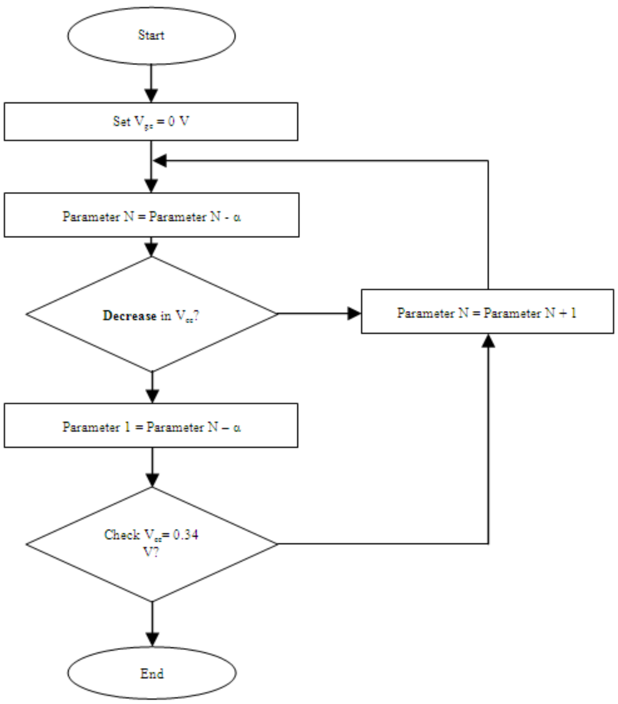

Figure 2. Flowchart of generating the short-circuit fault.

The parameters are dealt with one at a time and the process is started with Parameter 1 which is the I_{ces}. The I_{ces} is modified by decreasing its parameter value by α. From the experiment conducted, it was found that the decremental suitable value of α is 10. Then, the change in V_{ce} is observed. If V_{ce} decreases from its original value, it means that the parameter has a possibility to cause short-circuit fault to the IGBT. When this happen, the parameter value of I_{ces} is further decreased until the V_{ce} is approximately equal to 0.34 V which cause the IGBT to be under short-circuit fault. This process is necessary in order to confirm whether the parameter that has a possibility to cause short-circuit fault can really cause the short-circuit fault to the IGBT. But, if there is no change observed at the V_{ce}, the process is then continued by modifying the next parameter which is Parameter 2. The same process is repeated until all the six parameters are covered. From the simulation process, it was found that the *Threshold voltage;* $V_{ge(th)}$ parameter could cause short-circuit fault to the IGBT. By modifying the $V_{ge(th)}$, the short-circuit fault of the IGBT could be generated.

2.2 Generating the Incipient Faults of the Inverter

Once the parameter that are responsible for the short-circuit fault has been identified, the short-circuit incipient faults of the single phase PWM inverter are ready to be generated. Incipient faults are faults generated before the inverter is in short circuit condition (i.e., total failure). Section 2.1 has discussed about the process on identifying the parameter that cause the short circuit fault. Once the parameter that causes the short circuit fault is identified, the incipient faults of the inverter can then be generated by modifying the values of the parameter.

In order to generate the short-circuit incipient faults, a single phase PWM inverter system using unipolar PWM with Total Harmonic Distortion (THD) of load current less than ten percent is designed. The input voltage to the single phase PWM inverter system is set to 36 V and the amplitude modulation ratio, (m_a) is set to 0.9. The sample time of the simulation is set equal to sec which satisfied the Nyquist sampling theorem[26]. The designing load of the single phase PWM inverter consists of 10 Ω resistor (R), 10 mH inductor (L) and 50-Hz is set as reference frequency (f_{ref}). In order to achieve the THD of load current less than ten percent, the right value of carrier frequency need to be determined. From[24], it was calculated that carrier frequency (f_{tri}) associated with a single phase PWM inverter system with resistive and inductive load is equal to 1350Hz.

Figure 3 shows the circuit diagram of single phase inverter system. Notice that there are four IGBTs in the circuit named as IGBT 1, IGBT 2, IGBT 3, and IGBT 4.

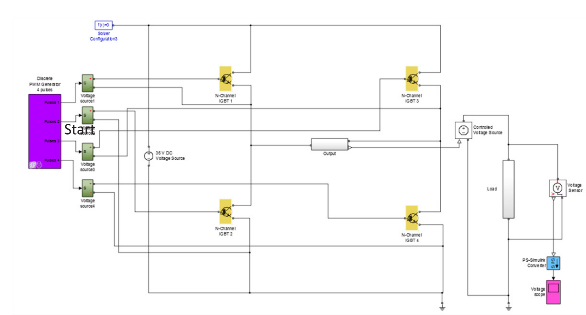

Figure 3. Circuit for single phase PWM inverter.

Once the designing of single phase PWM inverter is completed, the parameters of each of the IGBT need to be adjusted according to manufacturer datasheet[25]. The design is run for normal condition and the output voltage waveforms obtained are saved. The output voltage is chosen over current because, normally the output voltages are independent from the load. Furthermore, the output voltages can be used to determine the type and location of the faults[11]. Then, the design parameter is changed before it is run to produce incipient faults of the single phase PWM inverter. Note that only one IGBT is set to produce short-circuit incipient faults at a time. Figure 4 shows the flowchart to generate the incipient faults of short-circuit which starts with IGBT 1.

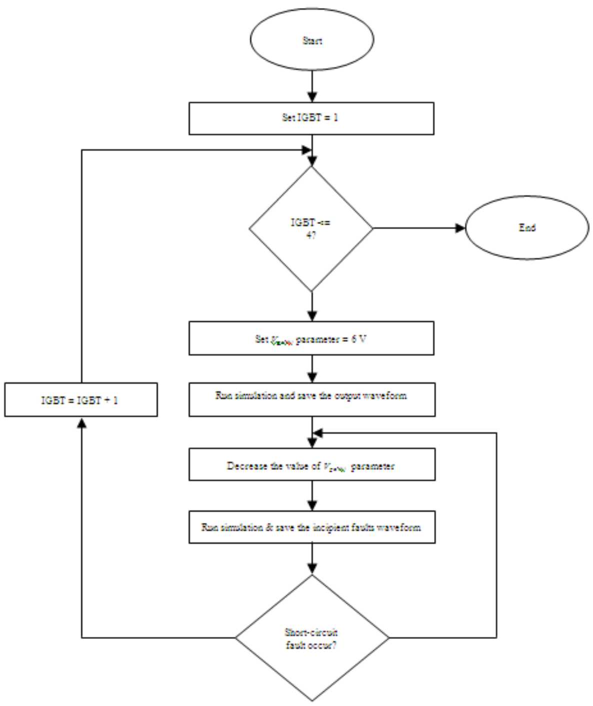

Figure 4. Flowchart for generating the incipient faults of short-circuit.

The $V_{ge(th)}$ parameter of IGBT 1 is set to 6 V based on the manufacturer datasheet[25]. The circuit is simulated to produce the single phase PWM inverter under normal condition. To produce short-circuit incipient faults, $V_{ge(th)}$ is decreased until the output voltage waveform of the PWM only produces the upper part of the waveform. This indicates short-circuit has occurred in IGBT 1. Once the incipient short-circuit faults of IGBT 1 are generated, the same process is repeated for IGBT 2, IGBT 3 and IGBT 4.

3. Analysis of Faults

Under this topic, the results obtained from simulated faults are shown and discussed. There are two sections involved which are short-circuit fault and short-circuit incipient faults.

3.1 Short-Circuit Fault

This section discusses about the simulated short-circuit fault from Section 2.1. Under normal condition when V_{ge} is equal to 0 V, the IGBT is expected always in off-state mode where the V_{ce} of the IGBT is equal to 20 V and the $I_{10\Omega}$ is equal to 0 A. Recall that for the IGBT to be in on-state, $V_{ge} > V_{ge(th)}$. Therefore, as V_{ge} remains at 0 V and as $V_{ge(th)}$ decreases to negative value, the IGBT changes from off-state to on-state. Figure 5 shows the graph of V_{ce} versus time when V_{ge} equals to 0 V at different $V_{ge(th)}$ values. Notice that when the value of $V_{ge(th)}$ parameter is equal to 6 V which represents the value for normal condition of the IGBT, the voltage across V_{ce} is equal to 20 V.

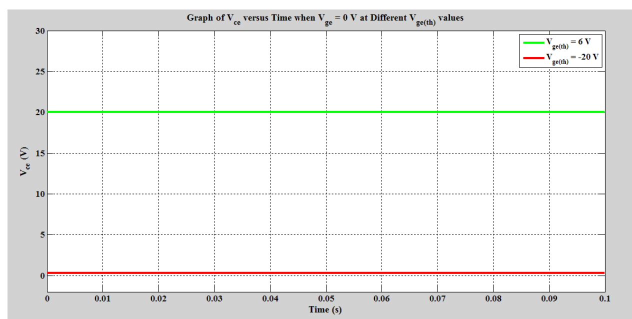

Figure 5. Graph of Vce versus time when V_{ge} = 0 V at different V_{ge}(th) values.

Now when the value of $V_{ge(th)}$ is reduced to a negative value, i.e., -20 V, the V_{ce} now will approximately equal to 0.34 V. This indicates that the IGBT now is in short-circuit fault even though the V_{ge} voltage equal to 0 V. Therefore, from the short-circuit simulation, it was concluded that the *Threshold voltage, $V_{ge(th)}$* parameter could cause short-circuit fault to the IGBT.

3.2 Short-Circuit Incipient Fault

This Section will discuss on the incipient faults of short-circuit. The discussion will focus on all IGBTs in the single phase PWM inverter.

3.2.1 Short-Circuit Incipient Faults at IGBT 1

The incipient faults of short-circuit are generated by modifying the $V_{ge(th)}$ parameter of IGBT at IGBT 1 as shown in Figure 6. When the value of $V_{ge(th)}$ is reduced, it was observed that the magnitude of the negative side of the inverter output waveform is also reduced. However, there is no change observed on the magnitude of the positive side of the inverter output waveform. Eventually if the $V_{ge(th)}$ is further decreased, the magnitude on the negative part equals to zero and the magnitude on positive part of the inverter output waveform remains the same. This indicate short-circuit fault occurred on IGBT 1. Similar patterns as in Figure 6 are observed for the incipient faults of short-circuit generated at IGBT 4.

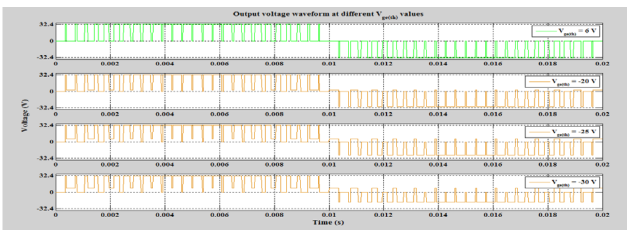

Figure 6. Incipient faults of short-circuit at IGBT 1.

3.2.2 Short-Circuit Incipient Faults at IGBT 2

Figure 7 shows the waveforms of the short-circuit incipient faults occurred at IGBT 2. When the $V_{ge(th)}$ is reduced, the positive side of the inverter output waveform will also reduce, while no change is observed on the negative side of the inverter output waveform. Eventually if the parameter value of $V_{ge(th)}$ is further decreased, the magnitude on the positive part equals to zero and the magnitude on negative part of the inverter output waveform remains the same. This indicate short-circuit fault occurred at IGBT 2. Note that similar patterns as in Figure 7 are observed for short-circuit incipient faults generated at IGBT 3.

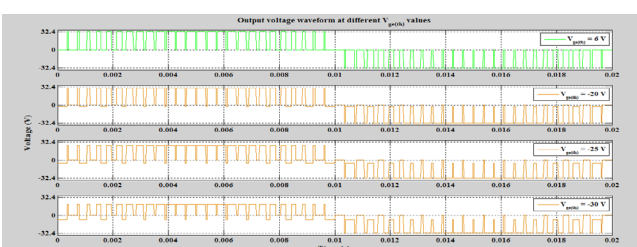

Figure 7. Incipient faults of short-circuit at IGBT 2.

In conclusion, the incipient faults of short-circuit are generated by modifying the parameter value of $V_{ge(th)}$. It was observed that when IGBT 1 or IGBT 4 was modified, the inverter produced similar output waveform. On the other hand, the inverter produced similar output waveform when IGBT 2 or IGBT 3 was modified. When incipient faults of short-circuit occurred at IGBT 1 or IGBT 4, it was expected that the magnitude of the negative part of the inverter output waveform would reduce. Note that when short-circuit fault occurred at IGBT 1 or IGBT 4, the magnitude of the negative-part of the inverter output waveform would equal to zero. For IGBT 2 or IGBT 3, the reduction on the magnitude on the positive side of inverter output waveform when the incipient fault of short-circuit occurred was expected because when short-circuit fault happen at IGBT 2 or IGBT 3, the magnitude on the positive-side of inverter output waveform would equal to zero. Figure 8 shows the inverter output waveform when short-circuit fault occurred on all IGBTs.

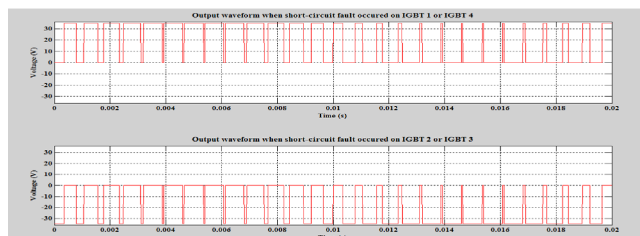

Figure 8. Short-circuit fault on the IGBTs.

Note that the single phase PWM inverter is set to produce 50 short-circuit incipient faults data by modifying IGBT 1 or IGBT 4 and another 50 short-circuit incipient faults data by modifying IGBT 2 or IGBT 3. These incipient faults data will be used for the neural network training.

4. Feature Extraction and Feature Selection

The neural network can be utilized for classifying all short-circuit incipient faults once they are generated. But first, the feature extraction and feature selection processes need to be applied to the generated incipient faults data before the faults are input into the neural network. The goal of feature extraction is to extract a set of different measures to form a new representation of the signal without losing any of its most important characteristic. Feature selection on the other hand, is used to enhance the feature extraction result by eliminating the irrelevant features. Feature extraction and feature selection methodologies from[27] are applied to the generated data in this paper. By performing feature extraction process, the waveforms are extracted into basic signal measurement and statistical features. For signal measurement feature extraction, Root-Mean-Square (RMS), peak-magnitude-to-RMS (peak-to-RMS) and maximum-to-minimum difference (peak-to-peak) are used. For statistical feature extraction, standard deviation, mean, median, variance, minimum, maximum, mode, range, kurtosis and skewness are taken to obtain the signature of the waveform. Feature selection process is then used to enhance the extracted features. Figure 9 summarizes the result obtained through feature selection process.

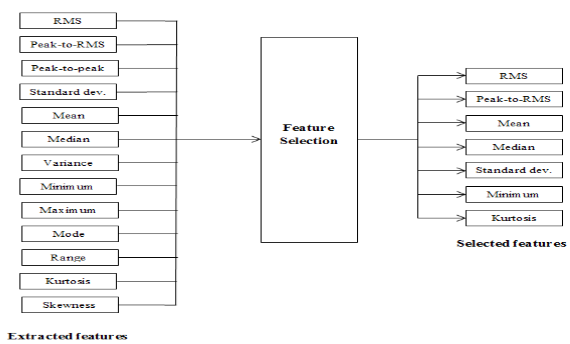

Figure 9. Features selection result.

Selected features comprise the Root-Mean-Square (RMS), peak-magnitude-to-RMS (peak-to-RMS), mean, median, standard deviation, minimum and kurtosis. Once the features selection process completed, the neural network can be employed for the classification of the incipient faults locations.

5. Short-Circuit Incipient Faults Classification

In this section, the methodology of classifying the short-circuit incipient faults of the single phase PWM inverter is discussed. The input to the neural network will be the enhanced features obtained from Section 4.2. The neural network input comprises input of the normal condition, short-circuit incipient faults produced by IGBT 1 or IGBT 4 and short-circuit incipient faults produced by IGBT 2 or IGBT 3. Three groups make up the target data. These are; 1. Data that represent the inverter under normal condition, 2. Short-circuit incipient faults data due to IGBT 1 or IGBT 4 and 3. The short-circuit incipient faults data due to IGBT 2 or IGBT 3. This paper sees the feedforward backpropagation network used for the incipient faults classification and the selected architecture used is 1 hidden layer and 1 output layer. Mean Square Error (MSE) is used to determine the performance of the network since the *MSE* is commonly used as a performance measure[28]. Equation (3) shows the equation of the *MSE*.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(\hat{Y}_l - Y_i\right)^2 \qquad (3)$$

Where $\hat{Y}$ = vector on n prediction and Y = vector of true value. After a few trials, it was seen that the neural network produces the minimum *MSE* when '*tansig*' is used both on the input and output layer. For the training, the '*trainlm*' is chosen as the training function because it has a fastest training time[11]. The training starts with the neurons set equal to one. Then the network is trained and the *MSE* is observed. According to[29,30], 0.009 *MSE* is the optimum value for prediction and detection application using the back-propagation network. Therefore, in this paper the network is trained until an *MSE* of less than 0.009 is achieved. If the targeted *MSE* is not achieved, the number of neurons is increased by one and the network is trained again. The process is repeated until the targeted *MSE* of less than 0.009 is achieved. Figure 10 shows the flowchart of the neural network training.

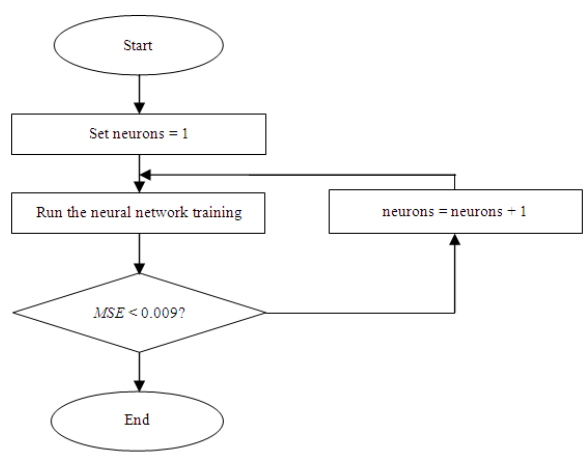

Figure 10. Flowchart of the network training.

From the training, *MSE* is achieved with 7 hidden neurons. Figure 11 shows the proposed neural network architecture while Table 1 shows the confusion table for the testing data set. The classification performance for all the three classes is 100%.

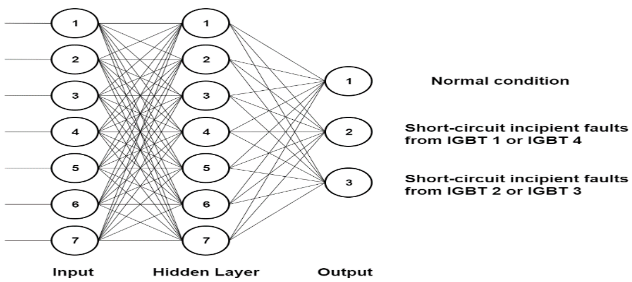

Figure 11. Proposed neural network architecture.

5.1. Detection of the Source of the Short-circuit Incipient Faults

Once the neural network is trained to classify the three classes, the feedforward backpropagation neural network is then tested with untrained data to validate that feedforward backpropagation neural network is able to detect which IGBT component is causing the short-circuit incipient faults. For this purpose, a set of normal condition data and 4 sets of untrained short-circuit incipient faults data are used. Note that, the feature extraction and selection processes as described in Section 4.1 and Section 4.2, are applied to these untrained data before they are fed into feedforward backpropagation neural network.

Three matrices are defined to differentiate the condition of the single phase PWM inverter, 1. *001*: represents the single phase PWM inverter under normal condition, 2. *010*: represents the short-circuit incipient faults occur due to IGBT 1 or IGBT 4 and 3. *100*: represents the short-circuit incipient faults occur due to IGBT 2 or IGBT 3, shown in Equation (4) to (6). The dimension matrix is *1-by-3* because only one test data at a time is used for validation.

Normal condition =[0 0 1] (4)

Short-circuitincipient faults from IGBT 1 or IGBT 4 =[0 1 0] (5)

Short-circuit incipient faults from IGBT 2 or IGBT 3 =[1 0 0] (6)

Figure 12 shows the trained feedforward backpropagation neural network produced with the untrained data sets as the inputs to the network, one at a time.

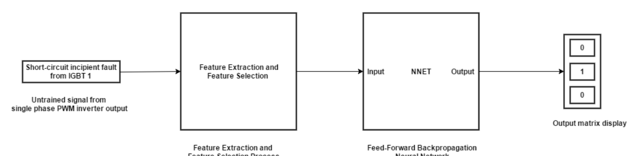

Figure 12. Feedforward backpropagation neural network

Table 2 shows that the neural network is able to indicate the possible IGBT of the single phase PWM inverter that produces the incipient faults.

Table 1. Confusion matrix for testing data

Classification		Target Class		
		Normal	Short-circuit incipient faults from IGBT 1 or IGBT 4	Short-circuit incipient faults from IGBT 2 or IGBT 3
Output Class	Normal	100%	0%	0%
	Short-circuit incipient faults from IGBT 1 or IGBT 4	0%	100%	0%
	Short-circuit incipient faults from IGBT 2 or IGBT 3	0%	0%	100%

Table 2. Testing result for untrained data

Test Data	Expected output	Result from neural network testing
Normal condition	0 0 1	0 0 1
Short-circuit incipient fault from IGBT 1	0 1 0	0 1 0
Short-circuit incipient fault from IGBT 2	1 0 0	1 0 0
Short-circuit incipient fault from IGBT 3	1 0 0	1 0 0
Short-circuit incipient fault from IGBT 4	0 1 0	0 1 0

6. Conclusion

This paper has proposed a method on generating incipient faults of the single phase PWM inverter by modifying the parameters values of the IGBT. From the simulation, it was found that the parameter $V_{ge(th)}$ could cause the short-circuit to IGBT. Therefore, the incipient faults of short-circuit can be generated by modifying the parameter $V_{ge(th)}$. From the simulation, it was observed that the single phase PWM inverter produces similar output waveform when the parameter of IGBT 1 or IGBT 4 was modified. Another set of similar waveform was produced by the inverter when the parameter of IGBT 2 or IGBT 3 was modified. The features of the incipient faults were then extracted and enhanced before fed into feedforward backpropagation neural network. It was found that the feedforward backpropagationneural network is able to detect which IGBT of the single phase PWM inverter produces the incipient faults. Future works can be done on detecting the incipient faults in the three phase PWM inverter by using feedforward backpropagationneural network.

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