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# LOCATION OF VOLTAGE SAG SOURCE BY USING ARTIFICIAL NEURAL NETWORK

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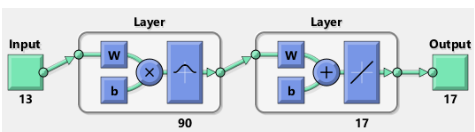
## Graphical abstract




## Abstract

Power quality (PQ) is a major concern for number of electrical equipment such as sophisticated electronics equipment, high efficiency variable speed drive (VSD) and power electronic controller. The most common power quality event is the voltage sag. The objective is to estimate the location of voltage sag source using ANN. In this paper, the multi-monitor based method is used. Based on the simulation results, the voltage deviation (VD) index of voltage sag is calculated and assigned as a training data for ANN. The Radial Basis Function Network (RBFN) is used due to its superior performances (lower training time and errors). The three types of performance analysis considered are coefficient of determination ($R^2$), root mean square error (RMSE) and sum of square error (SSE). The RBFN is developed by using MATLAB software. The proposed method is tested on the CIVANLAR distribution test system and the Permas Jaya distribution network. The voltage sags are simulated using Power World software which is a common simulation tool for power system analysis. The asymmetrical fault namely line to ground (LG) fault, double line to ground (LLG) fault and line to line (LL) fault are applied in the simulation. Based on the simulation results of voltage sag analysis, the highest VD is contributed by LLG for both test systems. Based on the proposed RBFN results, the best performance analysis are $R^2$, RMSE and SSE of 0.9999, 5.24E-04 and 3.90E-05, respectively. Based on the results, the highest VD shows the location of voltage sag source in that system. The proposed RBFN accurately identifies the location of voltage sag source for both test systems.

*Keywords*: Power quality, voltage sag, multi-monitor based method, radial basis function network, voltage deviation index

## Abstrak

Kualiti kuasa adalah perkara yang amat dititikberatkan bagi bilangan peralatan-peralatan elektronik yang canggih, pemacu halaju bolehubah berkecekapan tinggi dan pengawal elektronik kuasa. Kebanyakan peristiwa daripada kualiti kuasa disebabkan oleh voltan lendut. Tujuan projek ini adalah untuk analisa voltan lendut dan menganggar lokasi berlakunya voltan lendut dengan menggunakan rangkaian neural buatan (RNB). Di dalam kajian ini, kaedah berdasarkan paparan pelbagai akan digunakan. Berdasarkan keputusan simulasi, indek perbezaan voltan bagi voltan lendut akan dikira dan akan dijadikan sebagai data latihan untuk RNB. Rangkaian fungsi asas jejarian (RFAS) digunakan disebabkan prestasi yang tinggi (rendah masa latihan dan kesilapan). Tiga jenis analisis prestasi digunakan ialah pekali penentuan (R2), ralat punca min kuasa dua (RMPKD) and hasil tambah ralat kuasa dua (HTRKD).

RFAS dibangunkan dengan menggunakan perisian MATLAB. Kaedah cadangan ini akan diuji pada sistem ujian pengagihan CIVANLAR dan rangkaian pengagihan Permas Jaya. Voltan lendut telah disimulasi menggunakan perisian Power World yang mana perisian ini adalah perisian yang biasa digunakan untuk analisis sistem kuasa. Kerosakan tidak simetri yang akan diaplikasi ialah talian ke bumi, talian ke talian dan dua talian ke bumi. Berdasarkan keputusan simulasi indek perbezaan voltan daripada sistem ujian pengagihan CIVANLAR dan rangkaian pengagihan Permas Jaya, indek perbezaan voltan yang tertinggi disumbangkan oleh LLG bagi kedua-dua sistem. Berdasarkan keputusan RFAS, analisis prestasi terbaik adalah R2, RMSE dan SSE adalah 0.9999, 5.24E-04 dan 3.90E-05. Berdasarkan keputusan tersebut, indek perbezaan voltan yang paling tinggi menunjukkan lokasi berlakunya voltan lendut pada sistem. RFAS telah dapat mengenal pasti secara tepat lokasi sumber voltan lendut pada kedua-dua sistem.

*Kata kunci:* Kualiti kuasa, voltan lendut, kaedah berdasarkan paparan pelbagai, rangkaian fungsi asas jejarian, indek perbezaan voltan



## 1.0 INTRODUCTION

The increasing numbers of sophisticated electronics equipment, high efficiency variable speed drive (VSD) and power electronic controller which can cause electromagnetic interference have heightened interest in power quality (PQ). Many utilities and consumers have increased their concerns about power quality. Power quality problems occur when the 50 or 60 Hertz sine wave alternating-voltage power sources are distorted. The characteristics of power quality problems are variation of voltage, current and also frequency from nominal rating. The effects of power quality problem which are motors overheating, adjustable-speed drives (ASDs) tripping off, computers shut down, flickering lights and production halt [1]. The types of power quality problems are voltage sag, voltage swell, undervoltage, overvoltages, harmonics distortion, flickers and transients [2]. The voltage sag is the most common disturbance of power quality issue at power frequency [3].

Generally, voltage sag is reduction of voltage magnitude of rms voltage in between 10 to 90 percent of nominal voltage around 0.5 cycles to 1 minute [4]. Voltage sag can be caused by utility and end users. The utility consists of transmission and distribution systems. The most common cause of voltage sag is faults (short circuit) in the system [5]. The single line to ground fault contributes up to 70 percent of the fault in the power system [6-7].

The estimation of the voltage sag source location is the most important method for the feature study of the power system. After the location of the sag source is identified, the diagnosis and mitigation can be applied to improve the power quality in the power system [8]. There are two categories of voltage sag source location method, namely single monitor and multi monitor methods. Recently, most researchers focus on the application of multi monitor method due to its accuracy in getting the data needed.

Artificial intelligence (AI) is an area of computer science which is emphasizes the creation of intelligent machines that work and reacts like humans. AI such as artificial neuron network (ANN), expert systems (ES) and fuzzy logic (FL) are widely used in electrical applications. The ANN has been applied widely in the power system such as fault diagnosis/fault location, load forecasting, economic dispatch, security assessment and transient stability [9]. The main advantage of ANN is to solve problems related to classification and optimization [10]. It is very suitable to be used in the voltage sag source location as it has the ability to recognize complex patterns in the power system.

The single monitor method uses only one power quality monitor (PQM) installed in the power system network. Figure 1 shows the basic concept of the single monitor method.

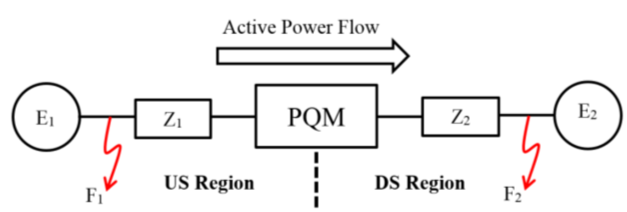



**Figure 1** Basic concept of the single monitor based method

Referring to Figure 1, the PQM is located between the upstream (US) and downstream (DS) regions. The active power flow will determine the region based on the direction of the flow from US to DS [11]. The method [12] is based on the disturbance energy (DE) and disturbance power (DP). The difference between the power delivered during the disturbance and the normal condition will determine the DP. The method [13] is based on the polarity of the variation of real part of the current to determine the location of fault in the power system. In this method [14], the variation of reactive power was examined at PQM in the power system. By referring to this method, when the reactive power changes, the voltage will also change. R.Ch. Leborgne *et al*. [15] introduced the voltage sag source location based on the voltage magnitude only. The single monitor method was considered in the paper. The voltage magnitude measures both sides of transformer. D. J. Sunil Dhas *et al*. [16] presented a voltage sag source location using ANN. The single monitor based was considered in this paper. The concept of voltage measurement, test system and results are the same as [15]. The improvement of this paper is by introducing the ANN to estimate the sag source location.

Recently, numerous researchers focus on multi-monitor method due to its accuracy to estimate the source location of sag for asymmetrical fault. The echo state network (ESN) method [17] is used as the voltage sag waveform estimator (VSWE). Basically, the ESN is adapted from recurrent neural network (RNN) of ANNs. In this paper, the asymmetrical fault applies LG, LLG, LL and LLL faults. The method is tested on IEEE 37-bus which is an unbalanced distribution network. The GNN method was proposed in [18] which adapted from ANN. In this method, the GNN was based on the current sag waveform which was analysed using wavelet transform. After that, the data was used as an input of GNN model to estimate the location of fault. This method was tested on single 500 kV transmission line with two sources. Only the three phase fault (3LG) is implemented in the test system. The support vector regression (SVR) was introduced [19] which was suitable to solve classification problem such as fault location detection in the power system. The SVR resembles the multi-layer perceptron (MLP) of ANN. In this paper, the voltage sag waveform is transformed by using wavelet transform. Then, the data from the transformation was used as the input data of the SVR, whereas the output data of SVR was the location of fault in the network. The method was tested on the radial distribution network and only the LG fault was implemented in the simulation. H. Shareef *et al*. [20] introduced a voltage sag source identification using radial basis function network (RBFN). The paper was used multi monitor method in the system network. In this paper, the IEEE 30 bus test system was simulated. In this method, the voltage sag magnitude measured using PQM was tabulated for different types of faults which are LLLG, LLG and LG faults. Then, the percentage of voltage deviation (%VD) was calculated and assigned as a training data for RBFN. A. Kazemi *et al*. [21] introduced a new method to identify voltage sag source location by using multivariable regression (MVR) model. The main objective of this paper is to estimate the bus voltages at unmonitored bus based on the measurement of voltage sag magnitude. The MVR is one of the types of supervised learning method, so the accuracy depends on the training data. The data is based on voltage deviation from simulation.

In this paper, the voltage sag source location estimation is proposed by using ANN. In this method, the multi-monitor based method will be used considering the VD index as a training data for ANN. The radial basis function network (RBFN) will be carried out to estimate the exact bus location. The proposed method will be tested on mesh systems which are the CIVANLAR distribution test system and Permas Jaya distribution network. RBFN is the most suitable technique to estimate the unmonitored buses voltage and the highest value of VD used to identify the source location of the voltage sag in the systems.

## 2.0 METHODOLOGY

Radial basis function network (RBFN) is widely utilized to solve many prediction problems. RBFN offers superior performances compared to multi-layer perceptron (MLP) in term of training time consume and errors [20]. The architecture of RBFN is depicted in Figure 2. It consists of three layers which are input, hidden and output. The input and output layers are represented with x and y, respectively. Meanwhile, the hidden layer contains non-linear transformation (Ø) and linear combiner (∑) functions [22].

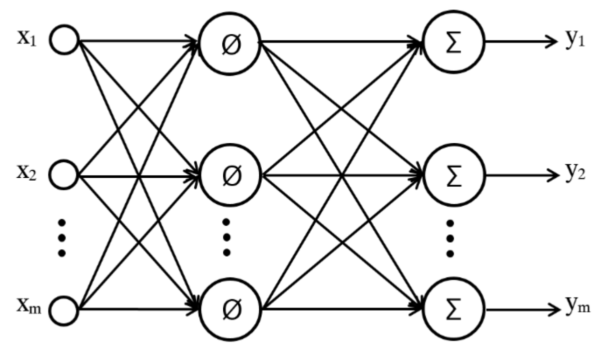



**Figure 2** Architecture of RBFN

### 2.1 Test System

In this paper, the proposed method will be tested on CIVANLAR distribution test system and Permas Jaya distribution network.

#### *2.1.1 CIVANLAR Distribution Test System*

The CIVANLAR system is a 23 kV meshed distribution system consists of 16 buses, 16 lines and 13 loads. It is obtained from [23]. The single-line diagram is depicted in Figure 3.

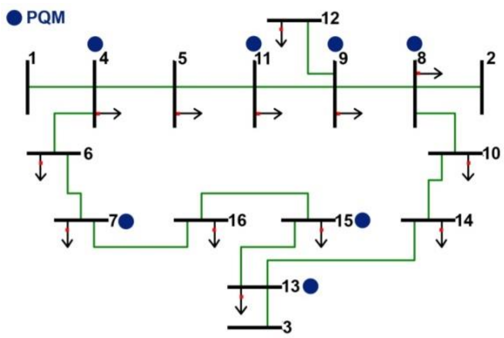



**Figure 3** The single-line diagram of CIVANLAR distribution test system

#### 2.1.2 Permas Jaya Distribution Network

The Permas Jaya distribution network is a real 11kV underground distribution network which is located in south of Peninsular Malaysia. It consists of 30 buses, 56 lines and 26 loads. In addition, the network also consists of some Normal Off Points (NOP) at the certain buses. In this paper, the NOP are excluded in the analysis. The single-line diagram is depicted in Figure 4 and the network data in Appendix A.

### 2.2 Develop Proposed RBFN for Voltage Sag Source Location

The methods to estimate the voltage sag source location using proposed RBFN are simulated of voltage sag, calculate voltage deviation index, create and pre-processing data, develop structure of RBFN and training and testing of RBFN. The step by step methodology will be explained next.

#### 2.2.1 Simulation of Voltage Sag

The test systems were constructed and simulated using Power World software which is a common simulation tool for power system analysis. For the Permas Jaya network which is the real distribution network, the cable parameters (R, X and C) need to be converted into parameters (R, X and B) in per unit (p.u) where its parameters suit the power world software. The conversion results are shown in Table A3 in Appendix A.

The load flow analysis was carried-out first to determine the pre-fault voltage for every single bus and the results were recorded. As mentioned in the introduction, the most common of voltage sag is due to fault. Therefore, the magnitude of voltage at the bus during fault was taken from the simulation and it represented the voltage sag ($V_{sag}$). The asymmetrical fault which are line to ground (LG) fault, double line to ground (LLG) fault and line to line (LL) fault were applied in the simulation. For all cases, the simulations were repeated with varies value of fault resistance ($R_f$) for 0.1 Ω, 0.2 Ω and 0.3 Ω. Based on the results, the magnitude of sag for different types of faults was tabulated to create voltage sag database.

#### 2.2.2 Voltage Deviation Index

Based on the simulation results of voltage sag, the voltage deviation (VD) index was calculated using equation (1) as given as follows:

$$\boldsymbol{VD} = \frac{\boldsymbol{V_{pre-fault}} - \boldsymbol{V_{sag}}}{\boldsymbol{V_{pre-fault}}} \quad (1)$$

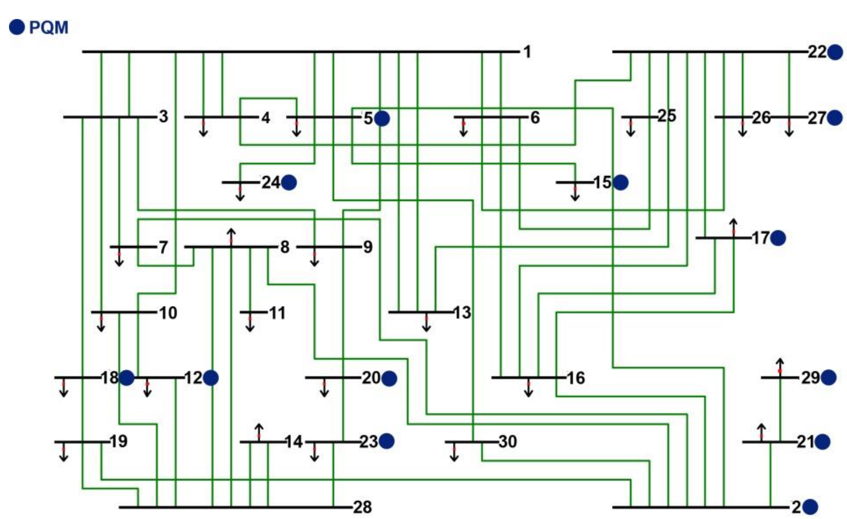



**Figure 4** The single-line diagram of Permas Jaya distribution network

#### 2.2.3 Create and Pre-Processing the Input and Output Data

After all VD had been calculated and the database had been created, the data was divided into two parts which were input data (D) and target data (T) for training and testing of proposed RBFN. The input data represented VD as monitored buses (with PQMs) while the output data represented VD as unmonitored buses (without PQMs) in test system. In the CIVANLAR test system, the monitored buses were located at bus 4, 7, 8, 9, 11, 13 and 15 while the remaining buses were unmonitored buses. For the Permas Jaya distribution network, the monitored buses located at bus 2, 5, 12, 15, 17, 18, 20, 21, 22, 23, 24, 27 and 29 while the remaining buses were unmonitored buses. The trial and error method was used to determine the optimal number and placement of the PQMs.

#### 2.2.4 Structure of RBFN

In this paper, the proposed RBFN was developed using MATLAB R2013a software. MATLAB R2013a provides the Neural Network Toolbox to develop the network. The proposed RBFN used the exact radial basis (newrbe) function. This function produces zero error on training vectors [24]. This function required three parameters which are input vector, output vector and spread constant. The input vector is the value of VD of monitored buses while the output vector is the value of VD of unmonitored buses. The spread constant will be discussed in next sub-section. Three types of networks had been developed for each test system namely LG, LL and LLG.

#### 2.2.5 Training and Testing of RBFN

In the training process, the spread constant value influenced to the target output. Therefore, the most suitable spread constant value should be chosen to obtain the best performance of network during testing process. In the testing process, the performance of the network which is based on the value of spread constant will be evaluated. In this paper, three types of performance analysis that will be evaluated are coefficient of determination ($R^2$), root mean square error (RMSE) and sum of square error (SSE). The performance analysis can be calculated by using formulae as follows:

$$\boldsymbol{R^2 = 1 - \frac{\sum_{i=n}^{n}(\hat{y}_i - y_i)^2}{\sum_{i=n}^{n}(\hat{y}_i - \bar{y}_i)^2}} \qquad (2)$$

$$\boldsymbol{RMSE = \sqrt{\left(\frac{\sum_{i=n}^{n}(\hat{y}_i - y_i)^2}{n}\right)}} \qquad (3)$$

$$\boldsymbol{SSE = \sum_{i=n}^{n}(\hat{y}_i - y_i)^2} \qquad (4)$$

Where the $\hat{y}_i$ is the predicted VD, $\bar{y}_i$ is the simulated VD in average, $y_i$ is the simulated VD and $n$ is the number of dataset.

In this paper, the training and testing processes were repeated using difference values of spread constant until the lowest value of errors was obtained. In the testing process, the VD data with fault resistance of 0.25 Ω was used as input and output vectors.

The procedure to estimate the voltage sag source location is described as follows:

Step 1: Obtain voltage sag data from simulation
Step 2: Calculate VD from voltage sag data
Step 3: Assemble and pre-process the training data for the proposed RBFN
Step 4: Develop RBFN and train the network
Step 5: Test the network and analyse the network performances
Step 6: Save the trained and test the network

## 3.0 RESULTS AND DISCUSSION

The proposed voltage sag source location estimation using RBFN was tested on CIVANLAR distribution test system and Permas Jaya distribution network and the results were presented in this section.

Three types of fault were applied on these test systems which were LG, LL and LLG with various value of fault resistance that were 0.1 Ω, 0.2 Ω and 0.3 Ω for training data and 0.25 Ω for testing data were simulated using Power World software.

### 3.1 Results of the CIVANLAR Test System

The voltage sag was simulated and the proposed RBFN was tested in the CIVANLAR distribution test system. The voltage sag simulation, proposed RBFN training and testing and voltage sag source location results were presented.

#### 3.1.1 Voltage Sag Simulation results

After the simulation results of voltage sag had been obtained, VD was calculated. The VD for testing data for proposed RBFN was shown in Tables 1, 2 and 3. Based on Tables 1, 2 and 3, the highest VD was recorded when the fault occurred at bus 12 with 0.491 during LLG. The highlighted numbers which were the highest value of VD when fault occurred at every single bus were produced diagonally in the tables. The highest value of VD indicated the exact source location of the voltage sag in the test system.

#### 3.1.2 RBFN Training and Testing Results

Figure 5 shows the architecture of proposed RBFN for this test system. Referring to Figure 5, the numbers of neuron for input and output layers are 7 and 9, respectively. Meanwhile, the hidden layer which consists of radial basis and linear layers contain 48 and 9 neurons, respectively. The number of neurons for the input, output, radial basis and linear layer depend on the number of the input data, the output data, the dataset and the output, respectively.

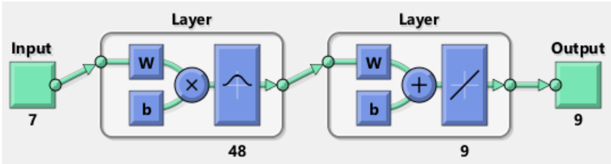



**Figure 5** Architecture of proposed RBFN for CIVANLAR test system

Table 4 shows the performance analysis of the proposed RBFN for various values of spread constant. There are three types of analysis which are $R^2$, RMSE and SSE. $R^2$ of 1 indicates the regression line perfectly fits the data that means the predicted data is equal to target data. In this case, the value which is closer to 1 indicates that the spread constant is the most suitable for the network. Meanwhile, as for the RMSE and the SSE, the value which is closer to 0 indicates that it is more useful for prediction. Therefore, the spread constant is also suitable for the network.

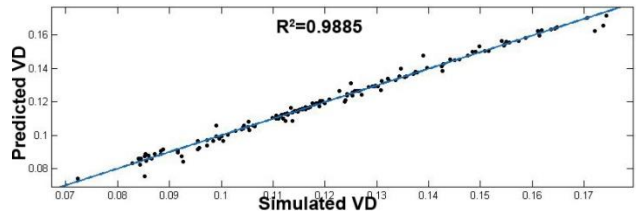
Based on Table 4, the spread constant had been chosen for LG, LL and LLG and they are 0.4, 9.0 and 0.2, respectively due to the $R^2$ which is the closest to 1 and RMSE and SSE that are the lowest compared to the others.

The regression plot which predicted VD versus simulated VD for different types of networks is depicted in Figure 6. In this plot, the vertical axis represents the predicted VD of proposed RBFN and the horizontal axis represents the simulated VD. The best prediction the most VD values that fit on the regression line will produce $R^2$ which is the closest to 1. $R^2$ values based on Figure 6(a), (b) and (c) are 0.9885, 0.9940 and 0.9999, respectively. Thus, the best proposed RBFN network for the three types of faults is LLG network due to the value of $R^2$ which is the closest to 1.

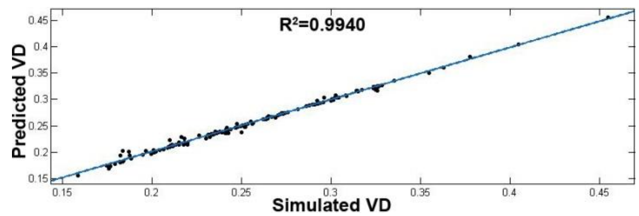
### *3.1.3 Voltage Sag Source Location Results*

The output of proposed RBFN is the predicted value of VD for unmonitored buses. The results were tabulated in Tables 9, 10 and 11 which are VD of LG, VD of LL and VD of LLG for all buses, respectively. Based on Tables 9, 10 and 11, the highlighted numbers which were the highest values of VD when fault occurred at every single bus were produced diagonally in the tables. The highest value of each VD indicated the exact source location of the voltage sag in the test system. The proposed method can estimate accurate VD and exact location of voltage sag source.

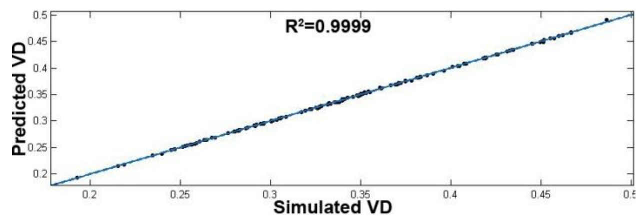
Based on the Table 11, for example, by considering a fault occurs at Bus 5 ($B_5$) which is the unmonitored bus; the Bus 5 is the predicted VD from the proposed RBFN. Then, to identify the location of fault, the VD from monitored buses and unmonitored buses is compared and observed to get the highest value of VD. As a result, the $VD_{5,5}$ is the highest value with 0.462 and it shows that, the Bus 5 is the location of fault. The predicted $VD_{55}$ from proposed RBFN is equal to simulated $VD_{5,5}$. It shows that the proposed RBFN produce exact value of VD and consequently identify the exact location of fault in the test system. All the proposed RBFN which are LG, LL and LLG produce the best performance as they can identify perfectly the location of voltage sag source for this test system.




(a) LG




(b) LL




(c) LLG

**Figure 6** Regression plots of RBFN for different types of fault on CIVANLAR test system

## 3.2 Results of the Permas Jaya Distribution Network

The voltage sag was simulated and the proposed RBFN was tested in the Permas Jaya distribution network. The voltage sag simulation, proposed RBFN training and testing and voltage sag source location results were presented.

### *3.2.1 Voltage Sag Simulation Results*

After the simulation results of voltage sag had been obtained, VD was calculated. The VD for testing data for proposed RBFN was shown in Tables 5, 6 and 7. Based on Tables 5, 6 and 7, the highest VD recorded when the fault occurred at Bus 29 with 0.571 during LLG. The highlighted numbers which were the highest value of VD when fault occurred at every single bus were produced diagonally in the tables. The highest value of VD is indicated the exact or possible source location of the voltage sag in the test system.

### 3.2.2 RBFN Training and Testing Results

Figure 7 shows the architecture of proposed RBFN for this test system. Referring to Figure 7, the numbers of neuron for input and output layers are 13 and 17, respectively. Meanwhile, the hidden layer which consists of radial basis and linear layers contain 90 and 17 neurons, respectively. The number of neurons for the input, output, radial basis and linear layer depend on the number of the input data, the output data, the dataset and the output, respectively.

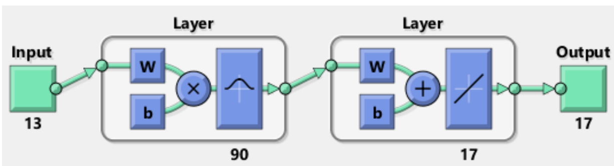
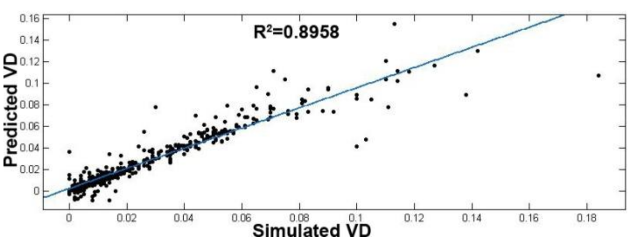


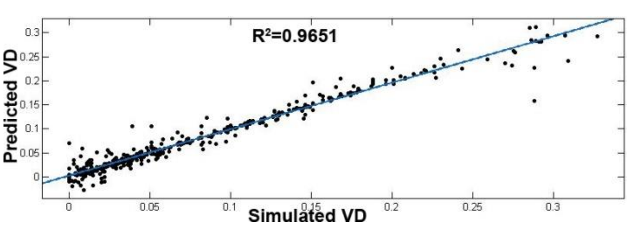

**Figure 7** Architecture of proposed RBFN for Permas Jaya distribution network

Table 8 shows the performance analysis of the proposed RBFN for various values of spread constant. There are three types of analysis which are $R^2$, RMSE and SSE. Based on Table 8, the spread constant has been chosen for LG, LL and LLG and they are 65, 65 and 80, respectively due to the $R^2$ which is the closest to 1 and RMSE and SSE that are the lowest compared to the others.

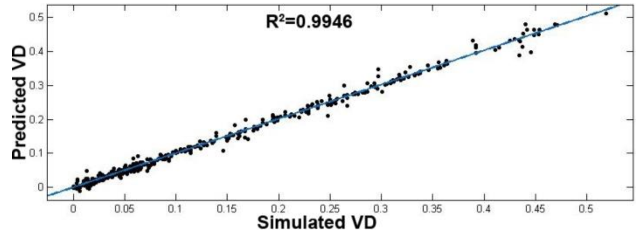
The regression plot which predicted VD versus simulated VD for different types of networks is depicted in Figure 8. $R^2$ values based on Figure 8(a), (b) and (c) are 0.8958, 0.9651 and 0.9946, respectively. Thus, the best RBFN network for the three types of faults is LLG network due to the value of $R^2$ which is the closest to 1.




(a) LG




(b) LL




(c) LLG

**Figure 8** Regression plots of proposed RBFN for different types of fault on Permas Jaya distribution network

### 3.2.3 Voltage Sag Source Location Results

The output of proposed RBFN is the predicted value of VD for unmonitored buses. The results were tabulated in Tables 12, 13 and 14 which are VD of LG, VD of LL and VD of LLG for all buses, respectively. Based on Tables 12, 13 and 14, the highlighted numbers which were the highest value of VD when fault occurred at every single bus were not fully produced diagonally in the tables.

Referring to Table 14, for example, by considering fault occurs at Bus 7 ($B_7$) which is unmonitored bus; the Bus 7 is the predicted VD from proposed RBFN. Then, to identify the location of fault, the VD from monitored buses and unmonitored buses are compared and observed to get the highest value of VD. As a result, the $VD_{7,7}$ is the highest value with 0.43 and it shows that, the bus 7 is the location of fault. The simulated $VD_{7,7}$ is 0.43 and it produce zero error. It still shows that the proposed RBFN produce same value of VD and consequently identify the exact location of fault in the test system.

For another example, by considering fault occurs at Bus 8 ($B_8$) which is unmonitored bus; the Bus 8 is predicted VD from the proposed RBFN. Then, to identify the location of fault, the VD from monitored buses and unmonitored buses are compared and observed to get the highest value of VD. As a result, the $VD_{11,8}$ which is predicted VD from proposed RBFN is the highest value with 0.483 compared to simulated $VD_{11,8}$ with 0.440 and produce error of 0.043. While, the predicted $VD_{8,8}$ of proposed RBFN which is 0.462 compared to simulated $VD_{8,8}$ with 0.442 produce error of 0.02. Based on fault analysis theory, the faulted bus indicates the highest VD. In this case, the proposed RBFN output is less accurate to predict the same value of VD at Bus 8 and VD at Bus 11. The training and testing data for VD at Bus 8 and VD at Bus 11 are so close value with 0.02 different. It due to both buses is close to each other, Bus 11 is not interconnected to other buses in the test system. Same thing happen when fault occurs at buses 6, 11 and 25. It looks like a radial system characteristic when deals with faults. When a fault occurs at the nearest bus in the network, the value of the VD of the bus which is located at the end of the system is so close or same with the value of VD at the faulted bus.

**Table 1** The simulated VD for LG with $R_f$ = 0.25 Ω of CILANVAR test system

| Fault Bus/$B_j$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ | $B_{16}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **0.174** | 0.089 | 0.087 | 0.149 | 0.127 | 0.124 | 0.116 | 0.100 | 0.104 | 0.092 | 0.119 | 0.085 | 0.098 | 0.092 | 0.101 | 0.104 |
| 2 | 0.085 | **0.172** | 0.086 | 0.092 | 0.096 | 0.084 | 0.083 | 0.135 | 0.115 | 0.111 | 0.099 | 0.095 | 0.097 | 0.105 | 0.087 | 0.084 |
| 3 | 0.085 | 0.088 | **0.174** | 0.093 | 0.086 | 0.097 | 0.100 | 0.099 | 0.088 | 0.111 | 0.085 | 0.072 | 0.139 | 0.118 | 0.120 | 0.112 |
| 4 | 0.159 | 0.103 | 0.101 | **0.163** | 0.144 | 0.142 | 0.134 | 0.116 | 0.120 | 0.106 | 0.136 | 0.099 | 0.114 | 0.106 | 0.117 | 0.120 |
| 5 | 0.148 | 0.117 | 0.103 | 0.155 | **0.164** | 0.132 | 0.126 | 0.130 | 0.137 | 0.115 | 0.156 | 0.116 | 0.116 | 0.113 | 0.115 | 0.116 |
| 6 | 0.146 | 0.104 | 0.117 | 0.155 | 0.134 | **0.165** | 0.157 | 0.116 | 0.116 | 0.114 | 0.127 | 0.095 | 0.130 | 0.117 | 0.138 | 0.143 |
| 7 | 0.140 | 0.105 | 0.123 | 0.149 | 0.129 | 0.160 | **0.165** | 0.117 | 0.115 | 0.117 | 0.123 | 0.094 | 0.136 | 0.121 | 0.145 | 0.151 |
| 8 | 0.106 | 0.150 | 0.107 | 0.115 | 0.118 | 0.104 | 0.103 | **0.159** | 0.140 | 0.135 | 0.122 | 0.117 | 0.120 | 0.129 | 0.108 | 0.105 |
| 9 | 0.123 | 0.140 | 0.107 | 0.131 | 0.138 | 0.116 | 0.112 | 0.152 | **0.162** | 0.129 | 0.143 | 0.143 | 0.120 | 0.125 | 0.112 | 0.110 |
| 10 | 0.105 | 0.132 | 0.128 | 0.114 | 0.112 | 0.110 | 0.111 | 0.144 | 0.126 | **0.161** | 0.114 | 0.104 | 0.143 | 0.155 | 0.125 | 0.119 |
| 11 | 0.141 | 0.123 | 0.104 | 0.149 | 0.158 | 0.128 | 0.122 | 0.136 | 0.145 | 0.119 | **0.164** | 0.123 | 0.117 | 0.116 | 0.114 | 0.115 |
| 12 | 0.123 | 0.140 | 0.107 | 0.131 | 0.137 | 0.116 | 0.112 | 0.152 | 0.161 | 0.129 | 0.142 | **0.170** | 0.119 | 0.124 | 0.112 | 0.110 |
| 13 | 0.105 | 0.108 | 0.151 | 0.113 | 0.105 | 0.118 | 0.121 | 0.120 | 0.108 | 0.133 | 0.103 | 0.088 | **0.161** | 0.141 | 0.144 | 0.135 |
| 14 | 0.105 | 0.125 | 0.136 | 0.114 | 0.110 | 0.113 | 0.114 | 0.137 | 0.121 | 0.154 | 0.111 | 0.100 | 0.150 | **0.162** | 0.131 | 0.124 |
| 15 | 0.119 | 0.107 | 0.141 | 0.128 | 0.114 | 0.137 | 0.142 | 0.119 | 0.110 | 0.127 | 0.111 | 0.091 | 0.154 | 0.133 | **0.164** | 0.156 |
| 16 | 0.125 | 0.106 | 0.135 | 0.134 | 0.119 | 0.145 | 0.151 | 0.118 | 0.112 | 0.124 | 0.115 | 0.092 | 0.148 | 0.130 | 0.159 | **0.164** |

**Table 2** The simulated VD for LL with $R_f$ = 0.25 Ω of CILANVAR test system

| Fault Bus/$B_j$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ | $B_{16}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **0.326** | 0.182 | 0.176 | 0.303 | 0.265 | 0.252 | 0.241 | 0.218 | 0.226 | 0.202 | 0.252 | 0.183 | 0.211 | 0.201 | 0.300 | 0.220 |
| 2 | 0.176 | **0.325** | 0.179 | 0.201 | 0.211 | 0.184 | 0.182 | 0.293 | 0.250 | 0.247 | 0.218 | 0.205 | 0.215 | 0.235 | 0.269 | 0.187 |
| 3 | 0.175 | 0.184 | **0.326** | 0.200 | 0.188 | 0.210 | 0.216 | 0.220 | 0.196 | 0.243 | 0.187 | 0.158 | 0.296 | 0.255 | 0.355 | 0.242 |
| 4 | 0.302 | 0.209 | 0.202 | **0.324** | 0.293 | 0.280 | 0.269 | 0.247 | 0.255 | 0.230 | 0.281 | 0.209 | 0.240 | 0.229 | 0.341 | 0.248 |
| 5 | 0.282 | 0.235 | 0.206 | 0.308 | **0.325** | 0.265 | 0.256 | 0.273 | 0.288 | 0.247 | 0.315 | 0.240 | 0.244 | 0.242 | 0.336 | 0.241 |
| 6 | 0.276 | 0.212 | 0.235 | 0.303 | 0.272 | **0.326** | 0.318 | 0.250 | 0.248 | 0.247 | 0.263 | 0.202 | 0.274 | 0.251 | 0.405 | 0.294 |
| 7 | 0.267 | 0.213 | 0.244 | 0.295 | 0.266 | 0.319 | **0.326** | 0.251 | 0.245 | 0.252 | 0.257 | 0.200 | 0.283 | 0.257 | 0.422 | 0.305 |
| 8 | 0.211 | 0.291 | 0.216 | 0.239 | 0.248 | 0.219 | 0.217 | **0.323** | 0.288 | 0.286 | 0.256 | 0.239 | 0.254 | 0.275 | 0.320 | 0.223 |
| 9 | 0.241 | 0.272 | 0.213 | 0.270 | 0.286 | 0.239 | 0.234 | 0.309 | **0.325** | 0.273 | 0.296 | 0.283 | 0.251 | 0.264 | 0.327 | 0.231 |
| 10 | 0.209 | 0.262 | 0.252 | 0.237 | 0.237 | 0.230 | 0.233 | 0.300 | 0.265 | **0.324** | 0.241 | 0.218 | 0.291 | 0.315 | 0.363 | 0.248 |
| 11 | 0.272 | 0.245 | 0.208 | 0.300 | 0.317 | 0.258 | 0.250 | 0.284 | 0.300 | 0.254 | **0.325** | 0.252 | 0.246 | 0.248 | 0.333 | 0.239 |
| 12 | 0.241 | 0.272 | 0.213 | 0.270 | 0.286 | 0.239 | 0.234 | 0.309 | 0.325 | 0.273 | 0.296 | **0.328** | 0.251 | 0.264 | 0.327 | 0.231 |
| 13 | 0.207 | 0.218 | 0.292 | 0.235 | 0.222 | 0.245 | 0.251 | 0.257 | 0.231 | 0.279 | 0.221 | 0.188 | **0.324** | 0.290 | 0.412 | 0.277 |
| 14 | 0.209 | 0.251 | 0.264 | 0.236 | 0.233 | 0.234 | 0.238 | 0.290 | 0.256 | 0.315 | 0.236 | 0.210 | 0.302 | **0.324** | 0.378 | 0.256 |
| 15 | 0.232 | 0.216 | 0.275 | 0.261 | 0.240 | 0.280 | 0.288 | 0.254 | 0.237 | 0.269 | 0.236 | 0.193 | 0.311 | 0.278 | **0.463** | 0.315 |
| 16 | 0.242 | 0.215 | 0.267 | 0.271 | 0.248 | 0.293 | 0.301 | 0.253 | 0.239 | 0.264 | 0.242 | 0.195 | 0.304 | 0.272 | 0.455 | **0.325** |

**Table 3** The simulated VD for LLG with $R_f$ = 0.25 Ω of CILANVAR test system

| Fault Bus/$B_j$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ | $B_{16}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **0.451** | 0.256 | 0.247 | 0.419 | 0.371 | 0.353 | 0.336 | 0.306 | 0.317 | 0.283 | 0.352 | 0.253 | 0.295 | 0.282 | 0.215 | 0.306 |
| 2 | 0.247 | **0.450** | 0.251 | 0.282 | 0.294 | 0.256 | 0.254 | 0.401 | 0.350 | 0.343 | 0.305 | 0.282 | 0.300 | 0.327 | 0.193 | 0.261 |
| 3 | 0.245 | 0.259 | **0.451** | 0.280 | 0.265 | 0.292 | 0.300 | 0.309 | 0.277 | 0.338 | 0.263 | 0.219 | 0.405 | 0.354 | 0.256 | 0.336 |
| 4 | 0.424 | 0.293 | 0.282 | **0.451** | 0.416 | 0.399 | 0.381 | 0.346 | 0.359 | 0.322 | 0.397 | 0.290 | 0.335 | 0.321 | 0.243 | 0.348 |
| 5 | 0.396 | 0.328 | 0.287 | 0.435 | **0.462** | 0.375 | 0.361 | 0.383 | 0.407 | 0.346 | 0.449 | 0.336 | 0.341 | 0.339 | 0.240 | 0.338 |
| 6 | 0.390 | 0.296 | 0.327 | 0.431 | 0.387 | **0.467** | 0.455 | 0.350 | 0.349 | 0.346 | 0.372 | 0.280 | 0.383 | 0.351 | 0.286 | 0.418 |
| 7 | 0.377 | 0.298 | 0.340 | 0.419 | 0.376 | 0.458 | **0.468** | 0.352 | 0.345 | 0.353 | 0.363 | 0.277 | 0.396 | 0.361 | 0.297 | 0.436 |
| 8 | 0.295 | 0.407 | 0.300 | 0.335 | 0.349 | 0.305 | 0.303 | **0.447** | 0.409 | 0.401 | 0.361 | 0.336 | 0.355 | 0.384 | 0.229 | 0.311 |
| 9 | 0.336 | 0.381 | 0.296 | 0.378 | 0.404 | 0.333 | 0.326 | 0.433 | **0.460** | 0.383 | 0.419 | 0.409 | 0.350 | 0.369 | 0.235 | 0.323 |
| 10 | 0.292 | 0.367 | 0.352 | 0.332 | 0.333 | 0.322 | 0.325 | 0.420 | 0.375 | **0.457** | 0.340 | 0.303 | 0.409 | 0.445 | 0.258 | 0.348 |
| 11 | 0.381 | 0.342 | 0.290 | 0.422 | 0.452 | 0.364 | 0.352 | 0.398 | 0.426 | 0.356 | **0.463** | 0.356 | 0.343 | 0.347 | 0.238 | 0.334 |
| 12 | 0.336 | 0.381 | 0.296 | 0.378 | 0.404 | 0.333 | 0.326 | 0.432 | 0.460 | 0.383 | 0.419 | **0.486** | 0.350 | 0.369 | 0.235 | 0.322 |
| 13 | 0.289 | 0.306 | 0.408 | 0.329 | 0.312 | 0.343 | 0.353 | 0.360 | 0.326 | 0.393 | 0.311 | 0.260 | **0.449** | 0.410 | 0.290 | 0.392 |
| 14 | 0.291 | 0.350 | 0.370 | 0.331 | 0.327 | 0.328 | 0.333 | 0.405 | 0.361 | 0.445 | 0.332 | 0.291 | 0.425 | **0.457** | 0.268 | 0.361 |
| 15 | 0.325 | 0.302 | 0.384 | 0.368 | 0.338 | 0.397 | 0.411 | 0.357 | 0.333 | 0.378 | 0.332 | 0.266 | 0.435 | 0.392 | **0.325** | 0.451 |
| 16 | 0.340 | 0.301 | 0.372 | 0.383 | 0.349 | 0.418 | 0.434 | 0.355 | 0.337 | 0.371 | 0.341 | 0.269 | 0.426 | 0.383 | 0.319 | **0.466** |

**Table 4** The performance analysis of the proposed RBFN on CILANVAR test system for various value of spread constant

| Type of Fault | Spread | $R^2$ | RMSE | SSE |
|---|---|---|---|---|
| LG | 0.3 | 0.9877 | 2.54E-03 | 9.17E-04 |
| | 0.4 | 0.9885 | 2.48E-03 | 8.71E-04 |
| | 0.6 | 0.9866 | 2.68E-03 | 1.02E-03 |
| | 1.0 | 0.9845 | 2.88E-03 | 1.17E-03 |
| LL | 5.0 | 0.9859 | 5.89E-03 | 4.92E-03 |
| | 7.0 | 0.9888 | 5.24E-03 | 3.90E-03 |
| | 9.0 | 0.9940 | 3.81E-03 | 2.06E-03 |
| | 11.0 | 0.9940 | 4.09E-03 | 2.38E-03 |
| LLG | 0.1 | 0.9994 | 1.57E-03 | 3.52E-04 |
| | 0.2 | 0.9999 | 5.24E-04 | 3.90E-05 |
| | 0.4 | 0.9999 | 5.91E-04 | 4.97E-05 |
| | 1.0 | 0.9998 | 8.75E-04 | 1.09E-04 |

The overall performances of proposed RBFN tested on CIVANLAR test system, could accurately predict the value of VD for three networks which are LG, LL and LLG. Thus the voltage sag source location could be exactly identified. Meanwhile for Permas Jaya distribution network, for LG network, the proposed RBFN could identify the exactly location of sag for 23 buses and the rest could be identified only their possible location of sag. For other network which is LL network, the proposed RBFN could identify exact location of sag for 26 buses and the rest could be identified only their possible location of sag. The last network which is LLG network, the proposed RBFN could identify exact location of sag for 27 buses and the rest could be identified only their possible location of sag. As a result, the accuracy of RBFN is depends on the training data in which the value of diagonal VD has obvious differences with off-diagonal value like the CIVANLAR test system and it do not happen at Permas Jaya distribution network.

## 4.0 CONCLUSION

This paper proposed RBFN to estimate voltage sag source location in distribution systems which tested on CIVANLAR test system and Permas Jaya distribution network. The highest VD was used to identify the location of voltage sag source. Based on the results showed that the proposed RBFN provided the more precise and accurate to identify the location of voltage sag source on CIVANLAR test system and less accurate on Permas Jaya distribution network.

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**Table 5** The simulated VD for LG with $R_f$ = 0.25 Ω of Permas Jaya distribution network

| Fault Bus / $B_j$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ | $B_{16}$ | $B_{17}$ | $B_{18}$ | $B_{19}$ | $B_{20}$ | $B_{21}$ | $B_{22}$ | $B_{23}$ | $B_{24}$ | $B_{25}$ | $B_{26}$ | $B_{27}$ | $B_{28}$ | $B_{29}$ | $B_{30}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **0.000** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **2** | 0.000 | **0.085** | 0.029 | 0.015 | 0.043 | 0.018 | 0.034 | 0.042 | 0.016 | 0.023 | 0.033 | 0.014 | 0.005 | 0.016 | 0.019 | 0.024 | 0.021 | 0.013 | 0.037 | 0.016 | 0.030 | 0.028 | 0.023 | 0.021 | 0.020 | 0.024 | 0.020 | 0.038 | 0.019 | 0.036 |
| **3** | 0.000 | 0.036 | **0.092** | 0.006 | 0.017 | 0.007 | 0.076 | 0.052 | 0.048 | 0.058 | 0.040 | 0.024 | 0.002 | 0.021 | 0.007 | 0.009 | 0.008 | 0.026 | 0.035 | 0.029 | 0.011 | 0.011 | 0.035 | 0.008 | 0.007 | 0.009 | 0.008 | 0.051 | 0.007 | 0.014 |
| **4** | 0.000 | 0.021 | 0.006 | **0.103** | 0.030 | 0.017 | 0.008 | 0.010 | 0.003 | 0.005 | 0.007 | 0.003 | 0.004 | 0.003 | 0.013 | 0.018 | 0.017 | 0.003 | 0.008 | 0.003 | 0.007 | 0.027 | 0.005 | 0.015 | 0.018 | 0.023 | 0.019 | 0.009 | 0.004 | 0.026 |
| **5** | 0.000 | 0.046 | 0.015 | 0.023 | **0.067** | 0.023 | 0.018 | 0.021 | 0.008 | 0.012 | 0.016 | 0.007 | 0.006 | 0.008 | 0.031 | 0.026 | 0.024 | 0.006 | 0.019 | 0.008 | 0.015 | 0.037 | 0.012 | 0.034 | 0.025 | 0.032 | 0.026 | 0.020 | 0.009 | 0.051 |
| **6** | 0.000 | 0.024 | 0.007 | 0.015 | 0.028 | **0.105** | 0.009 | 0.011 | 0.004 | 0.006 | 0.008 | 0.003 | 0.011 | 0.004 | 0.012 | 0.060 | 0.051 | 0.003 | 0.010 | 0.004 | 0.008 | 0.065 | 0.006 | 0.014 | 0.079 | 0.064 | 0.047 | 0.010 | 0.005 | 0.041 |
| **7** | 0.000 | 0.045 | 0.079 | 0.007 | 0.022 | 0.009 | **0.100** | 0.064 | 0.042 | 0.053 | 0.050 | 0.024 | 0.002 | 0.023 | 0.009 | 0.012 | 0.010 | 0.024 | 0.038 | 0.029 | 0.015 | 0.014 | 0.037 | 0.010 | 0.010 | 0.012 | 0.010 | 0.057 | 0.009 | 0.018 |
| **8** | 0.000 | 0.054 | 0.053 | 0.009 | 0.026 | 0.011 | 0.064 | **0.110** | 0.031 | 0.046 | 0.088 | 0.029 | 0.003 | 0.034 | 0.011 | 0.014 | 0.012 | 0.021 | 0.050 | 0.035 | 0.018 | 0.017 | 0.050 | 0.013 | 0.012 | 0.015 | 0.012 | 0.081 | 0.011 | 0.022 |
| **9** | 0.000 | 0.026 | 0.062 | 0.004 | 0.012 | 0.005 | 0.051 | 0.039 | **0.114** | 0.041 | 0.030 | 0.018 | 0.001 | 0.018 | 0.005 | 0.007 | 0.006 | 0.018 | 0.028 | 0.045 | 0.008 | 0.008 | 0.041 | 0.006 | 0.005 | 0.007 | 0.005 | 0.044 | 0.005 | 0.010 |
| **10** | 0.000 | 0.035 | 0.070 | 0.006 | 0.017 | 0.007 | 0.061 | 0.054 | 0.038 | **0.127** | 0.042 | 0.042 | 0.002 | 0.029 | 0.007 | 0.009 | 0.008 | 0.023 | 0.042 | 0.032 | 0.011 | 0.011 | 0.044 | 0.008 | 0.007 | 0.009 | 0.007 | 0.070 | 0.007 | 0.014 |
| **11** | 0.000 | 0.054 | 0.053 | 0.009 | 0.026 | 0.011 | 0.064 | 0.110 | 0.031 | 0.046 | **0.138** | 0.029 | 0.003 | 0.034 | 0.011 | 0.014 | 0.012 | 0.021 | 0.050 | 0.035 | 0.018 | 0.017 | 0.050 | 0.013 | 0.012 | 0.015 | 0.012 | 0.081 | 0.011 | 0.022 |
| **12** | 0.000 | 0.039 | 0.055 | 0.006 | 0.019 | 0.008 | 0.053 | 0.064 | 0.034 | 0.082 | 0.050 | **0.184** | 0.002 | 0.043 | 0.008 | 0.010 | 0.009 | 0.022 | 0.056 | 0.042 | 0.013 | 0.012 | 0.061 | 0.009 | 0.008 | 0.011 | 0.008 | 0.098 | 0.008 | 0.016 |
| **13** | 0.000 | 0.007 | 0.002 | 0.005 | 0.008 | 0.013 | 0.002 | 0.003 | 0.001 | 0.002 | 0.002 | 0.001 | **0.100** | 0.001 | 0.003 | 0.013 | 0.013 | 0.001 | 0.003 | 0.001 | 0.002 | 0.021 | 0.002 | 0.004 | 0.014 | 0.018 | 0.014 | 0.003 | 0.001 | 0.012 |
| **14** | 0.000 | 0.042 | 0.045 | 0.007 | 0.021 | 0.009 | 0.048 | 0.070 | 0.030 | 0.051 | 0.055 | 0.040 | 0.002 | **0.184** | 0.009 | 0.011 | 0.010 | 0.022 | 0.065 | 0.047 | 0.014 | 0.013 | 0.071 | 0.010 | 0.009 | 0.012 | 0.009 | 0.113 | 0.009 | 0.017 |
| **15** | 0.000 | 0.046 | 0.015 | 0.023 | 0.067 | 0.023 | 0.017 | 0.021 | 0.008 | 0.012 | 0.016 | 0.007 | 0.006 | 0.008 | **0.162** | 0.026 | 0.024 | 0.006 | 0.019 | 0.008 | 0.015 | 0.037 | 0.012 | 0.034 | 0.025 | 0.032 | 0.026 | 0.020 | 0.009 | 0.051 |
| **16** | 0.000 | 0.034 | 0.010 | 0.019 | 0.035 | 0.064 | 0.013 | 0.016 | 0.006 | 0.008 | 0.012 | 0.005 | 0.013 | 0.006 | 0.015 | **0.118** | 0.090 | 0.005 | 0.014 | 0.006 | 0.011 | 0.076 | 0.009 | 0.017 | 0.061 | 0.069 | 0.055 | 0.014 | 0.007 | 0.049 |
| **17** | 0.000 | 0.032 | 0.010 | 0.019 | 0.035 | 0.061 | 0.012 | 0.015 | 0.005 | 0.008 | 0.012 | 0.005 | 0.014 | 0.005 | 0.016 | 0.098 | **0.127** | 0.004 | 0.013 | 0.006 | 0.011 | 0.080 | 0.008 | 0.017 | 0.060 | 0.071 | 0.058 | 0.014 | 0.007 | 0.051 |
| **18** | 0.000 | 0.043 | 0.078 | 0.007 | 0.021 | 0.009 | 0.066 | 0.055 | 0.041 | 0.054 | 0.043 | 0.027 | 0.002 | 0.028 | 0.009 | 0.011 | 0.010 | **0.165** | 0.074 | 0.032 | 0.014 | 0.014 | 0.042 | 0.010 | 0.009 | 0.012 | 0.009 | 0.065 | 0.009 | 0.017 |
| **19** | 0.000 | 0.057 | 0.044 | 0.009 | 0.028 | 0.012 | 0.046 | 0.061 | 0.028 | 0.044 | 0.048 | 0.031 | 0.003 | 0.038 | 0.012 | 0.015 | 0.013 | 0.035 | **0.142** | 0.037 | 0.019 | 0.018 | 0.055 | 0.014 | 0.012 | 0.016 | 0.013 | 0.090 | 0.012 | 0.023 |
| **20** | 0.000 | 0.037 | 0.051 | 0.006 | 0.018 | 0.007 | 0.050 | 0.059 | 0.064 | 0.048 | 0.046 | 0.032 | 0.002 | 0.039 | 0.008 | 0.010 | 0.008 | 0.021 | 0.052 | **0.167** | 0.012 | 0.011 | 0.127 | 0.008 | 0.008 | 0.010 | 0.008 | 0.091 | 0.007 | 0.015 |
| **21** | 0.000 | 0.084 | 0.028 | 0.015 | 0.043 | 0.018 | 0.034 | 0.042 | 0.016 | 0.023 | 0.033 | 0.014 | 0.004 | 0.016 | 0.019 | 0.024 | 0.021 | 0.013 | 0.037 | 0.016 | **0.183** | 0.028 | 0.023 | 0.021 | 0.019 | 0.024 | 0.020 | 0.038 | 0.117 | 0.036 |
| **22** | 0.000 | 0.030 | 0.009 | 0.020 | 0.036 | 0.054 | 0.011 | 0.014 | 0.005 | 0.007 | 0.011 | 0.004 | 0.015 | 0.005 | 0.016 | 0.059 | 0.056 | 0.004 | 0.012 | 0.005 | 0.010 | **0.084** | 0.007 | 0.018 | 0.060 | 0.075 | 0.062 | 0.013 | 0.006 | 0.053 |
| **23** | 0.000 | 0.040 | 0.048 | 0.006 | 0.019 | 0.008 | 0.049 | 0.065 | 0.045 | 0.050 | 0.052 | 0.037 | 0.002 | 0.046 | 0.008 | 0.011 | 0.009 | 0.021 | 0.060 | 0.100 | 0.013 | 0.013 | **0.153** | 0.009 | 0.009 | 0.011 | 0.009 | 0.105 | 0.008 | 0.016 |
| **24** | 0.000 | 0.046 | 0.015 | 0.023 | 0.067 | 0.023 | 0.017 | 0.021 | 0.008 | 0.012 | 0.016 | 0.007 | 0.006 | 0.008 | 0.031 | 0.026 | 0.024 | 0.006 | 0.019 | 0.008 | 0.015 | 0.037 | 0.012 | **0.166** | 0.025 | 0.032 | 0.026 | 0.020 | 0.009 | 0.051 |
| **25** | 0.000 | 0.027 | 0.008 | 0.018 | 0.032 | 0.082 | 0.010 | 0.012 | 0.004 | 0.007 | 0.009 | 0.004 | 0.013 | 0.004 | 0.014 | 0.059 | 0.053 | 0.004 | 0.011 | 0.005 | 0.009 | 0.075 | 0.007 | 0.016 | **0.111** | 0.069 | 0.054 | 0.011 | 0.005 | 0.047 |
| **26** | 0.000 | 0.029 | 0.009 | 0.020 | 0.035 | 0.059 | 0.011 | 0.013 | 0.005 | 0.007 | 0.010 | 0.004 | 0.015 | 0.005 | 0.016 | 0.059 | 0.055 | 0.004 | 0.012 | 0.005 | 0.009 | 0.083 | 0.007 | 0.017 | 0.061 | **0.100** | 0.061 | 0.012 | 0.006 | 0.052 |
| **27** | 0.000 | 0.030 | 0.009 | 0.020 | 0.036 | 0.054 | 0.011 | 0.014 | 0.005 | 0.007 | 0.011 | 0.004 | 0.015 | 0.005 | 0.016 | 0.059 | 0.056 | 0.004 | 0.012 | 0.005 | 0.010 | 0.084 | 0.007 | 0.018 | 0.060 | 0.075 | **0.133** | 0.013 | 0.006 | 0.053 |
| **28** | 0.000 | 0.042 | 0.045 | 0.007 | 0.021 | 0.009 | 0.048 | 0.070 | 0.031 | 0.052 | 0.056 | 0.040 | 0.002 | 0.051 | 0.009 | 0.011 | 0.010 | 0.022 | 0.065 | 0.047 | 0.014 | 0.013 | 0.071 | 0.010 | 0.009 | 0.012 | 0.009 | **0.114** | 0.009 | 0.017 |
| **29** | 0.000 | 0.084 | 0.028 | 0.015 | 0.043 | 0.018 | 0.034 | 0.042 | 0.016 | 0.023 | 0.033 | 0.014 | 0.004 | 0.016 | 0.019 | 0.024 | 0.021 | 0.013 | 0.037 | 0.016 | 0.182 | 0.028 | 0.023 | 0.021 | 0.019 | 0.024 | 0.020 | 0.038 | **0.199** | 0.036 |
| **30** | 0.000 | 0.042 | 0.013 | 0.022 | 0.054 | 0.036 | 0.016 | 0.019 | 0.007 | 0.010 | 0.015 | 0.006 | 0.010 | 0.007 | 0.024 | 0.040 | 0.037 | 0.006 | 0.017 | 0.007 | 0.013 | 0.058 | 0.010 | 0.027 | 0.040 | 0.050 | 0.041 | 0.018 | 0.008 | **0.083** |

**Table 6** The simulated VD for LL with $R_f$ = 0.25 Ω of Permas Jaya distribution network

| Fault Bus / $B_j$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ | $B_{16}$ | $B_{17}$ | $B_{18}$ | $B_{19}$ | $B_{20}$ | $B_{21}$ | $B_{22}$ | $B_{23}$ | $B_{24}$ | $B_{25}$ | $B_{26}$ | $B_{27}$ | $B_{28}$ | $B_{29}$ | $B_{30}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **0.000** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **2** | 0.000 | **0.243** | 0.089 | 0.047 | 0.135 | 0.056 | 0.106 | 0.122 | 0.050 | 0.066 | 0.090 | 0.034 | 0.014 | 0.039 | 0.050 | 0.070 | 0.060 | 0.032 | 0.098 | 0.043 | 0.073 | 0.086 | 0.061 | 0.053 | 0.059 | 0.073 | 0.055 | 0.104 | 0.044 | 0.114 |
| **3** | 0.000 | 0.104 | **0.259** | 0.018 | 0.054 | 0.022 | 0.213 | 0.144 | 0.139 | 0.155 | 0.107 | 0.058 | 0.005 | 0.051 | 0.019 | 0.027 | 0.023 | 0.064 | 0.090 | 0.072 | 0.029 | 0.033 | 0.089 | 0.021 | 0.023 | 0.028 | 0.021 | 0.135 | 0.017 | 0.045 |
| **4** | 0.000 | 0.062 | 0.020 | **0.274** | 0.098 | 0.051 | 0.025 | 0.029 | 0.011 | 0.015 | 0.021 | 0.008 | 0.014 | 0.009 | 0.036 | 0.054 | 0.049 | 0.007 | 0.023 | 0.010 | 0.017 | 0.082 | 0.014 | 0.038 | 0.054 | 0.070 | 0.052 | 0.024 | 0.010 | 0.085 |
| **5** | 0.000 | 0.130 | 0.044 | 0.072 | **0.207** | 0.068 | 0.053 | 0.061 | 0.025 | 0.032 | 0.044 | 0.017 | 0.018 | 0.019 | 0.078 | 0.074 | 0.066 | 0.016 | 0.049 | 0.021 | 0.036 | 0.108 | 0.030 | 0.085 | 0.072 | 0.091 | 0.069 | 0.052 | 0.022 | 0.155 |
| **6** | 0.000 | 0.073 | 0.024 | 0.049 | 0.091 | **0.276** | 0.029 | 0.034 | 0.013 | 0.017 | 0.025 | 0.009 | 0.035 | 0.010 | 0.033 | 0.168 | 0.144 | 0.008 | 0.027 | 0.011 | 0.020 | 0.196 | 0.016 | 0.035 | 0.218 | 0.188 | 0.129 | 0.028 | 0.012 | 0.130 |
| **7** | 0.000 | 0.130 | 0.226 | 0.023 | 0.068 | 0.028 | **0.275** | 0.178 | 0.121 | 0.141 | 0.132 | 0.058 | 0.007 | 0.057 | 0.024 | 0.034 | 0.029 | 0.058 | 0.100 | 0.073 | 0.036 | 0.042 | 0.094 | 0.026 | 0.029 | 0.036 | 0.027 | 0.149 | 0.022 | 0.057 |
| **8** | 0.000 | 0.157 | 0.162 | 0.028 | 0.083 | 0.034 | 0.188 | **0.289** | 0.096 | 0.127 | 0.227 | 0.071 | 0.009 | 0.082 | 0.030 | 0.042 | 0.036 | 0.051 | 0.130 | 0.088 | 0.045 | 0.052 | 0.126 | 0.032 | 0.035 | 0.044 | 0.033 | 0.208 | 0.027 | 0.069 |
| **9** | 0.000 | 0.076 | 0.179 | 0.013 | 0.039 | 0.015 | 0.148 | 0.110 | **0.296** | 0.110 | 0.081 | 0.045 | 0.004 | 0.044 | 0.014 | 0.020 | 0.017 | 0.044 | 0.073 | 0.110 | 0.021 | 0.024 | 0.103 | 0.015 | 0.016 | 0.020 | 0.015 | 0.118 | 0.013 | 0.032 |
| **10** | 0.000 | 0.103 | 0.205 | 0.018 | 0.053 | 0.021 | 0.176 | 0.151 | 0.114 | **0.292** | 0.112 | 0.098 | 0.005 | 0.070 | 0.019 | 0.027 | 0.023 | 0.055 | 0.108 | 0.082 | 0.028 | 0.033 | 0.111 | 0.020 | 0.022 | 0.028 | 0.021 | 0.180 | 0.017 | 0.044 |
| **11** | 0.000 | 0.157 | 0.162 | 0.028 | 0.083 | 0.034 | 0.188 | 0.289 | 0.096 | 0.127 | **0.309** | 0.071 | 0.009 | 0.082 | 0.030 | 0.042 | 0.036 | 0.051 | 0.130 | 0.088 | 0.045 | 0.052 | 0.126 | 0.032 | 0.035 | 0.044 | 0.033 | 0.208 | 0.027 | 0.069 |
| **12** | 0.000 | 0.118 | 0.169 | 0.021 | 0.062 | 0.025 | 0.161 | 0.182 | 0.104 | 0.212 | 0.136 | **0.327** | 0.006 | 0.101 | 0.022 | 0.031 | 0.027 | 0.055 | 0.144 | 0.105 | 0.033 | 0.038 | 0.153 | 0.024 | 0.026 | 0.033 | 0.024 | 0.249 | 0.020 | 0.051 |
| **13** | 0.000 | 0.019 | 0.006 | 0.014 | 0.026 | 0.037 | 0.008 | 0.009 | 0.004 | 0.005 | 0.006 | 0.002 | **0.288** | 0.003 | 0.009 | 0.037 | 0.034 | 0.002 | 0.007 | 0.003 | 0.005 | 0.060 | 0.004 | 0.010 | 0.039 | 0.051 | 0.038 | 0.007 | 0.003 | 0.038 |
| **14** | 0.000 | 0.128 | 0.145 | 0.022 | 0.067 | 0.027 | 0.151 | 0.201 | 0.098 | 0.146 | 0.151 | 0.097 | 0.007 | **0.327** | 0.024 | 0.034 | 0.029 | 0.055 | 0.167 | 0.120 | 0.036 | 0.042 | 0.179 | 0.026 | 0.028 | 0.036 | 0.026 | 0.285 | 0.022 | 0.056 |
| **15** | 0.000 | 0.130 | 0.044 | 0.072 | 0.206 | 0.068 | 0.053 | 0.061 | 0.025 | 0.032 | 0.044 | 0.017 | 0.018 | 0.019 | **0.320** | 0.074 | 0.066 | 0.016 | 0.049 | 0.021 | 0.036 | 0.108 | 0.030 | 0.085 | 0.072 | 0.091 | 0.069 | 0.052 | 0.022 | 0.155 |
| **16** | 0.000 | 0.100 | 0.034 | 0.059 | 0.112 | 0.187 | 0.040 | 0.047 | 0.019 | 0.024 | 0.034 | 0.013 | 0.040 | 0.014 | 0.040 | **0.291** | 0.232 | 0.012 | 0.037 | 0.016 | 0.028 | 0.221 | 0.023 | 0.043 | 0.174 | 0.196 | 0.146 | 0.040 | 0.017 | 0.151 |
| **17** | 0.000 | 0.096 | 0.032 | 0.061 | 0.113 | 0.178 | 0.039 | 0.045 | 0.018 | 0.023 | 0.033 | 0.012 | 0.042 | 0.014 | 0.041 | 0.256 | **0.303** | 0.011 | 0.036 | 0.015 | 0.027 | 0.230 | 0.022 | 0.044 | 0.173 | 0.202 | 0.153 | 0.038 | 0.016 | 0.156 |
| **18** | 0.000 | 0.129 | 0.215 | 0.023 | 0.068 | 0.027 | 0.186 | 0.155 | 0.118 | 0.142 | 0.115 | 0.064 | 0.007 | 0.067 | 0.024 | 0.034 | 0.029 | **0.328** | 0.193 | 0.080 | 0.036 | 0.042 | 0.108 | 0.026 | 0.029 | 0.036 | 0.027 | 0.173 | 0.022 | 0.057 |
| **19** | 0.000 | 0.168 | 0.136 | 0.030 | 0.090 | 0.036 | 0.141 | 0.173 | 0.086 | 0.122 | 0.129 | 0.074 | 0.009 | 0.090 | 0.033 | 0.046 | 0.039 | 0.087 | **0.307** | 0.092 | 0.048 | 0.056 | 0.136 | 0.035 | 0.038 | 0.048 | 0.036 | 0.226 | 0.029 | 0.075 |
| **20** | 0.000 | 0.109 | 0.158 | 0.019 | 0.057 | 0.023 | 0.150 | 0.169 | 0.183 | 0.133 | 0.126 | 0.078 | 0.006 | 0.093 | 0.020 | 0.029 | 0.025 | 0.051 | 0.134 | **0.321** | 0.030 | 0.035 | 0.276 | 0.022 | 0.024 | 0.030 | 0.022 | 0.233 | 0.018 | 0.047 |
| **21** | 0.000 | 0.243 | 0.089 | 0.047 | 0.135 | 0.056 | 0.106 | 0.122 | 0.050 | 0.066 | 0.090 | 0.034 | 0.014 | 0.039 | 0.050 | 0.070 | 0.060 | 0.032 | 0.098 | 0.043 | **0.327** | 0.086 | 0.061 | 0.053 | 0.059 | 0.073 | 0.055 | 0.104 | 0.237 | 0.114 |
| **22** | 0.000 | 0.088 | 0.029 | 0.064 | 0.116 | 0.160 | 0.035 | 0.041 | 0.016 | 0.021 | 0.030 | 0.011 | 0.045 | 0.013 | 0.042 | 0.163 | 0.152 | 0.010 | 0.033 | 0.014 | 0.024 | **0.246** | 0.020 | 0.045 | 0.171 | 0.214 | 0.166 | 0.035 | 0.015 | 0.165 |
| **23** | 0.000 | 0.120 | 0.151 | 0.021 | 0.063 | 0.025 | 0.151 | 0.188 | 0.135 | 0.141 | 0.141 | 0.089 | 0.006 | 0.110 | 0.023 | 0.032 | 0.027 | 0.053 | 0.153 | 0.225 | 0.034 | 0.039 | **0.313** | 0.024 | 0.027 | 0.033 | 0.025 | 0.266 | 0.020 | 0.052 |
| **24** | 0.000 | 0.130 | 0.044 | 0.072 | 0.206 | 0.068 | 0.053 | 0.061 | 0.025 | 0.032 | 0.044 | 0.017 | 0.018 | 0.019 | 0.078 | 0.074 | 0.066 | 0.016 | 0.049 | 0.021 | 0.036 | 0.108 | 0.030 | **0.315** | 0.072 | 0.091 | 0.069 | 0.052 | 0.022 | 0.155 |
| **25** | 0.000 | 0.080 | 0.026 | 0.056 | 0.103 | 0.230 | 0.032 | 0.037 | 0.015 | 0.019 | 0.027 | 0.010 | 0.040 | 0.011 | 0.037 | 0.165 | 0.147 | 0.009 | 0.029 | 0.012 | 0.022 | 0.220 | 0.018 | 0.040 | **0.288** | 0.200 | 0.146 | 0.031 | 0.013 | 0.146 |
| **26** | 0.000 | 0.087 | 0.029 | 0.063 | 0.114 | 0.174 | 0.035 | 0.040 | 0.016 | 0.021 | 0.029 | 0.011 | 0.044 | 0.012 | 0.041 | 0.163 | 0.151 | 0.010 | 0.032 | 0.014 | 0.024 | 0.241 | 0.020 | 0.044 | 0.176 | **0.270** | 0.162 | 0.034 | 0.014 | 0.161 |
| **27** | 0.000 | 0.088 | 0.029 | 0.064 | 0.116 | 0.160 | 0.035 | 0.041 | 0.016 | 0.021 | 0.030 | 0.011 | 0.045 | 0.013 | 0.042 | 0.163 | 0.152 | 0.010 | 0.033 | 0.014 | 0.024 | 0.245 | 0.020 | 0.045 | 0.171 | 0.214 | **0.300** | 0.035 | 0.015 | 0.165 |
| **28** | 0.000 | 0.128 | 0.145 | 0.022 | 0.067 | 0.027 | 0.151 | 0.201 | 0.098 | 0.146 | 0.151 | 0.097 | 0.007 | 0.121 | 0.024 | 0.034 | 0.029 | 0.055 | 0.167 | 0.120 | 0.036 | 0.042 | 0.179 | 0.026 | 0.028 | 0.036 | 0.026 | **0.286** | 0.022 | 0.056 |
| **29** | 0.000 | 0.243 | 0.089 | 0.047 | 0.135 | 0.056 | 0.106 | 0.122 | 0.050 | 0.066 | 0.090 | 0.034 | 0.014 | 0.039 | 0.050 | 0.070 | 0.060 | 0.032 | 0.098 | 0.043 | 0.327 | 0.086 | 0.061 | 0.053 | 0.059 | 0.073 | 0.055 | 0.104 | **0.331** | 0.114 |
| **30** | 0.000 | 0.119 | 0.040 | 0.068 | 0.169 | 0.106 | 0.048 | 0.056 | 0.022 | 0.029 | 0.041 | 0.015 | 0.029 | 0.017 | 0.062 | 0.111 | 0.101 | 0.014 | 0.045 | 0.019 | 0.033 | 0.168 | 0.027 | 0.067 | 0.113 | 0.143 | 0.109 | 0.047 | 0.020 | **0.243** |

**Table 7** The simulated VD for LLG with $R_f$ = 0.25 Ω of Permas Jaya distribution network

| Fault Bus / $B_j$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ | $B_{16}$ | $B_{17}$ | $B_{18}$ | $B_{19}$ | $B_{20}$ | $B_{21}$ | $B_{22}$ | $B_{23}$ | $B_{24}$ | $B_{25}$ | $B_{26}$ | $B_{27}$ | $B_{28}$ | $B_{29}$ | $B_{30}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **0.333** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **2** | 0.291 | **0.409** | 0.166 | 0.085 | 0.301 | 0.100 | 0.181 | 0.193 | 0.079 | 0.107 | 0.131 | 0.044 | 0.024 | 0.051 | 0.068 | 0.113 | 0.091 | 0.041 | 0.147 | 0.058 | 0.096 | 0.167 | 0.089 | 0.077 | 0.096 | 0.130 | 0.085 | 0.169 | 0.055 | 0.222 |
| **3** | 0.315 | 0.199 | **0.425** | 0.033 | 0.128 | 0.039 | 0.355 | 0.227 | 0.215 | 0.253 | 0.156 | 0.076 | 0.009 | 0.067 | 0.026 | 0.044 | 0.035 | 0.083 | 0.135 | 0.100 | 0.037 | 0.067 | 0.130 | 0.030 | 0.038 | 0.051 | 0.033 | 0.221 | 0.021 | 0.090 |
| **4** | 0.326 | 0.124 | 0.040 | **0.438** | 0.232 | 0.089 | 0.044 | 0.047 | 0.018 | 0.025 | 0.031 | 0.010 | 0.022 | 0.012 | 0.049 | 0.087 | 0.075 | 0.009 | 0.035 | 0.013 | 0.022 | 0.160 | 0.020 | 0.055 | 0.089 | 0.123 | 0.082 | 0.041 | 0.013 | 0.168 |
| **5** | 0.317 | 0.245 | 0.083 | 0.129 | **0.399** | 0.117 | 0.090 | 0.096 | 0.039 | 0.053 | 0.065 | 0.022 | 0.029 | 0.025 | 0.108 | 0.117 | 0.099 | 0.020 | 0.073 | 0.029 | 0.047 | 0.203 | 0.044 | 0.122 | 0.114 | 0.157 | 0.106 | 0.084 | 0.027 | 0.291 |
| **6** | 0.312 | 0.146 | 0.047 | 0.089 | 0.212 | **0.437** | 0.052 | 0.055 | 0.022 | 0.029 | 0.037 | 0.012 | 0.056 | 0.014 | 0.045 | 0.273 | 0.220 | 0.011 | 0.041 | 0.016 | 0.026 | 0.364 | 0.024 | 0.051 | 0.356 | 0.328 | 0.202 | 0.048 | 0.015 | 0.250 |
| **7** | 0.309 | 0.249 | 0.392 | 0.042 | 0.161 | 0.050 | **0.434** | 0.282 | 0.188 | 0.229 | 0.195 | 0.076 | 0.012 | 0.075 | 0.034 | 0.056 | 0.045 | 0.076 | 0.149 | 0.100 | 0.047 | 0.085 | 0.137 | 0.038 | 0.048 | 0.065 | 0.042 | 0.242 | 0.027 | 0.114 |
| **8** | 0.290 | 0.297 | 0.294 | 0.052 | 0.195 | 0.061 | 0.317 | **0.442** | 0.149 | 0.206 | 0.346 | 0.093 | 0.014 | 0.108 | 0.041 | 0.069 | 0.055 | 0.066 | 0.194 | 0.121 | 0.058 | 0.104 | 0.184 | 0.046 | 0.059 | 0.079 | 0.052 | 0.338 | 0.033 | 0.139 |
| **9** | 0.321 | 0.149 | 0.323 | 0.024 | 0.095 | 0.028 | 0.248 | 0.175 | **0.454** | 0.179 | 0.118 | 0.059 | 0.007 | 0.058 | 0.019 | 0.032 | 0.026 | 0.057 | 0.109 | 0.153 | 0.027 | 0.049 | 0.150 | 0.021 | 0.028 | 0.038 | 0.024 | 0.194 | 0.015 | 0.066 |
| **10** | 0.309 | 0.199 | 0.363 | 0.033 | 0.127 | 0.039 | 0.296 | 0.238 | 0.176 | **0.453** | 0.163 | 0.129 | 0.009 | 0.092 | 0.026 | 0.044 | 0.035 | 0.072 | 0.160 | 0.112 | 0.037 | 0.067 | 0.162 | 0.029 | 0.037 | 0.051 | 0.033 | 0.293 | 0.021 | 0.090 |
| **11** | 0.290 | 0.297 | 0.294 | 0.052 | 0.195 | 0.061 | 0.317 | 0.440 | 0.149 | 0.206 | **0.471** | 0.093 | 0.014 | 0.108 | 0.041 | 0.069 | 0.055 | 0.066 | 0.194 | 0.121 | 0.058 | 0.104 | 0.184 | 0.046 | 0.059 | 0.079 | 0.052 | 0.338 | 0.033 | 0.139 |
| **12** | 0.289 | 0.229 | 0.307 | 0.038 | 0.148 | 0.045 | 0.272 | 0.288 | 0.163 | 0.341 | 0.200 | **0.520** | 0.011 | 0.134 | 0.031 | 0.051 | 0.041 | 0.072 | 0.215 | 0.146 | 0.043 | 0.078 | 0.225 | 0.034 | 0.044 | 0.060 | 0.038 | 0.400 | 0.025 | 0.105 |
| **13** | 0.332 | 0.039 | 0.012 | 0.025 | 0.061 | 0.063 | 0.014 | 0.015 | 0.006 | 0.008 | 0.010 | 0.003 | **0.449** | 0.004 | 0.012 | 0.059 | 0.051 | 0.003 | 0.011 | 0.004 | 0.007 | 0.114 | 0.006 | 0.014 | 0.063 | 0.087 | 0.058 | 0.013 | 0.004 | 0.073 |
| **14** | 0.274 | 0.248 | 0.267 | 0.042 | 0.161 | 0.049 | 0.257 | 0.318 | 0.154 | 0.237 | 0.222 | 0.129 | 0.012 | **0.519** | 0.033 | 0.056 | 0.045 | 0.072 | 0.250 | 0.167 | 0.047 | 0.085 | 0.264 | 0.037 | 0.048 | 0.065 | 0.042 | 0.434 | 0.027 | 0.114 |
| **15** | 0.317 | 0.245 | 0.083 | 0.129 | 0.397 | 0.117 | 0.090 | 0.096 | 0.039 | 0.053 | 0.065 | 0.022 | 0.029 | 0.025 | **0.498** | 0.117 | 0.099 | 0.020 | 0.073 | 0.029 | 0.047 | 0.203 | 0.044 | 0.122 | 0.114 | 0.157 | 0.106 | 0.084 | 0.027 | 0.291 |
| **16** | 0.305 | 0.196 | 0.065 | 0.105 | 0.251 | 0.322 | 0.071 | 0.076 | 0.030 | 0.041 | 0.050 | 0.016 | 0.063 | 0.019 | 0.055 | **0.449** | 0.362 | 0.015 | 0.056 | 0.022 | 0.036 | 0.392 | 0.033 | 0.062 | 0.284 | 0.336 | 0.228 | 0.066 | 0.021 | 0.286 |
| **17** | 0.304 | 0.189 | 0.062 | 0.108 | 0.254 | 0.308 | 0.068 | 0.073 | 0.029 | 0.039 | 0.048 | 0.016 | 0.066 | 0.018 | 0.056 | 0.413 | **0.462** | 0.015 | 0.054 | 0.021 | 0.034 | 0.401 | 0.032 | 0.063 | 0.281 | 0.346 | 0.239 | 0.063 | 0.020 | 0.293 |
| **18** | 0.304 | 0.250 | 0.374 | 0.042 | 0.161 | 0.050 | 0.309 | 0.245 | 0.182 | 0.230 | 0.168 | 0.084 | 0.012 | 0.088 | 0.034 | 0.056 | 0.045 | **0.525** | 0.293 | 0.110 | 0.047 | 0.085 | 0.157 | 0.038 | 0.048 | 0.065 | 0.042 | 0.281 | 0.027 | 0.114 |
| **19** | 0.284 | 0.319 | 0.250 | 0.056 | 0.211 | 0.066 | 0.239 | 0.272 | 0.134 | 0.196 | 0.188 | 0.097 | 0.016 | 0.119 | 0.045 | 0.075 | 0.060 | 0.114 | **0.469** | 0.127 | 0.063 | 0.113 | 0.198 | 0.050 | 0.064 | 0.086 | 0.056 | 0.361 | 0.036 | 0.151 |
| **20** | 0.295 | 0.213 | 0.289 | 0.035 | 0.137 | 0.042 | 0.254 | 0.268 | 0.288 | 0.216 | 0.185 | 0.103 | 0.010 | 0.124 | 0.028 | 0.047 | 0.038 | 0.066 | 0.199 | **0.499** | 0.040 | 0.072 | 0.424 | 0.031 | 0.040 | 0.055 | 0.035 | 0.378 | 0.023 | 0.097 |
| **21** | 0.291 | 0.408 | 0.166 | 0.085 | 0.302 | 0.100 | 0.181 | 0.193 | 0.079 | 0.107 | 0.131 | 0.044 | 0.024 | 0.051 | 0.068 | 0.113 | 0.091 | 0.041 | 0.147 | 0.058 | **0.521** | 0.167 | 0.089 | 0.077 | 0.096 | 0.130 | 0.085 | 0.169 | 0.326 | 0.222 |
| **22** | 0.302 | 0.173 | 0.057 | 0.115 | 0.261 | 0.276 | 0.062 | 0.066 | 0.026 | 0.035 | 0.044 | 0.014 | 0.072 | 0.017 | 0.058 | 0.261 | 0.230 | 0.013 | 0.049 | 0.019 | 0.031 | **0.413** | 0.029 | 0.065 | 0.276 | 0.365 | 0.260 | 0.058 | 0.018 | 0.310 |
| **23** | 0.283 | 0.234 | 0.276 | 0.039 | 0.151 | 0.046 | 0.256 | 0.298 | 0.211 | 0.228 | 0.207 | 0.118 | 0.011 | 0.146 | 0.031 | 0.053 | 0.042 | 0.069 | 0.229 | 0.326 | 0.044 | 0.079 | **0.479** | 0.035 | 0.045 | 0.061 | 0.039 | 0.420 | 0.025 | 0.107 |
| **24** | 0.317 | 0.245 | 0.083 | 0.129 | 0.397 | 0.117 | 0.090 | 0.096 | 0.039 | 0.053 | 0.065 | 0.022 | 0.029 | 0.025 | 0.108 | 0.117 | 0.099 | 0.020 | 0.073 | 0.029 | 0.047 | 0.203 | 0.044 | **0.491** | 0.114 | 0.157 | 0.106 | 0.084 | 0.027 | 0.291 |
| **25** | 0.309 | 0.157 | 0.051 | 0.101 | 0.233 | 0.389 | 0.056 | 0.060 | 0.024 | 0.032 | 0.040 | 0.013 | 0.063 | 0.015 | 0.051 | 0.267 | 0.224 | 0.012 | 0.044 | 0.017 | 0.028 | 0.392 | 0.026 | 0.057 | **0.446** | 0.345 | 0.228 | 0.052 | 0.016 | 0.277 |
| **26** | 0.304 | 0.170 | 0.056 | 0.112 | 0.255 | 0.301 | 0.061 | 0.065 | 0.026 | 0.035 | 0.043 | 0.014 | 0.071 | 0.016 | 0.056 | 0.262 | 0.229 | 0.013 | 0.048 | 0.019 | 0.031 | 0.411 | 0.029 | 0.063 | 0.286 | **0.430** | 0.254 | 0.057 | 0.018 | 0.304 |
| **27** | 0.302 | 0.173 | 0.057 | 0.115 | 0.261 | 0.276 | 0.062 | 0.066 | 0.026 | 0.035 | 0.044 | 0.014 | 0.072 | 0.017 | 0.058 | 0.261 | 0.230 | 0.013 | 0.049 | 0.019 | 0.031 | 0.411 | 0.029 | 0.065 | 0.276 | 0.366 | **0.461** | 0.058 | 0.018 | 0.310 |
| **28** | 0.274 | 0.248 | 0.267 | 0.042 | 0.161 | 0.049 | 0.256 | 0.318 | 0.154 | 0.237 | 0.222 | 0.129 | 0.012 | 0.162 | 0.033 | 0.056 | 0.045 | 0.072 | 0.250 | 0.167 | 0.047 | 0.085 | 0.264 | 0.037 | 0.048 | 0.065 | 0.042 | **0.435** | 0.027 | 0.114 |
| **29** | 0.291 | 0.407 | 0.166 | 0.085 | 0.302 | 0.100 | 0.181 | 0.193 | 0.079 | 0.107 | 0.131 | 0.044 | 0.024 | 0.051 | 0.068 | 0.113 | 0.091 | 0.041 | 0.147 | 0.058 | 0.521 | 0.167 | 0.089 | 0.077 | 0.096 | 0.130 | 0.085 | 0.169 | **0.546** | 0.222 |
| **30** | 0.310 | 0.229 | 0.076 | 0.121 | 0.357 | 0.182 | 0.083 | 0.089 | 0.036 | 0.048 | 0.060 | 0.020 | 0.046 | 0.023 | 0.086 | 0.176 | 0.152 | 0.018 | 0.067 | 0.026 | 0.043 | 0.311 | 0.040 | 0.097 | 0.180 | 0.247 | 0.168 | 0.078 | 0.025 | **0.415** |

**Table 8** The performance analysis of the proposed RBFN on Permas Jaya distribution network for various value of spread constant

| Type of Fault | Spread | $R^2$ | RMSE | SSE |
|---|---|---|---|---|
| LG | 60 | 0.8950 | 8.71E-03 | 3.86E-02 |
| | 65 | 0.8958 | 8.67E-03 | 3.82E-02 |
| | 70 | 0.8936 | 8.74E-03 | 3.88E-02 |
| | 80 | 0.8926 | 8.76E-03 | 3.90E-02 |
| LL | 60 | 0.9597 | 1.41E-02 | 1.01E-01 |
| | 65 | 0.9651 | 1.31E-02 | 8.65E-02 |
| | 70 | 0.9643 | 1.32E-02 | 8.85E-02 |
| | 80 | 0.9639 | 1.45E-02 | 8.87E-02 |
| LLG | 75 | 0.9944 | 9.16E-03 | 4.26E-02 |
| | 80 | 0.9946 | 8.90E-03 | 4.02E-02 |
| | 85 | 0.9941 | 9.27E-03 | 4.37E-02 |
| | 90 | 0.9942 | 9.23E-03 | 4.33E-02 |

**Table 9** The Predicted VD for LG with $R_f$ = 0.25 Ω of CILANVAR test system

| Fault Bus/$B_j$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ | $B_{16}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **0.165** | 0.091 | 0.086 | 0.150 | 0.124 | 0.120 | 0.115 | 0.099 | 0.104 | 0.091 | 0.117 | 0.088 | 0.097 | 0.090 | 0.100 | 0.104 |
| **2** | 0.075 | **0.162** | 0.088 | 0.087 | 0.092 | 0.086 | 0.083 | 0.140 | 0.116 | 0.110 | 0.106 | 0.092 | 0.094 | 0.108 | 0.089 | 0.082 |
| **3** | 0.089 | 0.091 | **0.171** | 0.084 | 0.085 | 0.097 | 0.097 | 0.100 | 0.089 | 0.112 | 0.086 | 0.074 | 0.148 | 0.119 | 0.119 | 0.108 |
| **4** | 0.159 | 0.103 | 0.101 | **0.163** | 0.144 | 0.142 | 0.134 | 0.116 | 0.120 | 0.106 | 0.136 | 0.099 | 0.114 | 0.106 | 0.117 | 0.120 |
| **5** | 0.148 | 0.117 | 0.103 | 0.156 | **0.163** | 0.133 | 0.127 | 0.129 | 0.137 | 0.114 | 0.155 | 0.116 | 0.115 | 0.112 | 0.115 | 0.117 |
| **6** | 0.145 | 0.106 | 0.116 | 0.154 | 0.133 | **0.164** | 0.156 | 0.117 | 0.116 | 0.114 | 0.126 | 0.097 | 0.129 | 0.116 | 0.137 | 0.143 |
| **7** | 0.140 | 0.105 | 0.123 | 0.149 | 0.129 | 0.160 | **0.165** | 0.117 | 0.115 | 0.117 | 0.123 | 0.094 | 0.136 | 0.121 | 0.145 | 0.151 |
| **8** | 0.106 | 0.150 | 0.107 | 0.115 | 0.118 | 0.104 | 0.103 | **0.159** | 0.140 | 0.135 | 0.122 | 0.117 | 0.120 | 0.129 | 0.108 | 0.105 |
| **9** | 0.123 | 0.140 | 0.107 | 0.131 | 0.138 | 0.116 | 0.112 | 0.152 | **0.162** | 0.129 | 0.143 | 0.143 | 0.120 | 0.125 | 0.112 | 0.110 |
| **10** | 0.103 | 0.134 | 0.129 | 0.109 | 0.110 | 0.111 | 0.112 | 0.145 | 0.126 | **0.159** | 0.114 | 0.105 | 0.138 | 0.155 | 0.131 | 0.120 |
| **11** | 0.141 | 0.123 | 0.104 | 0.149 | 0.158 | 0.128 | 0.122 | 0.136 | 0.145 | 0.119 | **0.164** | 0.123 | 0.117 | 0.116 | 0.114 | 0.115 |
| **12** | 0.126 | 0.140 | 0.105 | 0.132 | 0.138 | 0.116 | 0.113 | 0.150 | 0.162 | 0.129 | 0.141 | **0.170** | 0.120 | 0.124 | 0.112 | 0.111 |
| **13** | 0.105 | 0.108 | 0.151 | 0.113 | 0.105 | 0.118 | 0.121 | 0.120 | 0.108 | 0.133 | 0.103 | 0.088 | **0.161** | 0.141 | 0.144 | 0.135 |
| **14** | 0.105 | 0.124 | 0.135 | 0.117 | 0.110 | 0.113 | 0.115 | 0.138 | 0.121 | 0.156 | 0.110 | 0.098 | 0.153 | **0.163** | 0.127 | 0.121 |
| **15** | 0.119 | 0.107 | 0.141 | 0.128 | 0.114 | 0.137 | 0.142 | 0.119 | 0.110 | 0.127 | 0.111 | 0.091 | 0.154 | 0.133 | **0.164** | 0.156 |
| **16** | 0.126 | 0.106 | 0.135 | 0.135 | 0.119 | 0.145 | 0.151 | 0.119 | 0.112 | 0.124 | 0.114 | 0.091 | 0.150 | 0.130 | 0.158 | **0.164** |

**Table 10** The Predicted VD for LL with $R_f$ = 0.25 Ω of CILANVAR test system

| Fault Bus/$B_j$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ | $B_{16}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **0.322** | 0.181 | 0.173 | 0.308 | 0.268 | 0.248 | 0.237 | 0.215 | 0.232 | 0.201 | 0.247 | 0.182 | 0.214 | 0.204 | 0.298 | 0.217 |
| **2** | 0.168 | **0.319** | 0.178 | 0.199 | 0.213 | 0.202 | 0.194 | 0.297 | 0.238 | 0.254 | 0.226 | 0.204 | 0.218 | 0.239 | 0.266 | 0.200 |
| **3** | 0.175 | 0.183 | **0.316** | 0.196 | 0.188 | 0.224 | 0.228 | 0.214 | 0.203 | 0.236 | 0.193 | 0.155 | 0.303 | 0.259 | 0.351 | 0.247 |
| **4** | 0.302 | 0.209 | 0.202 | **0.324** | 0.293 | 0.280 | 0.269 | 0.247 | 0.255 | 0.230 | 0.281 | 0.209 | 0.240 | 0.229 | 0.341 | 0.248 |
| **5** | 0.281 | 0.234 | 0.206 | 0.308 | **0.325** | 0.264 | 0.256 | 0.273 | 0.289 | 0.246 | 0.315 | 0.239 | 0.244 | 0.242 | 0.336 | 0.241 |
| **6** | 0.276 | 0.211 | 0.234 | 0.304 | 0.273 | **0.326** | 0.318 | 0.249 | 0.248 | 0.247 | 0.262 | 0.202 | 0.274 | 0.251 | 0.405 | 0.294 |
| **7** | 0.267 | 0.213 | 0.244 | 0.295 | 0.266 | 0.319 | **0.326** | 0.251 | 0.245 | 0.252 | 0.257 | 0.200 | 0.283 | 0.257 | 0.422 | 0.305 |
| **8** | 0.211 | 0.291 | 0.216 | 0.239 | 0.248 | 0.219 | 0.217 | **0.323** | 0.288 | 0.286 | 0.256 | 0.239 | 0.254 | 0.275 | 0.320 | 0.223 |
| **9** | 0.241 | 0.272 | 0.213 | 0.270 | 0.286 | 0.239 | 0.234 | 0.309 | **0.325** | 0.273 | 0.296 | 0.283 | 0.251 | 0.264 | 0.327 | 0.231 |
| **10** | 0.210 | 0.263 | 0.252 | 0.238 | 0.238 | 0.225 | 0.229 | 0.301 | 0.268 | **0.323** | 0.237 | 0.218 | 0.291 | 0.317 | 0.360 | 0.248 |
| **11** | 0.272 | 0.245 | 0.208 | 0.300 | 0.317 | 0.258 | 0.250 | 0.284 | 0.300 | 0.254 | **0.325** | 0.252 | 0.246 | 0.248 | 0.333 | 0.239 |
| **12** | 0.243 | 0.274 | 0.214 | 0.270 | 0.287 | 0.238 | 0.233 | 0.307 | 0.324 | 0.274 | 0.294 | **0.327** | 0.250 | 0.263 | 0.325 | 0.233 |
| **13** | 0.207 | 0.218 | 0.292 | 0.235 | 0.222 | 0.245 | 0.251 | 0.257 | 0.231 | 0.279 | 0.221 | 0.188 | **0.324** | 0.290 | 0.412 | 0.277 |
| **14** | 0.208 | 0.251 | 0.266 | 0.237 | 0.234 | 0.234 | 0.239 | 0.291 | 0.253 | 0.316 | 0.238 | 0.210 | 0.302 | **0.322** | 0.381 | 0.255 |
| **15** | 0.232 | 0.216 | 0.275 | 0.261 | 0.240 | 0.280 | 0.288 | 0.254 | 0.237 | 0.269 | 0.236 | 0.193 | 0.311 | 0.278 | **0.463** | 0.315 |
| **16** | 0.243 | 0.215 | 0.267 | 0.271 | 0.248 | 0.292 | 0.299 | 0.253 | 0.238 | 0.265 | 0.243 | 0.195 | 0.304 | 0.272 | 0.456 | **0.325** |

**Table 11** The Predicted VD for LLG with $R_f$ = 0.25 Ω of CILANVAR test system

| Fault Bus/$B_j$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ | $B_{16}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **0.449** | 0.256 | 0.248 | 0.418 | 0.371 | 0.353 | 0.336 | 0.305 | 0.317 | 0.283 | 0.352 | 0.252 | 0.296 | 0.282 | 0.215 | 0.306 |
| **2** | 0.248 | **0.451** | 0.251 | 0.284 | 0.294 | 0.256 | 0.254 | 0.402 | 0.349 | 0.344 | 0.305 | 0.281 | 0.301 | 0.326 | 0.193 | 0.262 |
| **3** | 0.245 | 0.259 | **0.453** | 0.280 | 0.264 | 0.292 | 0.299 | 0.308 | 0.277 | 0.336 | 0.264 | 0.218 | 0.404 | 0.355 | 0.256 | 0.335 |
| **4** | 0.424 | 0.293 | 0.282 | **0.451** | 0.416 | 0.399 | 0.381 | 0.346 | 0.359 | 0.322 | 0.397 | 0.290 | 0.335 | 0.321 | 0.243 | 0.348 |
| **5** | 0.394 | 0.328 | 0.288 | 0.434 | **0.462** | 0.376 | 0.363 | 0.383 | 0.408 | 0.346 | 0.449 | 0.336 | 0.341 | 0.339 | 0.239 | 0.337 |
| **6** | 0.389 | 0.296 | 0.326 | 0.431 | 0.387 | **0.468** | 0.456 | 0.350 | 0.348 | 0.346 | 0.372 | 0.280 | 0.383 | 0.351 | 0.286 | 0.418 |
| **7** | 0.377 | 0.298 | 0.340 | 0.419 | 0.376 | 0.458 | **0.468** | 0.352 | 0.345 | 0.353 | 0.363 | 0.277 | 0.396 | 0.361 | 0.297 | 0.436 |
| **8** | 0.295 | 0.407 | 0.300 | 0.335 | 0.349 | 0.305 | 0.303 | **0.447** | 0.409 | 0.401 | 0.361 | 0.336 | 0.355 | 0.384 | 0.229 | 0.311 |
| **9** | 0.336 | 0.381 | 0.296 | 0.378 | 0.404 | 0.333 | 0.326 | 0.433 | **0.460** | 0.383 | 0.419 | 0.409 | 0.350 | 0.369 | 0.235 | 0.323 |
| **10** | 0.293 | 0.367 | 0.354 | 0.334 | 0.333 | 0.322 | 0.325 | 0.420 | 0.375 | **0.456** | 0.341 | 0.303 | 0.408 | 0.445 | 0.257 | 0.348 |
| **11** | 0.381 | 0.342 | 0.290 | 0.422 | 0.452 | 0.364 | 0.352 | 0.398 | 0.426 | 0.356 | **0.463** | 0.356 | 0.343 | 0.347 | 0.238 | 0.334 |
| **12** | 0.335 | 0.382 | 0.296 | 0.377 | 0.404 | 0.332 | 0.324 | 0.432 | 0.460 | 0.382 | 0.418 | **0.491** | 0.350 | 0.369 | 0.235 | 0.323 |
| **13** | 0.289 | 0.306 | 0.408 | 0.329 | 0.312 | 0.343 | 0.353 | 0.360 | 0.326 | 0.393 | 0.311 | 0.260 | **0.449** | 0.410 | 0.290 | 0.392 |
| **14** | 0.291 | 0.351 | 0.369 | 0.331 | 0.327 | 0.328 | 0.333 | 0.404 | 0.361 | 0.446 | 0.331 | 0.291 | 0.425 | **0.456** | 0.268 | 0.361 |
| **15** | 0.325 | 0.302 | 0.384 | 0.368 | 0.338 | 0.397 | 0.411 | 0.357 | 0.333 | 0.378 | 0.332 | 0.266 | 0.435 | 0.392 | **0.325** | 0.451 |
| **16** | 0.339 | 0.301 | 0.372 | 0.383 | 0.349 | 0.419 | 0.433 | 0.355 | 0.336 | 0.371 | 0.341 | 0.270 | 0.426 | 0.383 | 0.319 | **0.466** |

**Table 12** The Predicted VD for LG with $R_f$ = 0.25 Ω of Permas Jaya distribution network

| Fault Bus / $B_j$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ | $B_{16}$ | $B_{17}$ | $B_{18}$ | $B_{19}$ | $B_{20}$ | $B_{21}$ | $B_{22}$ | $B_{23}$ | $B_{24}$ | $B_{25}$ | $B_{26}$ | $B_{27}$ | $B_{28}$ | $B_{29}$ | $B_{30}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **2** | 0.000 | **0.085** | 0.029 | 0.015 | 0.043 | 0.018 | 0.034 | 0.042 | 0.016 | 0.023 | 0.033 | 0.014 | 0.005 | 0.016 | 0.019 | 0.024 | 0.021 | 0.013 | 0.037 | 0.016 | 0.030 | 0.028 | 0.023 | 0.021 | 0.020 | 0.024 | 0.020 | 0.038 | 0.019 | 0.036 |
| **3** | 0.000 | 0.039 | 0.073 | 0.007 | 0.021 | 0.009 | 0.071 | 0.052 | 0.051 | 0.061 | 0.035 | 0.024 | 0.001 | 0.021 | 0.009 | 0.006 | 0.008 | 0.038 | 0.041 | 0.027 | 0.012 | 0.011 | 0.038 | 0.007 | 0.006 | 0.012 | 0.008 | 0.049 | 0.006 | 0.017 |
| **4** | 0.015 | 0.019 | 0.007 | **0.048** | **0.078** | 0.021 | 0.012 | 0.008 | 0.004 | 0.009 | 0.005 | 0.004 | 0.014 | 0.007 | 0.015 | 0.016 | 0.017 | 0.003 | 0.008 | 0.002 | 0.008 | 0.030 | 0.007 | 0.014 | 0.020 | 0.026 | 0.021 | 0.007 | 0.001 | 0.055 |
| **5** | 0.000 | 0.046 | 0.015 | 0.023 | 0.067 | 0.023 | 0.018 | 0.021 | 0.008 | 0.012 | 0.016 | 0.007 | 0.006 | 0.008 | 0.031 | 0.026 | 0.024 | 0.006 | 0.019 | 0.008 | 0.015 | 0.037 | 0.012 | 0.034 | 0.025 | 0.032 | 0.026 | 0.020 | 0.009 | 0.051 |
| **6** | 0.001 | 0.020 | 0.013 | 0.021 | 0.037 | **0.085** | 0.003 | 0.005 | 0.009 | 0.021 | 0.005 | 0.001 | 0.014 | 0.011 | 0.017 | 0.075 | 0.057 | 0.005 | 0.015 | 0.005 | 0.012 | 0.096 | 0.022 | 0.009 | 0.071 | 0.079 | 0.061 | 0.019 | 0.001 | 0.049 |
| **7** | 0.002 | 0.054 | 0.068 | 0.010 | 0.027 | 0.012 | **0.089** | 0.067 | 0.046 | 0.054 | 0.045 | 0.022 | 0.002 | 0.024 | 0.011 | 0.007 | 0.010 | 0.041 | 0.043 | 0.032 | 0.012 | 0.015 | 0.043 | 0.012 | 0.008 | 0.017 | 0.010 | 0.053 | 0.008 | 0.021 |
| **8** | 0.001 | 0.057 | 0.046 | 0.009 | 0.026 | 0.011 | 0.063 | 0.103 | 0.034 | 0.052 | 0.074 | 0.036 | 0.004 | 0.036 | 0.012 | 0.015 | 0.013 | 0.023 | 0.055 | 0.030 | 0.016 | 0.016 | 0.054 | 0.010 | 0.013 | 0.016 | 0.012 | 0.081 | 0.008 | 0.024 |
| **9** | 0.000 | 0.028 | 0.068 | 0.005 | 0.015 | 0.003 | 0.054 | 0.042 | **0.102** | 0.038 | 0.030 | 0.018 | 0.001 | 0.019 | 0.009 | 0.007 | 0.006 | 0.025 | 0.026 | 0.054 | 0.014 | 0.005 | 0.039 | 0.005 | 0.006 | 0.007 | 0.005 | 0.046 | 0.003 | 0.013 |
| **10** | 0.001 | 0.030 | 0.076 | 0.006 | 0.018 | 0.007 | 0.059 | 0.056 | 0.039 | **0.117** | 0.042 | 0.053 | 0.001 | 0.033 | 0.008 | 0.007 | 0.008 | 0.025 | 0.041 | 0.037 | 0.013 | 0.009 | 0.043 | 0.007 | 0.006 | 0.010 | 0.006 | 0.073 | 0.008 | 0.017 |
| **11** | 0.000 | 0.064 | 0.046 | 0.008 | 0.023 | 0.010 | 0.067 | **0.121** | 0.035 | 0.053 | **0.089** | 0.039 | 0.005 | 0.041 | 0.011 | 0.016 | 0.012 | 0.022 | 0.058 | 0.028 | 0.015 | 0.015 | 0.054 | 0.011 | 0.013 | 0.016 | 0.010 | 0.085 | 0.008 | 0.025 |
| **12** | 0.000 | 0.039 | 0.055 | 0.006 | 0.019 | 0.008 | 0.053 | 0.064 | 0.034 | 0.082 | 0.050 | **0.184** | 0.002 | 0.043 | 0.008 | 0.010 | 0.009 | 0.022 | 0.056 | 0.042 | 0.013 | 0.012 | 0.061 | 0.009 | 0.008 | 0.011 | 0.008 | 0.098 | 0.008 | 0.016 |
| **13** | **0.036** | 0.006 | 0.001 | 0.018 | 0.008 | 0.022 | 0.006 | 0.005 | 0.004 | 0.006 | 0.010 | 0.002 | **0.041** | 0.005 | 0.002 | 0.011 | 0.005 | 0.001 | 0.001 | 0.005 | 0.001 | 0.026 | 0.008 | 0.012 | 0.034 | 0.033 | 0.008 | 0.007 | 0.002 | 0.012 |
| **14** | 0.012 | 0.043 | 0.039 | 0.007 | 0.014 | 0.007 | 0.056 | 0.078 | 0.030 | 0.069 | 0.079 | 0.051 | 0.010 | **0.107** | 0.006 | 0.013 | 0.008 | 0.016 | 0.076 | 0.046 | 0.011 | 0.013 | 0.111 | 0.015 | 0.009 | 0.010 | 0.006 | **0.155** | 0.010 | 0.012 |
| **15** | 0.000 | 0.046 | 0.015 | 0.023 | 0.067 | 0.023 | 0.017 | 0.021 | 0.008 | 0.012 | 0.016 | 0.007 | 0.006 | 0.008 | **0.162** | 0.026 | 0.024 | 0.006 | 0.019 | 0.008 | 0.015 | 0.037 | 0.012 | 0.034 | 0.025 | 0.032 | 0.026 | 0.020 | 0.009 | 0.051 |
| **16** | 0.000 | 0.033 | 0.009 | 0.017 | 0.033 | 0.063 | 0.012 | 0.016 | 0.004 | 0.007 | 0.014 | 0.007 | 0.014 | 0.005 | 0.015 | **0.111** | 0.094 | 0.003 | 0.012 | 0.007 | 0.015 | 0.074 | 0.008 | 0.016 | 0.059 | 0.066 | 0.054 | 0.014 | 0.009 | 0.050 |
| **17** | 0.000 | 0.032 | 0.010 | 0.019 | 0.035 | 0.061 | 0.012 | 0.015 | 0.005 | 0.008 | 0.012 | 0.005 | 0.014 | 0.005 | 0.016 | 0.098 | **0.127** | 0.004 | 0.013 | 0.006 | 0.011 | 0.080 | 0.008 | 0.017 | 0.060 | 0.071 | 0.058 | 0.014 | 0.007 | 0.051 |
| **18** | 0.000 | 0.043 | **0.078** | 0.007 | 0.021 | 0.009 | 0.066 | 0.055 | 0.041 | 0.054 | 0.043 | 0.027 | 0.002 | 0.028 | 0.009 | 0.011 | 0.010 | **0.165** | 0.074 | 0.032 | 0.014 | 0.014 | 0.042 | 0.010 | 0.009 | 0.012 | 0.009 | 0.065 | 0.009 | 0.017 |
| **19** | 0.001 | 0.055 | 0.070 | 0.007 | 0.021 | 0.010 | 0.051 | 0.061 | 0.022 | 0.040 | 0.057 | 0.036 | 0.004 | 0.040 | 0.008 | 0.020 | 0.013 | 0.026 | **0.130** | 0.042 | 0.016 | 0.020 | 0.049 | 0.016 | 0.015 | 0.013 | 0.012 | 0.095 | 0.014 | 0.017 |
| **20** | 0.000 | 0.037 | 0.051 | 0.006 | 0.018 | 0.007 | 0.050 | 0.059 | 0.064 | 0.048 | 0.046 | 0.032 | 0.002 | 0.039 | 0.008 | 0.010 | 0.008 | 0.021 | 0.052 | **0.167** | 0.012 | 0.011 | 0.127 | 0.008 | 0.008 | 0.010 | 0.008 | 0.091 | 0.007 | 0.015 |
| **21** | 0.000 | 0.084 | 0.028 | 0.015 | 0.043 | 0.018 | 0.034 | 0.042 | 0.016 | 0.023 | 0.033 | 0.014 | 0.004 | 0.016 | 0.019 | 0.024 | 0.021 | 0.013 | 0.037 | 0.016 | **0.183** | 0.028 | 0.023 | 0.021 | 0.019 | 0.024 | 0.020 | 0.038 | 0.117 | 0.036 |
| **22** | 0.000 | 0.030 | 0.009 | 0.020 | 0.036 | 0.054 | 0.011 | 0.014 | 0.005 | 0.007 | 0.011 | 0.004 | 0.015 | 0.005 | 0.016 | 0.059 | 0.056 | 0.004 | 0.012 | 0.005 | 0.010 | 0.084 | 0.007 | 0.018 | 0.060 | 0.075 | 0.062 | 0.013 | 0.006 | 0.053 |
| **23** | 0.000 | 0.040 | 0.048 | 0.006 | 0.019 | 0.008 | 0.049 | 0.065 | 0.045 | 0.050 | 0.052 | 0.037 | 0.002 | 0.046 | 0.008 | 0.011 | 0.009 | 0.021 | 0.060 | 0.100 | 0.013 | 0.013 | **0.153** | 0.009 | 0.009 | 0.011 | 0.009 | 0.105 | 0.008 | 0.016 |
| **24** | 0.000 | 0.046 | 0.015 | 0.023 | 0.067 | 0.023 | 0.017 | 0.021 | 0.008 | 0.012 | 0.016 | 0.007 | 0.006 | 0.008 | 0.031 | 0.026 | 0.024 | 0.006 | 0.019 | 0.008 | 0.015 | 0.037 | 0.012 | **0.166** | 0.025 | 0.032 | 0.026 | 0.020 | 0.009 | 0.051 |
| **25** | 0.002 | 0.023 | 0.012 | 0.021 | 0.037 | 0.084 | 0.000 | 0.009 | 0.007 | 0.017 | 0.001 | 0.000 | 0.018 | 0.008 | 0.016 | 0.070 | 0.055 | 0.005 | 0.015 | 0.003 | 0.011 | **0.104** | 0.017 | 0.000 | **0.078** | **0.090** | 0.064 | 0.018 | 0.002 | 0.054 |
| **26** | 0.003 | 0.030 | 0.009 | 0.020 | 0.035 | 0.059 | 0.010 | 0.014 | 0.005 | 0.006 | 0.011 | 0.004 | 0.016 | 0.004 | 0.016 | 0.059 | 0.055 | 0.003 | 0.012 | 0.005 | 0.010 | 0.094 | 0.006 | 0.018 | 0.068 | 0.085 | 0.060 | 0.013 | 0.006 | 0.053 |
| **27** | 0.000 | 0.030 | 0.009 | 0.020 | 0.036 | 0.054 | 0.011 | 0.014 | 0.005 | 0.007 | 0.011 | 0.004 | 0.015 | 0.005 | 0.016 | 0.059 | 0.056 | 0.004 | 0.012 | 0.005 | 0.010 | 0.084 | 0.007 | 0.018 | 0.060 | 0.075 | **0.133** | 0.013 | 0.006 | 0.053 |
| **28** | 0.000 | 0.044 | 0.045 | 0.006 | 0.019 | 0.008 | 0.049 | 0.069 | 0.031 | 0.053 | 0.055 | 0.042 | 0.002 | 0.047 | 0.007 | 0.012 | 0.010 | 0.021 | 0.066 | 0.048 | 0.013 | 0.014 | 0.076 | 0.010 | 0.009 | 0.011 | 0.008 | 0.111 | 0.009 | 0.016 |
| **29** | 0.000 | 0.084 | 0.028 | 0.015 | 0.043 | 0.018 | 0.034 | 0.042 | 0.016 | 0.023 | 0.033 | 0.014 | 0.004 | 0.016 | 0.019 | 0.024 | 0.021 | 0.013 | 0.037 | 0.016 | 0.182 | 0.028 | 0.023 | 0.021 | 0.019 | 0.024 | 0.020 | 0.038 | **0.199** | 0.036 |
| **30** | 0.002 | 0.042 | 0.012 | 0.025 | 0.054 | 0.035 | 0.016 | 0.020 | 0.007 | 0.009 | 0.016 | 0.006 | 0.010 | 0.007 | 0.024 | 0.039 | 0.037 | 0.005 | 0.016 | 0.008 | 0.014 | 0.060 | 0.009 | 0.028 | 0.040 | 0.052 | 0.042 | 0.018 | 0.009 | **0.074** |

**Table 13** The Predicted VD for LL with $R_f = 0.25\ \Omega$ of Permas Jaya distribution network

| Fault Bus / $B_j$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ | $B_{16}$ | $B_{17}$ | $B_{18}$ | $B_{19}$ | $B_{20}$ | $B_{21}$ | $B_{22}$ | $B_{23}$ | $B_{24}$ | $B_{25}$ | $B_{26}$ | $B_{27}$ | $B_{28}$ | $B_{29}$ | $B_{30}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **2** | 0.000 | **0.243** | 0.089 | 0.047 | 0.135 | 0.056 | 0.106 | 0.122 | 0.050 | 0.066 | 0.090 | 0.034 | 0.014 | 0.039 | 0.050 | 0.070 | 0.060 | 0.032 | 0.098 | 0.043 | 0.073 | 0.086 | 0.061 | 0.053 | 0.059 | 0.073 | 0.055 | 0.104 | 0.044 | 0.114 |
| **3** | 0.003 | 0.101 | **0.245** | 0.017 | 0.047 | 0.025 | 0.214 | 0.142 | 0.140 | 0.171 | 0.107 | 0.051 | 0.004 | 0.048 | 0.019 | 0.031 | 0.027 | 0.080 | 0.096 | 0.071 | 0.017 | 0.038 | 0.087 | 0.020 | 0.020 | 0.028 | 0.020 | 0.130 | 0.020 | 0.052 |
| **4** | 0.017 | 0.052 | 0.004 | **0.231** | 0.121 | 0.071 | 0.051 | 0.040 | 0.028 | 0.018 | 0.011 | 0.059 | 0.021 | 0.000 | 0.043 | 0.037 | 0.033 | 0.043 | 0.043 | 0.005 | 0.051 | 0.067 | 0.035 | 0.032 | 0.057 | 0.085 | 0.048 | 0.056 | 0.002 | 0.123 |
| **5** | 0.000 | 0.130 | 0.044 | 0.072 | **0.207** | 0.068 | 0.053 | 0.061 | 0.025 | 0.032 | 0.044 | 0.017 | 0.018 | 0.019 | 0.078 | 0.074 | 0.066 | 0.016 | 0.049 | 0.021 | 0.036 | 0.108 | 0.030 | 0.085 | 0.072 | 0.091 | 0.069 | 0.052 | 0.022 | 0.155 |
| **6** | 0.000 | 0.079 | 0.026 | 0.055 | 0.069 | **0.258** | 0.019 | 0.033 | 0.006 | 0.017 | 0.028 | 0.008 | 0.045 | 0.015 | 0.035 | 0.204 | 0.138 | 0.012 | 0.029 | 0.023 | 0.011 | 0.201 | 0.016 | 0.037 | 0.215 | 0.199 | 0.120 | 0.027 | 0.031 | 0.135 |
| **7** | 0.004 | 0.127 | 0.218 | 0.022 | 0.058 | 0.030 | **0.262** | 0.176 | 0.122 | 0.157 | 0.134 | 0.049 | 0.007 | 0.053 | 0.023 | 0.036 | 0.032 | 0.078 | 0.107 | 0.071 | 0.025 | 0.046 | 0.092 | 0.026 | 0.026 | 0.038 | 0.026 | 0.146 | 0.027 | 0.068 |
| **8** | 0.000 | 0.160 | 0.161 | 0.029 | 0.073 | 0.030 | 0.193 | 0.283 | 0.098 | 0.137 | 0.207 | 0.070 | 0.004 | 0.091 | 0.029 | 0.047 | 0.040 | 0.061 | 0.133 | 0.086 | 0.035 | 0.055 | 0.125 | 0.032 | 0.035 | 0.044 | 0.033 | 0.205 | 0.029 | 0.071 |
| **9** | 0.000 | 0.074 | 0.182 | 0.014 | 0.037 | 0.016 | 0.147 | 0.112 | **0.294** | 0.103 | 0.081 | 0.050 | 0.005 | 0.043 | 0.011 | 0.017 | 0.016 | 0.047 | 0.078 | 0.107 | 0.018 | 0.024 | 0.103 | 0.016 | 0.015 | 0.021 | 0.015 | 0.112 | 0.010 | 0.035 |
| **10** | 0.001 | 0.101 | 0.209 | 0.019 | 0.059 | 0.022 | 0.174 | 0.151 | 0.114 | **0.281** | 0.111 | 0.104 | 0.006 | 0.069 | 0.020 | 0.021 | 0.023 | 0.052 | 0.108 | 0.082 | 0.030 | 0.030 | 0.111 | 0.021 | 0.021 | 0.029 | 0.019 | 0.178 | 0.019 | 0.042 |
| **11** | 0.003 | 0.168 | 0.164 | 0.034 | 0.057 | 0.023 | 0.203 | **0.311** | 0.099 | 0.136 | **0.241** | 0.071 | 0.002 | 0.105 | 0.027 | 0.047 | 0.040 | 0.064 | 0.135 | 0.083 | 0.027 | 0.051 | 0.125 | 0.033 | 0.034 | 0.043 | 0.033 | 0.207 | 0.032 | 0.068 |
| **12** | 0.000 | 0.118 | 0.169 | 0.021 | 0.062 | 0.025 | 0.161 | 0.182 | 0.104 | 0.212 | 0.136 | **0.327** | 0.006 | 0.101 | 0.022 | 0.031 | 0.027 | 0.055 | 0.144 | 0.105 | 0.033 | 0.038 | 0.153 | 0.024 | 0.026 | 0.033 | 0.024 | 0.249 | 0.020 | 0.051 |
| **13** | **0.070** | 0.006 | 0.011 | 0.028 | 0.049 | 0.023 | 0.005 | 0.027 | 0.009 | 0.003 | 0.015 | 0.009 | **0.158** | 0.026 | 0.019 | 0.023 | 0.045 | 0.019 | 0.015 | 0.034 | 0.021 | 0.042 | 0.008 | 0.002 | 0.105 | 0.106 | 0.028 | 0.019 | 0.009 | 0.018 |
| **14** | 0.002 | 0.118 | 0.121 | 0.011 | 0.092 | 0.033 | 0.140 | 0.193 | 0.093 | 0.169 | 0.197 | 0.074 | 0.014 | **0.292** | 0.023 | 0.046 | 0.028 | 0.039 | 0.166 | 0.114 | 0.045 | 0.035 | 0.184 | 0.024 | 0.036 | 0.032 | 0.026 | **0.311** | 0.000 | 0.045 |
| **15** | 0.000 | 0.130 | 0.044 | 0.072 | 0.206 | 0.068 | 0.053 | 0.061 | 0.025 | 0.032 | 0.044 | 0.017 | 0.018 | 0.019 | **0.320** | 0.074 | 0.066 | 0.016 | 0.049 | 0.021 | 0.036 | 0.108 | 0.030 | 0.085 | 0.072 | 0.091 | 0.069 | 0.052 | 0.022 | 0.155 |
| **16** | 0.001 | 0.099 | 0.032 | 0.059 | 0.116 | 0.189 | 0.043 | 0.048 | 0.020 | 0.025 | 0.034 | 0.013 | 0.040 | 0.013 | 0.041 | **0.282** | 0.234 | 0.011 | 0.037 | 0.013 | 0.035 | 0.221 | 0.023 | 0.044 | 0.175 | 0.194 | 0.147 | 0.040 | 0.012 | 0.152 |
| **17** | 0.000 | 0.096 | 0.032 | 0.061 | 0.113 | 0.178 | 0.039 | 0.045 | 0.018 | 0.023 | 0.033 | 0.012 | 0.042 | 0.014 | 0.041 | 0.256 | **0.303** | 0.011 | 0.036 | 0.015 | 0.027 | 0.230 | 0.022 | 0.044 | 0.173 | 0.202 | 0.153 | 0.038 | 0.016 | 0.156 |
| **18** | 0.000 | 0.129 | 0.215 | 0.023 | 0.068 | 0.027 | 0.186 | 0.155 | 0.118 | 0.142 | 0.115 | 0.064 | 0.007 | 0.067 | 0.024 | 0.034 | 0.029 | **0.328** | 0.193 | 0.080 | 0.036 | 0.042 | 0.108 | 0.026 | 0.029 | 0.036 | 0.027 | 0.173 | 0.022 | 0.057 |
| **19** | 0.003 | 0.169 | 0.150 | 0.034 | 0.096 | 0.035 | 0.143 | 0.174 | 0.084 | 0.107 | 0.129 | 0.080 | 0.012 | 0.094 | 0.032 | 0.041 | 0.035 | 0.072 | **0.294** | 0.092 | 0.060 | 0.052 | 0.139 | 0.035 | 0.042 | 0.048 | 0.037 | 0.230 | 0.028 | 0.070 |
| **20** | 0.000 | 0.109 | 0.158 | 0.019 | 0.057 | 0.023 | 0.150 | 0.169 | 0.183 | 0.133 | 0.126 | 0.078 | 0.006 | 0.093 | 0.020 | 0.029 | 0.025 | 0.051 | 0.134 | **0.321** | 0.030 | 0.035 | 0.276 | 0.022 | 0.024 | 0.030 | 0.022 | 0.233 | 0.018 | 0.047 |
| **21** | 0.000 | 0.243 | 0.089 | 0.047 | 0.135 | 0.056 | 0.106 | 0.122 | 0.050 | 0.066 | 0.090 | 0.034 | 0.014 | 0.039 | 0.050 | 0.070 | 0.060 | 0.032 | 0.098 | 0.043 | **0.327** | 0.086 | 0.061 | 0.053 | 0.059 | 0.073 | 0.055 | 0.104 | 0.237 | 0.114 |
| **22** | 0.000 | 0.088 | 0.029 | 0.064 | 0.116 | 0.160 | 0.035 | 0.041 | 0.016 | 0.021 | 0.030 | 0.011 | 0.045 | 0.013 | 0.042 | 0.163 | 0.152 | 0.010 | 0.033 | 0.014 | 0.024 | 0.246 | 0.020 | 0.045 | 0.171 | 0.214 | 0.166 | 0.035 | 0.015 | 0.165 |
| **23** | 0.000 | 0.120 | 0.151 | 0.021 | 0.063 | 0.025 | 0.151 | 0.188 | 0.135 | 0.141 | 0.141 | 0.089 | 0.006 | 0.110 | 0.023 | 0.032 | 0.027 | 0.053 | 0.153 | 0.225 | 0.034 | 0.039 | **0.313** | 0.024 | 0.027 | 0.033 | 0.025 | 0.266 | 0.020 | 0.052 |
| **24** | 0.000 | 0.130 | 0.044 | 0.072 | 0.206 | 0.068 | 0.053 | 0.061 | 0.025 | 0.032 | 0.044 | 0.017 | 0.018 | 0.019 | 0.078 | 0.074 | 0.066 | 0.016 | 0.049 | 0.021 | 0.036 | 0.108 | 0.030 | **0.315** | 0.072 | 0.091 | 0.069 | 0.052 | 0.022 | 0.155 |
| **25** | 0.009 | 0.080 | 0.027 | 0.058 | 0.085 | 0.246 | 0.019 | 0.032 | 0.003 | 0.018 | 0.033 | 0.007 | 0.057 | 0.015 | 0.036 | 0.188 | 0.145 | 0.005 | 0.031 | 0.026 | 0.011 | 0.222 | 0.018 | 0.040 | **0.227** | 0.227 | 0.130 | 0.028 | 0.035 | 0.148 |
| **26** | 0.005 | 0.084 | 0.028 | 0.062 | 0.116 | 0.169 | 0.033 | 0.042 | 0.016 | 0.018 | 0.031 | 0.008 | 0.051 | 0.012 | 0.041 | 0.161 | 0.153 | 0.009 | 0.034 | 0.014 | 0.022 | **0.264** | 0.019 | 0.042 | 0.188 | **0.237** | 0.158 | 0.037 | 0.018 | 0.165 |
| **27** | 0.000 | 0.088 | 0.029 | 0.064 | 0.116 | 0.160 | 0.035 | 0.041 | 0.016 | 0.021 | 0.030 | 0.011 | 0.045 | 0.013 | 0.042 | 0.163 | 0.152 | 0.010 | 0.033 | 0.014 | 0.024 | 0.245 | 0.020 | 0.045 | 0.171 | 0.214 | **0.300** | 0.035 | 0.015 | 0.165 |
| **28** | 0.000 | 0.128 | 0.144 | 0.022 | 0.067 | 0.026 | 0.152 | 0.202 | 0.098 | 0.149 | 0.152 | 0.094 | 0.005 | 0.121 | 0.024 | 0.035 | 0.029 | 0.055 | 0.166 | 0.120 | 0.036 | 0.043 | 0.178 | 0.025 | 0.029 | 0.035 | 0.027 | 0.285 | 0.021 | 0.056 |
| **29** | 0.000 | 0.243 | 0.089 | 0.047 | 0.135 | 0.056 | 0.106 | 0.122 | 0.050 | 0.066 | 0.090 | 0.034 | 0.014 | 0.039 | 0.050 | 0.070 | 0.060 | 0.032 | 0.098 | 0.043 | 0.327 | 0.086 | 0.061 | 0.053 | 0.059 | 0.073 | 0.055 | 0.104 | **0.331** | 0.114 |
| **30** | 0.004 | 0.120 | 0.043 | 0.071 | 0.167 | 0.107 | 0.047 | 0.057 | 0.022 | 0.031 | 0.040 | 0.011 | 0.030 | 0.017 | 0.060 | 0.114 | 0.102 | 0.011 | 0.042 | 0.018 | 0.031 | 0.172 | 0.025 | 0.068 | 0.114 | 0.142 | 0.111 | 0.046 | 0.020 | **0.225** |

**Table 14** The Predicted VD for LLG with $R_f$ = 0.25 Ω of Permas Jaya distribution network

| Fault Bus / $B_j$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{14}$ | $B_{15}$ | $B_{16}$ | $B_{17}$ | $B_{18}$ | $B_{19}$ | $B_{20}$ | $B_{21}$ | $B_{22}$ | $B_{23}$ | $B_{24}$ | $B_{25}$ | $B_{26}$ | $B_{27}$ | $B_{28}$ | $B_{29}$ | $B_{30}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **0.333** | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.002 |
| **2** | 0.291 | **0.409** | 0.166 | 0.085 | 0.301 | 0.100 | 0.181 | 0.193 | 0.079 | 0.107 | 0.131 | 0.044 | 0.024 | 0.051 | 0.068 | 0.113 | 0.091 | 0.041 | 0.147 | 0.058 | 0.096 | 0.167 | 0.089 | 0.077 | 0.096 | 0.130 | 0.085 | 0.169 | 0.055 | 0.222 |
| **3** | 0.317 | 0.202 | **0.431** | 0.033 | 0.133 | 0.045 | 0.349 | 0.224 | 0.213 | 0.249 | 0.154 | 0.073 | 0.009 | 0.069 | 0.027 | 0.039 | 0.037 | 0.083 | 0.132 | 0.099 | 0.041 | 0.073 | 0.124 | 0.026 | 0.034 | 0.046 | 0.034 | 0.227 | 0.021 | 0.094 |
| **4** | 0.324 | 0.126 | 0.036 | **0.453** | 0.223 | 0.086 | 0.051 | 0.051 | 0.023 | 0.021 | 0.030 | 0.015 | 0.026 | 0.012 | 0.041 | 0.090 | 0.068 | 0.010 | 0.035 | 0.013 | 0.016 | 0.146 | 0.014 | 0.055 | 0.087 | 0.133 | 0.081 | 0.037 | 0.014 | 0.198 |
| **5** | 0.317 | 0.245 | 0.083 | 0.129 | **0.399** | 0.117 | 0.090 | 0.096 | 0.039 | 0.053 | 0.065 | 0.022 | 0.029 | 0.025 | 0.108 | 0.117 | 0.099 | 0.020 | 0.073 | 0.029 | 0.047 | 0.203 | 0.044 | 0.122 | 0.114 | 0.157 | 0.106 | 0.084 | 0.027 | 0.291 |
| **6** | 0.310 | 0.119 | 0.044 | 0.086 | 0.206 | 0.417 | 0.054 | 0.050 | 0.018 | 0.022 | 0.037 | 0.014 | 0.055 | 0.013 | 0.042 | 0.269 | 0.208 | 0.008 | 0.033 | 0.010 | 0.044 | 0.367 | 0.017 | 0.065 | 0.365 | 0.351 | 0.204 | 0.047 | 0.014 | 0.244 |
| **7** | 0.311 | 0.260 | 0.410 | 0.042 | 0.171 | 0.057 | **0.432** | 0.280 | 0.188 | 0.229 | 0.193 | 0.074 | 0.012 | 0.079 | 0.039 | 0.050 | 0.050 | 0.069 | 0.147 | 0.105 | 0.046 | 0.094 | 0.133 | 0.030 | 0.042 | 0.056 | 0.045 | 0.253 | 0.028 | 0.120 |
| **8** | 0.293 | 0.315 | 0.293 | 0.049 | 0.213 | 0.063 | 0.321 | 0.462 | 0.149 | 0.211 | 0.343 | 0.085 | 0.015 | 0.111 | 0.042 | 0.067 | 0.059 | 0.066 | 0.198 | 0.119 | 0.066 | 0.105 | 0.188 | 0.034 | 0.055 | 0.075 | 0.054 | 0.337 | 0.034 | 0.151 |
| **9** | 0.321 | 0.153 | 0.341 | 0.023 | 0.087 | 0.032 | 0.242 | 0.166 | **0.463** | 0.174 | 0.120 | 0.057 | 0.005 | 0.064 | 0.021 | 0.030 | 0.030 | 0.062 | 0.104 | 0.156 | 0.023 | 0.050 | 0.135 | 0.021 | 0.023 | 0.033 | 0.022 | 0.214 | 0.015 | 0.067 |
| **10** | 0.309 | 0.202 | 0.373 | 0.033 | 0.119 | 0.040 | 0.289 | 0.233 | 0.178 | **0.451** | 0.165 | 0.127 | 0.008 | 0.095 | 0.028 | 0.044 | 0.038 | 0.082 | 0.157 | 0.118 | 0.031 | 0.068 | 0.150 | 0.030 | 0.037 | 0.047 | 0.032 | 0.307 | 0.021 | 0.089 |
| **11** | 0.297 | 0.331 | 0.294 | 0.044 | 0.228 | 0.069 | 0.329 | **0.483** | 0.152 | 0.220 | **0.473** | 0.087 | 0.023 | 0.114 | 0.042 | 0.070 | 0.060 | 0.061 | 0.209 | 0.124 | 0.079 | 0.109 | 0.195 | 0.030 | 0.052 | 0.076 | 0.059 | 0.334 | 0.032 | 0.164 |
| **12** | 0.289 | 0.229 | 0.307 | 0.038 | 0.148 | 0.045 | 0.272 | 0.288 | 0.163 | 0.341 | 0.200 | **0.520** | 0.011 | 0.134 | 0.031 | 0.051 | 0.041 | 0.072 | 0.215 | 0.146 | 0.043 | 0.078 | 0.225 | 0.034 | 0.044 | 0.060 | 0.038 | 0.400 | 0.025 | 0.105 |
| **13** | 0.327 | 0.049 | 0.024 | 0.031 | 0.054 | 0.058 | 0.002 | 0.002 | 0.001 | 0.004 | 0.017 | 0.004 | **0.462** | 0.019 | 0.011 | 0.066 | 0.054 | 0.012 | 0.005 | 0.026 | 0.000 | 0.098 | 0.010 | 0.006 | 0.091 | 0.083 | 0.051 | 0.045 | 0.001 | 0.057 |
| **14** | 0.279 | 0.204 | 0.238 | 0.043 | 0.177 | 0.043 | 0.261 | 0.324 | 0.156 | 0.248 | 0.223 | 0.130 | 0.013 | **0.513** | 0.037 | 0.045 | 0.030 | 0.047 | 0.258 | 0.141 | 0.043 | 0.097 | 0.293 | 0.050 | 0.054 | 0.075 | 0.044 | 0.390 | 0.028 | 0.109 |
| **15** | 0.317 | 0.245 | 0.083 | 0.129 | 0.397 | 0.117 | 0.090 | 0.096 | 0.039 | 0.053 | 0.065 | 0.022 | 0.029 | 0.025 | **0.498** | 0.117 | 0.099 | 0.020 | 0.073 | 0.029 | 0.047 | 0.203 | 0.044 | 0.122 | 0.114 | 0.157 | 0.106 | 0.084 | 0.027 | 0.291 |
| **16** | 0.306 | 0.191 | 0.066 | 0.105 | 0.243 | 0.320 | 0.070 | 0.078 | 0.030 | 0.043 | 0.051 | 0.017 | 0.063 | 0.019 | 0.058 | **0.448** | 0.364 | 0.015 | 0.060 | 0.024 | 0.036 | 0.396 | 0.037 | 0.063 | 0.281 | 0.335 | 0.232 | 0.064 | 0.021 | 0.282 |
| **17** | 0.304 | 0.189 | 0.062 | 0.108 | 0.254 | 0.308 | 0.068 | 0.073 | 0.029 | 0.039 | 0.048 | 0.016 | 0.066 | 0.018 | 0.056 | 0.413 | **0.462** | 0.015 | 0.054 | 0.021 | 0.034 | 0.401 | 0.032 | 0.063 | 0.281 | 0.346 | 0.239 | 0.063 | 0.020 | 0.293 |
| **18** | 0.304 | 0.250 | 0.374 | 0.042 | 0.161 | 0.050 | 0.309 | 0.245 | 0.182 | 0.230 | 0.168 | 0.084 | 0.012 | 0.088 | 0.034 | 0.056 | 0.045 | **0.525** | 0.293 | 0.110 | 0.047 | 0.085 | 0.157 | 0.038 | 0.048 | 0.065 | 0.042 | 0.281 | 0.027 | 0.114 |
| **19** | 0.280 | 0.323 | 0.249 | 0.056 | 0.200 | 0.059 | 0.243 | 0.273 | 0.137 | 0.199 | 0.190 | 0.100 | 0.015 | 0.119 | 0.048 | 0.082 | 0.059 | 0.111 | **0.479** | 0.133 | 0.052 | 0.107 | 0.201 | 0.053 | 0.069 | 0.091 | 0.055 | 0.360 | 0.035 | 0.145 |
| **20** | 0.295 | 0.213 | 0.289 | 0.035 | 0.137 | 0.042 | 0.254 | 0.268 | 0.288 | 0.216 | 0.185 | 0.103 | 0.010 | 0.124 | 0.028 | 0.047 | 0.038 | 0.066 | 0.199 | **0.499** | 0.040 | 0.072 | 0.424 | 0.031 | 0.040 | 0.055 | 0.035 | 0.378 | 0.023 | 0.097 |
| **21** | 0.291 | 0.408 | 0.166 | 0.085 | 0.302 | 0.100 | 0.181 | 0.193 | 0.079 | 0.107 | 0.131 | 0.044 | 0.024 | 0.051 | 0.068 | 0.113 | 0.091 | 0.041 | 0.147 | 0.058 | **0.521** | 0.167 | 0.089 | 0.077 | 0.096 | 0.130 | 0.085 | 0.169 | 0.326 | 0.222 |
| **22** | 0.302 | 0.173 | 0.057 | 0.115 | 0.261 | 0.276 | 0.062 | 0.066 | 0.026 | 0.035 | 0.044 | 0.014 | 0.072 | 0.017 | 0.058 | 0.261 | 0.230 | 0.013 | 0.049 | 0.019 | 0.031 | 0.413 | 0.029 | 0.065 | 0.276 | 0.365 | 0.260 | 0.058 | 0.018 | 0.310 |
| **23** | 0.283 | 0.234 | 0.276 | 0.039 | 0.151 | 0.046 | 0.256 | 0.298 | 0.211 | 0.228 | 0.207 | 0.118 | 0.011 | 0.146 | 0.031 | 0.053 | 0.042 | 0.069 | 0.229 | 0.326 | 0.044 | 0.079 | **0.479** | 0.035 | 0.045 | 0.061 | 0.039 | 0.420 | 0.025 | 0.107 |
| **24** | 0.317 | 0.245 | 0.083 | 0.129 | 0.397 | 0.117 | 0.090 | 0.096 | 0.039 | 0.053 | 0.065 | 0.022 | 0.029 | 0.025 | 0.108 | 0.117 | 0.099 | 0.020 | 0.073 | 0.029 | 0.047 | 0.203 | 0.044 | **0.491** | 0.114 | 0.157 | 0.106 | 0.084 | 0.027 | 0.291 |
| **25** | 0.308 | 0.186 | 0.046 | 0.101 | 0.241 | **0.431** | 0.061 | 0.063 | 0.034 | 0.028 | 0.037 | 0.017 | 0.064 | 0.008 | 0.052 | 0.270 | 0.226 | 0.017 | 0.042 | 0.003 | 0.037 | **0.415** | 0.031 | 0.059 | **0.393** | 0.355 | 0.237 | 0.037 | 0.016 | 0.274 |
| **26** | 0.304 | 0.142 | 0.060 | 0.111 | 0.247 | 0.282 | 0.058 | 0.067 | 0.021 | 0.038 | 0.045 | 0.014 | 0.067 | 0.017 | 0.062 | 0.254 | 0.224 | 0.010 | 0.051 | 0.025 | 0.033 | 0.405 | 0.032 | 0.068 | 0.307 | **0.436** | 0.252 | 0.061 | 0.017 | 0.302 |
| **27** | 0.302 | 0.173 | 0.057 | 0.115 | 0.261 | 0.276 | 0.062 | 0.066 | 0.026 | 0.035 | 0.044 | 0.014 | 0.072 | 0.017 | 0.058 | 0.261 | 0.230 | 0.013 | 0.049 | 0.019 | 0.031 | 0.411 | 0.029 | 0.065 | 0.276 | 0.366 | **0.461** | 0.058 | 0.018 | 0.310 |
| **28** | 0.274 | 0.245 | 0.263 | 0.041 | 0.165 | 0.048 | 0.258 | 0.321 | 0.154 | 0.239 | 0.222 | 0.129 | 0.013 | 0.159 | 0.034 | 0.056 | 0.043 | 0.067 | 0.252 | 0.165 | 0.047 | 0.085 | 0.270 | 0.037 | 0.049 | 0.067 | 0.042 | **0.429** | 0.027 | 0.114 |
| **29** | 0.291 | 0.407 | 0.166 | 0.085 | 0.302 | 0.100 | 0.181 | 0.193 | 0.079 | 0.107 | 0.131 | 0.044 | 0.024 | 0.051 | 0.068 | 0.113 | 0.091 | 0.041 | 0.147 | 0.058 | 0.521 | 0.167 | 0.089 | 0.077 | 0.096 | 0.130 | 0.085 | 0.169 | **0.546** | 0.222 |
| **30** | 0.310 | 0.220 | 0.076 | 0.121 | 0.350 | 0.183 | 0.084 | 0.089 | 0.036 | 0.049 | 0.061 | 0.021 | 0.046 | 0.022 | 0.089 | 0.173 | 0.153 | 0.019 | 0.069 | 0.026 | 0.046 | 0.316 | 0.042 | 0.102 | 0.179 | 0.246 | 0.171 | 0.076 | 0.025 | **0.411** |

# Appendix

## Appendix A

### A1. Cable Data

See Table A1

**Table A1** Cable data for Permas Jaya distribution network

| From | To | Size ($mm^2$) | Length (km) | No. of Cable | From | To | Size ($mm^2$) | Length (km) | No. of Cable |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 500 | 9.5 | 2 | 6 | 16 | 185 | 2.4 | 1 |
| 1 | 4 | 500 | 8.0 | 2 | 6 | 25 | 240 | 1.0 | 1 |
| 1 | 5 | 500 | 5.0 | 2 | 6 | 26 | 185 | 2.2 | 1 |
| 1 | 6 | 500 | 12.0 | 2 | 7 | 8 | 500 | 3.3 | 1 |
| 1 | 9 | 500 | 7.0 | 1 | 8 | 11 | 240 | 0.8 | 1 |
| 1 | 10 | 240 | 10.7 | 1 | 8 | 28 | 500 | 5.0 | 2 |
| 1 | 13 | 500 | 6.1 | 2 | 9 | 20 | 240 | 6.7 | 1 |
| 2 | 7 | 400 | 6.2 | 1 | 10 | 12 | 240 | 9.9 | 1 |
| 2 | 8 | 500 | 5.0 | 1 | 10 | 28 | 240 | 3.9 | 1 |
| 2 | 16 | 240 | 9.0 | 1 | 12 | 28 | 240 | 6.5 | 1 |
| 2 | 19 | 240 | 4.0 | 1 | 13 | 22 | 400 | 9.5 | 1 |
| 2 | 30 | 240 | 7.0 | 1 | 14 | 28 | 240 | 7.1 | 2 |
| 2 | 21 | 240 | 4.4 | 1 | 16 | 17 | 240 | 2.2 | 2 |
| 3 | 7 | 500 | 1.0 | 1 | 16 | 22 | 500 | 3.6 | 1 |
| 3 | 9 | 400 | 3.0 | 1 | 17 | 22 | 500 | 3.9 | 1 |
| 3 | 10 | 240 | 1.7 | 1 | 18 | 19 | 185 | 9.6 | 1 |
| 3 | 18 | 240 | 8.0 | 1 | 19 | 28 | 400 | 3.2 | 1 |
| 4 | 5 | 240 | 3.0 | 1 | 20 | 23 | 240 | 2.3 | 1 |
| 4 | 22 | 240 | 7.3 | 1 | 21 | 29 | 240 | 3.9 | 1 |
| 5 | 15 | 240 | 2.8 | 1 | 22 | 26 | 400 | 1.0 | 2 |
| 5 | 24 | 185 | 1.9 | 2 | 22 | 27 | 240 | 1.0 | 1 |
| 5 | 30 | 500 | 1.1 | 1 | 22 | 25 | 500 | 2.1 | 1 |
| 5 | 31 | 500 | 3.0 | 1 | 23 | 28 | 240 | 1.7 | 1 |

### A2. Load Data

See Table A2

**Table A2** Load data for Permas Jaya distribution network

| Bus | $P_{Load}$ (MW) | $Q_{Load}$ (MVar) | Bus | $P_{Load}$ (MW) | $Q_{Load}$ (MVar) |
|---|---|---|---|---|---|
| 4 | 3.35 | 2.08 | 17 | 3.00 | 1.86 |
| 5 | 3.40 | 2.11 | 18 | 2.55 | 1.58 |
| 6 | 3.40 | 2.11 | 19 | 2.55 | 1.58 |
| 7 | 2.00 | 1.24 | 20 | 0.85 | 0.53 |
| 8 | 1.70 | 1.05 | 21 | 1.76 | 1.09 |
| 9 | 2.00 | 1.24 | 23 | 2.55 | 1.58 |
| 10 | 3.76 | 2.33 | 24 | 2.55 | 1.58 |
| 11 | 1.50 | 0.93 | 25 | 2.55 | 1.58 |
| 12 | 1.26 | 0.78 | 26 | 2.55 | 1.58 |
| 13 | 1.46 | 0.90 | 27 | 1.26 | 0.78 |
| 14 | 1.46 | 0.90 | 29 | 0.85 | 0.53 |
| 15 | 2.76 | 1.71 | 30 | 3.19 | 1.98 |
| 16 | 4.16 | 2.58 | | | |

## A3. Line Data

See Table A3

**Table A3** Line data (p.u) for Permas Jaya distribution network

| From | To | $R_{1,2}$ (pu) | $X_{1,2}$ (pu) | $B_{1,2}$ (pu) | $R_0$ (pu) | $X_0$ (pu) | From | To | $R_{1,2}$ (pu) | $X_{1,2}$ (pu) | $B_{1,2}$ (pu) | $R_0$ (pu) | $X_0$ (pu) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 0.6305 | 0.7616 | 0.0022 | 2.5517 | 0.3062 | 6 | 16 | 0.4185 | 0.2221 | 0.0004 | 0.8489 | 0.1004 |
| 1 | 4 | 0.5309 | 0.6413 | 0.0019 | 2.1488 | 0.2579 | 6 | 25 | 0.1331 | 0.0884 | 0.0002 | 0.3215 | 0.0390 |
| 1 | 5 | 0.3318 | 0.4008 | 0.0012 | 1.3430 | 0.1612 | 6 | 26 | 0.3836 | 0.2036 | 0.0003 | 0.7782 | 0.0920 |
| 1 | 6 | 0.7964 | 0.9620 | 0.0028 | 3.2231 | 0.3868 | 7 | 8 | 0.2190 | 0.2645 | 0.0008 | 0.8864 | 0.1064 |
| 1 | 9 | 0.4645 | 0.5612 | 0.0016 | 1.8802 | 0.2256 | 8 | 11 | 0.1064 | 0.0707 | 0.0001 | 0.2572 | 0.0312 |
| 1 | 10 | 1.4237 | 0.9462 | 0.0018 | 3.4399 | 0.4174 | 8 | 28 | 0.3318 | 0.4008 | 0.0012 | 1.3430 | 0.1612 |
| 1 | 13 | 0.4048 | 0.4890 | 0.0014 | 1.6384 | 0.1966 | 9 | 20 | 0.8915 | 0.5925 | 0.0011 | 2.1540 | 0.2614 |
| 2 | 7 | 0.5226 | 0.5175 | 0.0013 | 1.7524 | 0.2142 | 10 | 12 | 1.3173 | 0.8755 | 0.0017 | 3.1827 | 0.3862 |
| 2 | 8 | 0.3318 | 0.4008 | 0.0012 | 1.3430 | 0.1612 | 10 | 28 | 0.5189 | 0.3449 | 0.0007 | 1.2538 | 0.1521 |
| 2 | 16 | 1.1975 | 0.7959 | 0.0015 | 2.8934 | 0.3511 | 12 | 28 | 0.8649 | 0.5748 | 0.0011 | 2.0897 | 0.2536 |
| 2 | 19 | 0.5322 | 0.3537 | 0.0007 | 1.2860 | 0.1560 | 13 | 22 | 0.8008 | 0.7930 | 0.0020 | 2.6851 | 0.3282 |
| 2 | 30 | 0.9314 | 0.6190 | 0.0012 | 2.2504 | 0.2731 | 14 | 28 | 0.9447 | 0.6279 | 0.0012 | 2.2826 | 0.2770 |
| 2 | 21 | 0.5855 | 0.3891 | 0.0007 | 1.4145 | 0.1716 | 16 | 17 | 0.2927 | 0.1945 | 0.0004 | 0.7073 | 0.0858 |
| 3 | 7 | 0.0664 | 0.0802 | 0.0002 | 0.2686 | 0.0322 | 16 | 22 | 0.2389 | 0.2886 | 0.0008 | 0.9669 | 0.1160 |
| 3 | 9 | 0.2529 | 0.2504 | 0.0006 | 0.8479 | 0.1036 | 17 | 22 | 0.2588 | 0.3126 | 0.0009 | 1.0475 | 0.1257 |
| 3 | 10 | 0.2262 | 0.1503 | 0.0003 | 0.5465 | 0.0663 | 18 | 19 | 1.6740 | 0.8886 | 0.0015 | 3.3957 | 0.4015 |
| 3 | 18 | 1.0645 | 0.7074 | 0.0014 | 2.5719 | 0.3121 | 19 | 28 | 0.2698 | 0.2671 | 0.0007 | 0.9045 | 0.1105 |
| 4 | 5 | 0.3992 | 0.2653 | 0.0005 | 0.9645 | 0.1170 | 20 | 23 | 0.3060 | 0.2034 | 0.0004 | 0.7394 | 0.0897 |
| 4 | 22 | 0.9713 | 0.6455 | 0.0012 | 2.3469 | 0.2848 | 21 | 29 | 0.5189 | 0.3449 | 0.0007 | 1.2538 | 0.1521 |
| 5 | 15 | 0.3726 | 0.2476 | 0.0005 | 0.9002 | 0.1092 | 22 | 26 | 0.0843 | 0.0835 | 0.0002 | 0.2826 | 0.0345 |
| 5 | 24 | 0.3313 | 0.1759 | 0.0003 | 0.6721 | 0.0795 | 22 | 27 | 0.1331 | 0.0884 | 0.0002 | 0.3215 | 0.0390 |
| 5 | 30 | 0.0730 | 0.0882 | 0.0003 | 0.2955 | 0.0355 | 22 | 25 | 0.1394 | 0.1683 | 0.0005 | 0.5640 | 0.0677 |
| 5 | 31 | 0.1991 | 0.2405 | 0.0007 | 0.8058 | 0.0967 | 23 | 28 | 0.2262 | 0.1503 | 0.0003 | 0.5465 | 0.0663 |