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Voltage Stability Indices based on PMU

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Abstract- Present-day power networks all over the world need to transfer bulk amount of power. This has resulted in vast interconnection of grids for assuring reliability, security, stability and economic operation. The challenges to ensure smooth system operation with stressed grid and averting system blackout provided the stimulus for research on voltage security. Voltage stability indices aid the security studies. Real-time voltage security assessment is based on synchronized phasor measurement obtained from phasor measurement units (PMUs).

Energy demand at the load centers around the globe has been increasing rapidly. Thishas pushed the operating point close to stability limits and thereby increased in voltage security issues and frequency of corresponding outages

Key terms- Voltage security assessment, Phasor measurement unit, Decision tree, Fuzzy decision tree, Voltage stability indices

Introduction- In recent years the thrust for electric power demand has grown exponentially. This has resulted in vast interconnection of formerly separated grids for assuring capacity expansion, reliability and security. In the present scenario grids operating with stressed operating point due to elevated load demand has resulted in noteworthy voltage limit deviations with respect to the imposed constraints due to which the issue of voltage collapse is looming prominently. The urgency for ensuring secure system operation has heightened the need for voltage security assessment. Due to emergence of fleet of sophisticated devices more and more data become available for the system study. Tactful utilization of data available for analysis and assessment of voltage security issues is fueled by machine learning, which has provided an evolutionary breakthrough in developing efficient and reliable tool for fast, accurate decision making under critical conditions with voltage stability indices acting as a vital tool in estimating system security status i.e. proximity to voltage collapse or signifying the stress of current operating point on power network.

Implementation Methodology

To perform the security assessment of power system under random load perturbations of adopted test system considered with in loading range: 50%-200%. The disturbance independent parameters i.e. bus voltage; bus angles, reactive power generation of generators, total real and reactive power generation of system etc. are considered to generate the database and thereby employed as security predictors when FDT scheme has been introduced.

For implementation, load flow analysis for the non-linear system has been performed. The complete step by step procedure for the voltage security assessment for the considered test-system employing FDT and VSI is shown in figure 1.1 Loads are represented in terms of constant power model, considered in the code (Appendix-B). System parameters for the test system are obtained. Voltage stability indices are used to determine the objective parameter representing proximity to voltage collapse or degree of stress of each disturbance on the network. Database split into two subsets, namely training set and testing set. Using MATLAB programming environment, the codes for fuzzy decision tree have been developed.

Once the FDT is being developed then implemented on IEEE 30-bus system on MATLAB 2014a programming environment for security status prediction and voltage security assessment has been obtained. Best voltage stability index has been determined based on computational efficiency, and performance of fuzzy decision tree. For the selected VSI security predictors are determined based on accuracy of fuzzy rule based decision tree.

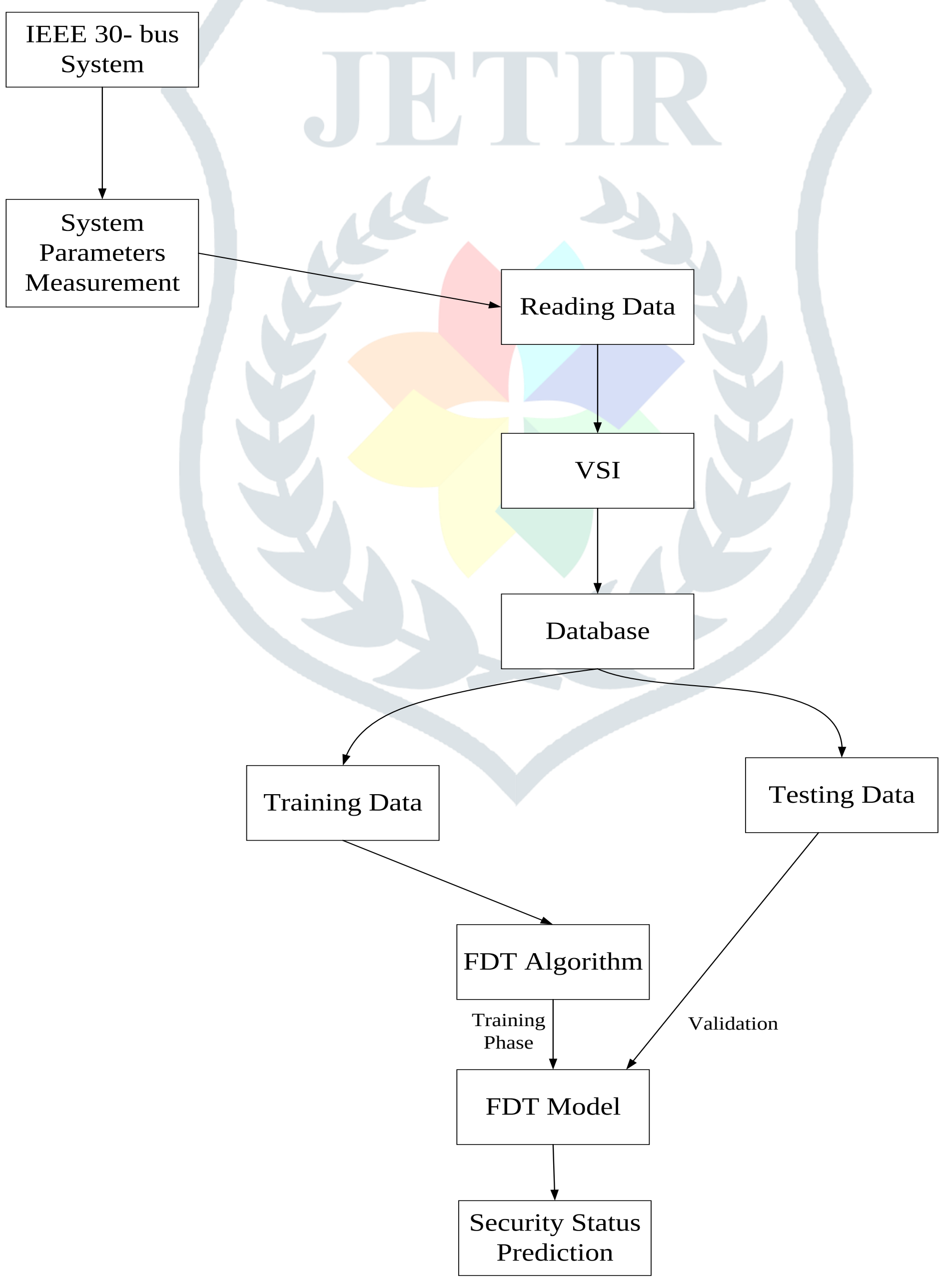


Figure 1.1 Fuzzy Decision Tree Scheme for Voltage Security Assessment

DATABASE GENERATION

For database generation, the bus data and line data for IEEE 30-bus system (Appendix-A) have been employed. Databases have been generated by storing synchrophasor data for different system parameters corresponding to different operating conditions, representing load perturbations. Different set of attributes are considered for building database and testing the performance of developed FDT.

System variables such as bus voltages, bus angles, real power generation, reactive power generation, real power loss, reactive power loss, total generation apparent power and total demand apparent power are employed for database generation. After this training and test set are obtained by randomly selecting the instances (Appendix-B).

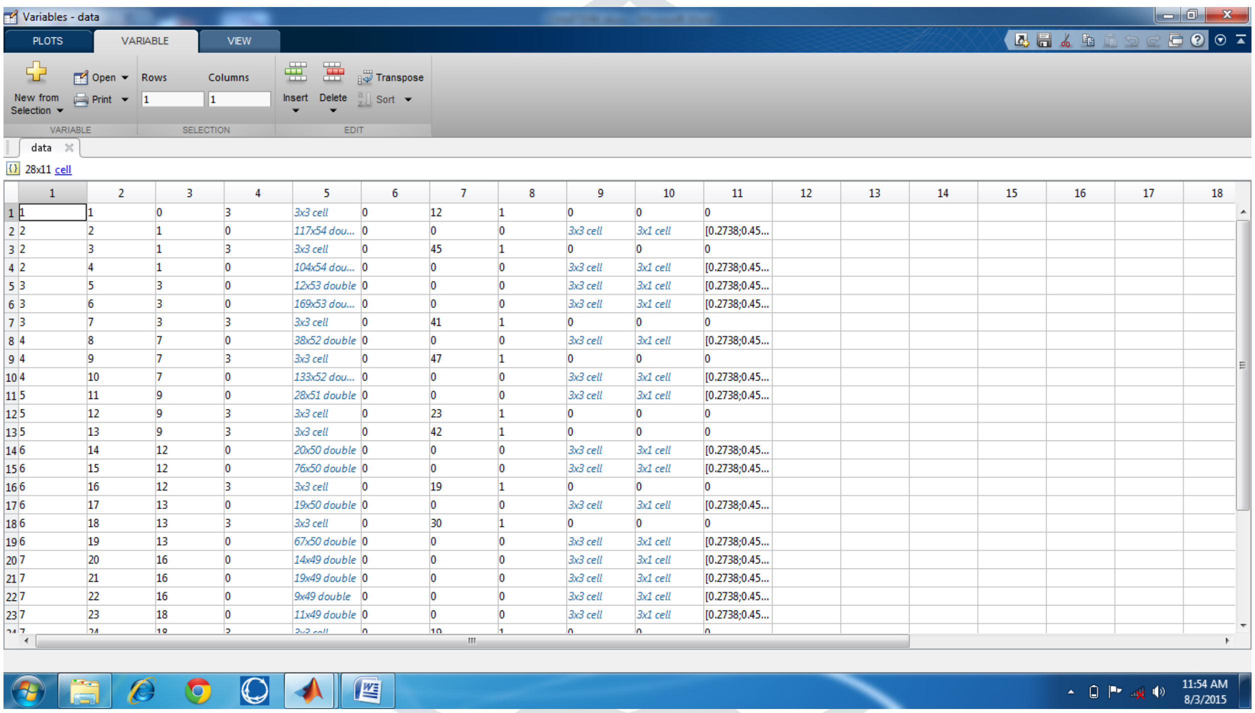
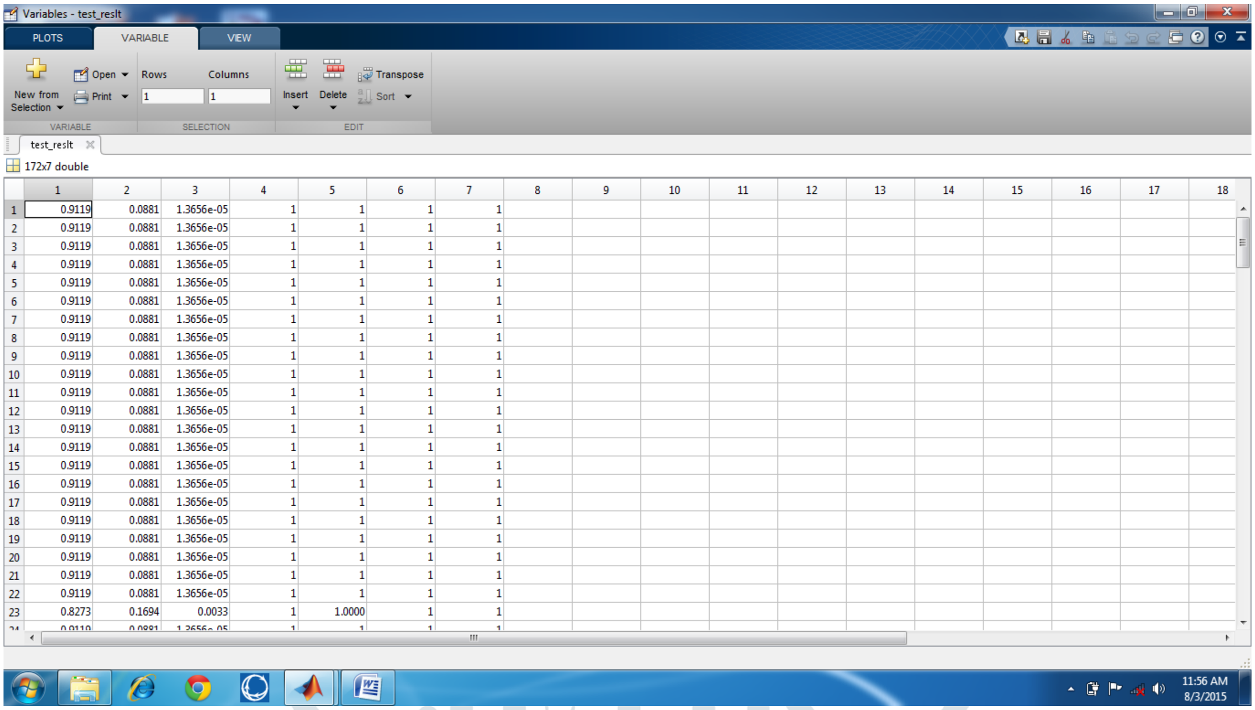


Figure 1.2 Fuzzy Decision Tree Matrix



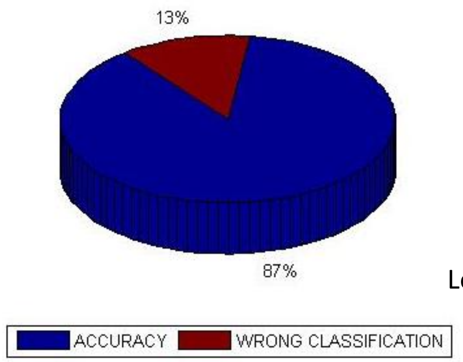
	1	2	3	4	5	6	7
1	0.9119	0.0881	1.3656e-05	1	1	1	1
2	0.9119	0.0881	1.3656e-05	1	1	1	1
3	0.9119	0.0881	1.3656e-05	1	1	1	1
4	0.9119	0.0881	1.3656e-05	1	1	1	1
5	0.9119	0.0881	1.3656e-05	1	1	1	1
6	0.9119	0.0881	1.3656e-05	1	1	1	1
7	0.9119	0.0881	1.3656e-05	1	1	1	1
8	0.9119	0.0881	1.3656e-05	1	1	1	1
9	0.9119	0.0881	1.3656e-05	1	1	1	1
10	0.9119	0.0881	1.3656e-05	1	1	1	1
11	0.9119	0.0881	1.3656e-05	1	1	1	1
12	0.9119	0.0881	1.3656e-05	1	1	1	1
13	0.9119	0.0881	1.3656e-05	1	1	1	1
14	0.9119	0.0881	1.3656e-05	1	1	1	1
15	0.9119	0.0881	1.3656e-05	1	1	1	1
16	0.9119	0.0881	1.3656e-05	1	1	1	1
17	0.9119	0.0881	1.3656e-05	1	1	1	1
18	0.9119	0.0881	1.3656e-05	1	1	1	1
19	0.9119	0.0881	1.3656e-05	1	1	1	1
20	0.9119	0.0881	1.3656e-05	1	1	1	1
21	0.9119	0.0881	1.3656e-05	1	1	1	1
22	0.9119	0.0881	1.3656e-05	1	1	1	1
23	0.8273	0.1694	0.0033	1	1.0000	1	1

Figure 1.3 Result Matrix

L-Index

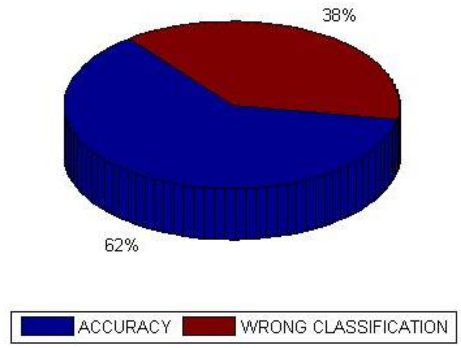
Voltage security assessment based on $L - index$ [Jasmon, 1993] carried out on three databases built by considering three sets of attributes. Different database signify the performance for the index and help to identify the system parameters which results in best performance among the attribute set considered. FDT performance on testing set accuracy given in figure 1.4. With reference to figure 1.4, it could be seen that the results for L-index have been plotted. Figure 1.4 (a) denotes the FDT performance for dataset-1. The systems total real power generation, total reactive power generation, total generation apparent power, total real power demand, total reactive power demand, total demand apparent power, total real power loss, total reactive power loss, total apparent power loss, equivalent resistance, equivalent reactance for the two bus equivalent of multi-bus system have been considered as the security predictors for the developed FDT. As shown in figure 1.4 (a) blue slice denotes accuracy percentage for FDT and red one show the misclassification accuracy. Figure 1.4 (b) denotes the accuracy for dataset-2. Bus-voltage has been employed as the attribute set for the dataset-2. Similarly 6.5 (c) Show the FDT performance for dataset-3 built by considering bus-voltage and bus-angles as the attribute set.

Legend



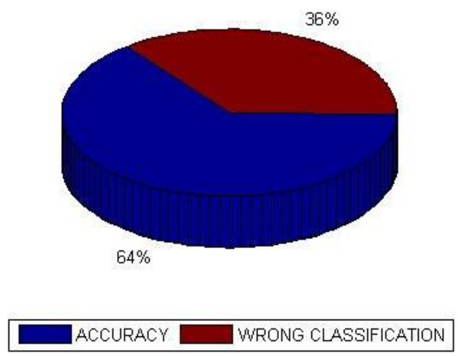
(a) Accuracy on Testset-1

Legend



(b) Accuracy on Testset-2

Legend



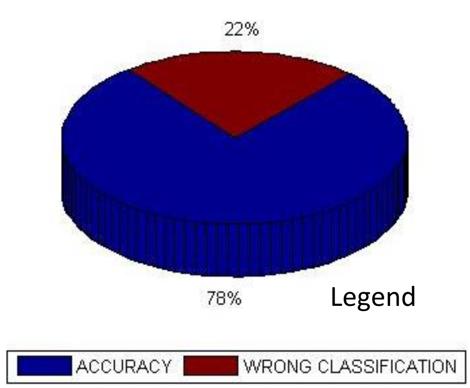
(c) Accuracy on Testset-3

Figure 1.4 L-index Implementation Results

PI_{VQ}- Index

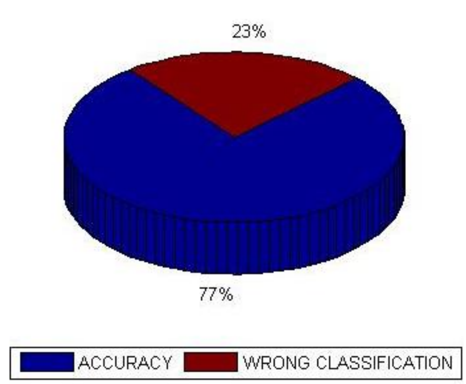
Tthe voltage magnitude violation and generators reactive power limit for denoting the degree of stress by penalizing the violations. Dataset-1 includes the bus-voltage and generators reactive power generations as the system attributes. Dataet-2 includes the bus-voltage and bus-angles while dataset-3 employs bus-voltage and generators real power generation as system attributes to build the database. Figure 1.5 shows the FDT performance for the test set obtained by splitting the database obtained above. Figure 1.5 (a) show the FDT accuracy for dataset-1. Similarly figure 1.5 (b) and figure 1.5 (c) shows the FDT performance in predicting the voltage security status for dataset-2, and dataset-3 respectively.

Legend

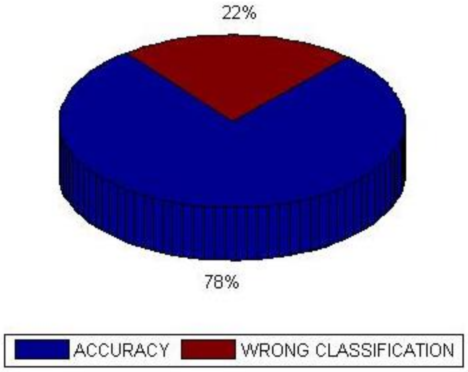


(a) Accuracy on Testset-1

Legend



(b) Accuracy on Testset-2

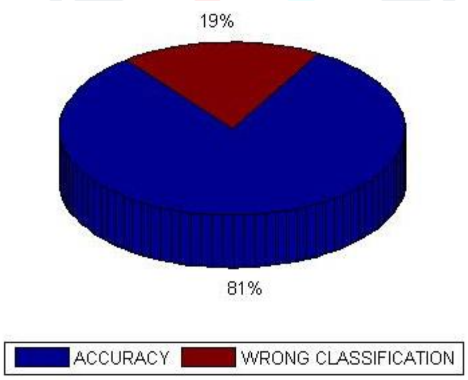


(c) Accuracy on Testset-3

Figure 1.5 $\boldsymbol{PI_{VQ} - Index\ Implementation\ Results}$

L_{mn}-Index

Performance for $L_{mn} - index$ [Moghavvemi, 1999] is shown in figure 1.6, which shows the security prediction performance for the dataset built by considering voltage synchrophasor. This index denotes the proximity to voltage collapse. As shown in figure 6.7 blue slice denotes accuracy percentage for FDT and red one show the misclassification accuracy.

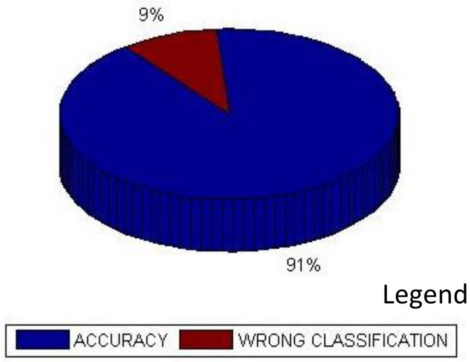


(a) Accuracy on Testset-1

Figure 1.6 $\mathbf{L_{mn} - IndexImplementationResults}$

PI_V-Index

Results obtained for PI_V-index [Ejebe, 1979] in association with FDT performance is shown in figure 1.7. For PI_V-Index dataset-1 built by considering bus-voltage, dataset-2 by bus-angles and dataset-3 by bus-angles and bus-voltages as the attribute sets respectively. Figure 1.7 shows the FDT performance for PI_V-index for three datasets explained above. Figure 1.7 (a), Figure 1.7 (b), Figure 1.7 (c) denotes the performance for dataset-1, dataset-2, and dataset-3 respectively.



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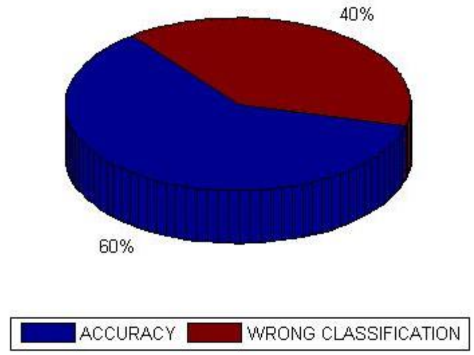
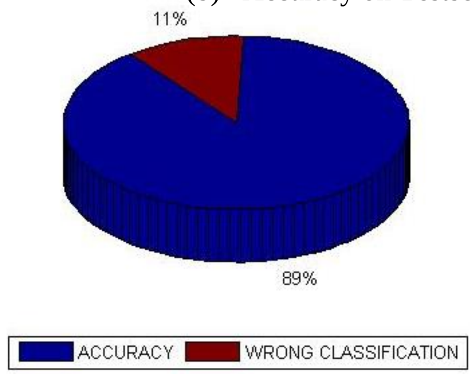


Legend

(a) Accuracy on Testset-1 (b) Accuracy on Testset-2



Legend

(c) Accuracy on Testset-3

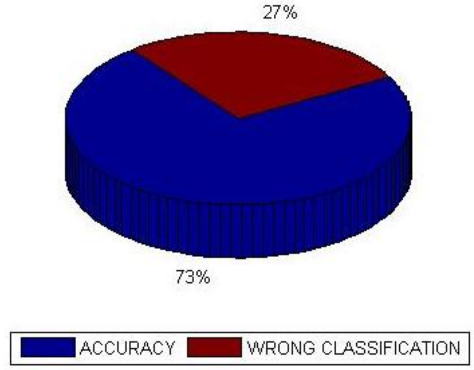
Figure 1.7 PI_V-Index Implementation Results

PI_VMV-Index

The degree of stress subjected by a disturbance on the system in terms of voltage magnitude violations. Voltage synchrophasor and real power generation by the generators have been employed to build the databases. Database-1 incorporates bus-voltage, bus-angles. Database-2 considered bus-angles and database-3 built by taking data of bus-angles and real power generation by generators. The class tagged to each instance determined by the $PI_{\_VMV}$-index, which denotes the degree of stress by penalizing the voltage limit violations. Figure 1.8 shows the FDT performance for three datasets.

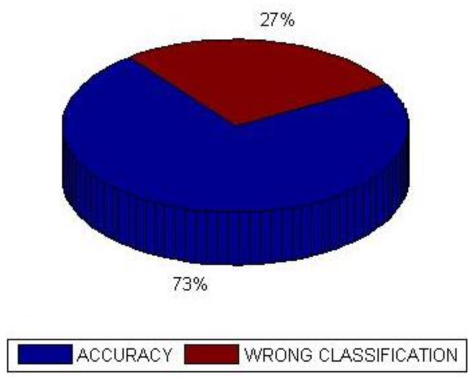
Legend

(a) Accuracy on Testset-1



Legend

(b) Accuracy on Testset-2



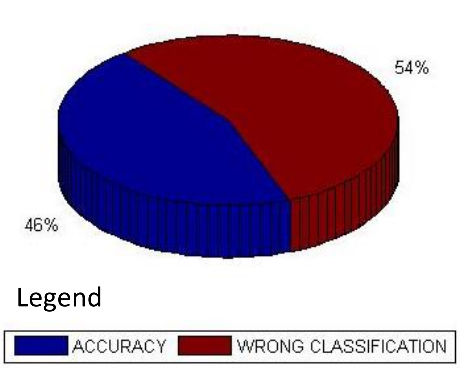
Legend

(c) Accuracy on Testset-3

Figure 1.8PI$_{VMV}$-Index Implementation Results

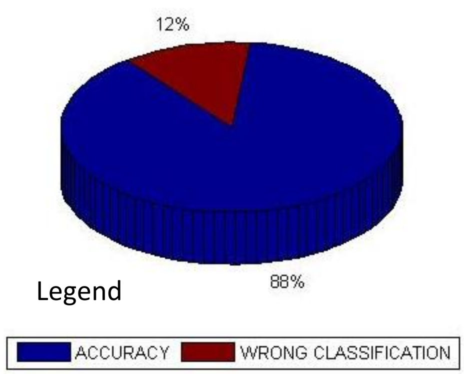
LVSI-Index

This has been implemented by adopting five datasets. Dataset-1 considers bus-voltage and bus-angles, dataset-2 includes bus-voltages, dataset-3 includes bus-angles, bus-angles and real power generation by generators employed in dataset-4, lastly bus-voltage and real power generation have been used for developing dataset-5. Figure 1.9 shows the LVSI and FDT performance on test set as obtained in workspace by MATLAB programming for the five datasets as explained above.



Legend

(a) Accuracy on Testset-1



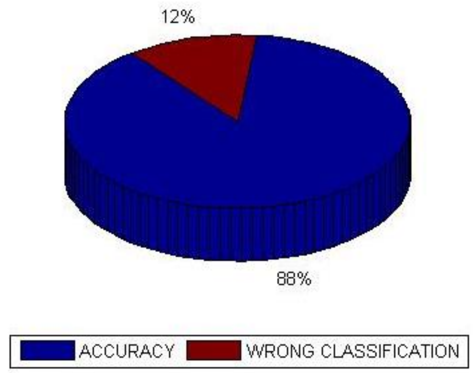
Legend

(b) Accuracy on Testset-2

Legend

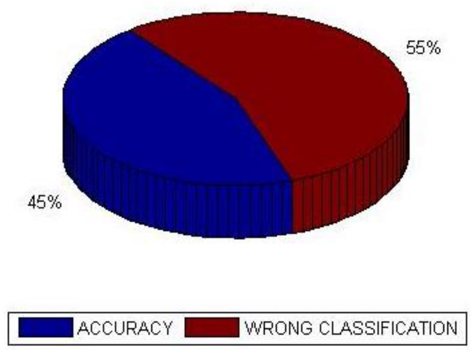
Legend

(c) Accuracy on Testset-3



(d) Accuracy on Testset-4

Legend



(e) Accuracy on Testset-5

Figure 1.9 LVSI Implementation Results

CONCLUSION: In this paper it provides glimpse of the systematic and novel approach of designing fuzzy decision tree based voltage security assessment model by employing voltage stability indices, major Grid blackouts, Mechanism of black out, Voltage Collapse Mechanisms in Power System, Classification of Power System Stability, Schematic Layout of Data Mining In Power System .were discussed at an introductory level. The importance of introducing fuzzy rule into conventional DT has been discussed

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