B. TECH. PROJECT REPORT

On

Synchronized measurements based Static Security Assessment and Classification of Power System using Wavelet Support Vector Machines

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DISCIPLINE OF ELECTRICAL ENGINEERING

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Synchronized measurements based Static Security Assessment and Classification of Power System using Wavelet Support Vector Machines

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degrees
of
BACHELOR OF TECHNOLOGY
in
ELECTRICAL ENGINEERING

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INDIAN INSTITUTE OF TECHNOLOGY INDORE

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CANDIDATE'S DECLARATION

We hereby declare that the project entitled **"Synchronized measurements based Static Security Assessment and classification of Power System using Wavelet Support Vector Machines"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'Electrical Engineering' completed under the supervision of **Dr. Trati Jain, Assistant Professor, Discipline of Electrical Engineering,** IIT Indore is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

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B.Tech IV Year

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CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the students is correct to the best of my knowledge.

Dr. Trapti Jain

Assistant Professor, IIT Indore

Preface

This report on “Synchronized measurements based Static Security Assessment and classification of Power System using Wavelet Support Vector Machines" is prepared under the guidance of Dr. Trapti Jain, Assistant Professor, IIT Indore.

Through this report we have tried to give a more accuracy having classifier for classification of power system than the other classifiers which is Wavelet support vector machine because it is good for classification of non-linear data with less computational time and good accuracy.

We have tried to the best of our abilities and knowledge to explain the content in a lucid manner. We have included images, figure and tables from standard source to make it more illustrative and interesting.

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It is their help and support, due to which we became able to complete the design and technical report. Without their support this report would not have been possible.

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Abstract

An important factor in the operation of a power system is the desire to maintain system security. But nowadays Deregulation of power system has turned static security assessment into a challenging task for which acceptably fast and accurate assessment methodology is essential. Occurrences related to over and under voltage and line overloading have been responsible for undesirable power system collapse leading to partial or even complete blackouts. The conventional method of static security assessment is performed by solving load flow equation for all the possible contingencies. This makes the security assessment a trivial task due to huge computational burden associated with it. Hence here Wavelet Support Vector Machines (WSVMs) technique is presented to examine whether the power system is secure or insecure. The training data of WSVM are derived from Newton Raphson load flow analysis. The result obtained from the WSVM method is compared with the Newton Raphson load flow analysis in terms of prediction accuracy. Also Comparison of performance of the proposed WSVM with other kernel SVM classifiers is done. This technique is tested on IEEE-14 bus system, IEEE-30 bus system and Indian 246 bus system.

Table of Contents

*	Candidate's Declaration	2
*	Supervisor's Certificate	2
*	Preface	3
*	Acknowledgements	4
*	Abstract	5
*	List of figures	7
*	List of tables	8
Chapter 1	Introduction	9
Chapter 2	PMUs and Load Flow Analysis	13
Chapter 3	Proposed Approach	24
Chapter 4	Support Vector Machine	26
Chapter 5	Wavelet Support Vector Machines	28
Chapter 6	Results and Discussions	30
Chapter 7	Conclusions	34
	References	35

List of Figures

Figure 1 – States of power system security……………………………………10

Figure 2 – IEEE 30 bus system………………………………………………...22

Figure 3 – IEEE 14 bus system………………………………………………23

Figure 4 – Proposed Approach………………………………………………24

Figure 5 - Kernel Mapping…………………………………………………..26

Figure 6 – Selection of best hyperplane………………………………………..27

List of Tables

Table 1 – Data about buses ………………………………………………………..23

Table 2 - Details of classified pattern ………………………………………….30

Table 3 – Result of classifier-1 using the proposed approach ………………....31

Table 4 – Result of classifier-2 using the proposed approach ………………....31

Table 5 - Comparison of performance of the proposed WSVM with other kernel SVM classifiers for IEEE 14 Bus system………………………………………32

Table 6 - Comparison of performance of the proposed WSVM with other kernel SVM classifiers for IEEE 30 Bus system………………………………………33

Table 7 - Comparison of performance of the proposed WSVM with other kernel SVM classifiers for Indian 246 Bus system……………………………………33

Chapter 1

Introduction

1.1 Power system security

The electrification of many processes through technological advances resulted in the continuous development and evolution of the electric power system over the last one hundred plus years. As an example more than one third of energy consumption is in the form of electric energy. The modern day electric power system is responsible for generating, transmitting and delivering more than one third of the total consumed energy. In some of last years happened blackouts have indicated that the operation and control of power systems may need to be improved. Even if a lot of data was available, the operators at different control centres did not take the proper actions in time to prevent the blackouts. Actually nowadays the size of power system is increasing day by day with the increasing demand of electricity. It is becoming large and complex. So to have attention of power system status at every moment is become very crucial task and power systems are forced to operate under stressed operating conditions closer to their security limits. Under such fragile conditions, any small disturbance could endanger system security and may lead to system collapse. Electricity plays important role in everyone’s life, so security of power system is become more concerned. So for security of power system, it is important to find out which line is overloaded and what is the amount of overloading in these lines and the load bus voltage magnitude? This is essential that power flows in all the branches and load bus voltage magnitude respect their specified limits not only in base case condition but also in stressed/line outage conditions. The most severe violation in a line flow and bus voltage magnitude limit can be due to different contingencies.

Power system is a dynamic system as the operating state of it continually changes with respect to time. The emergency state of line overloading may occur as a result of sudden increase in system demand, outages of generator or transmission line or failure in any of the system components. Alleviation of the emergency due to transmission line overload and bus voltage magnitude are a crucial problem in power system operation. Accurate as well as fast computation of lines flows, identification of overloaded lines and prediction of line class overloading in different overloaded branches are essential for secure and reliable operation of power system. In other words, fast security assessment of power system is of paramount importance in modern power system to provide reliable and secure electricity supply to its consumers and to manage this complex system, monitoring, control and operation functions are computer assisted. The systems for computer control of electric power systems have evolved as computer and monitoring technology evolved.

Power system security is the ability of the system to withstand credible contingencies without violating the normal operating limits and to remain free from unexpected failures and outages for providing of power supply.

There is mainly two types of power system security

1. Static security- Ability to reach the system in steady state in case of any outage of component without violating any constraints.
2. Transient Security Analysis – It tells about the system performance as after a disturbance it progresses. Transient security analysis entails evaluation of power system's ability to withstand a set of severe but credible contingencies and to continue the transition to steady-state satisfactory conditions.

In this project about static security is focused. Now power system security may be identified to be operating in a number of states. The three states are defined as follows:

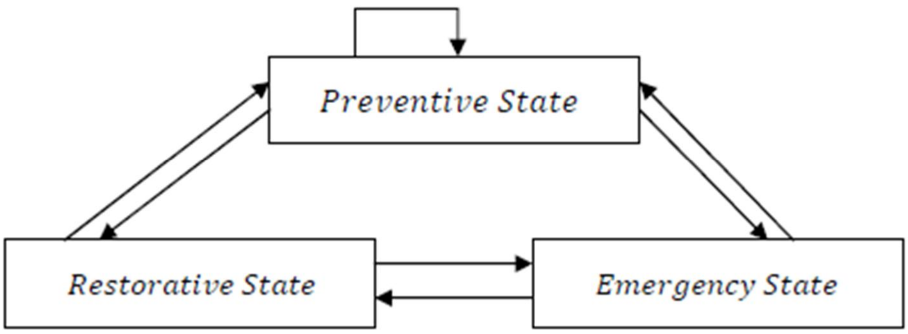

Figure 1

A. Preventive state: The preventive state is actually the normal state. The term preventive was used to stress the security aspect of the normal operation. Normal operating condition usually means that all the apparatus are running within their prescribed limits, and all the system variables are within acceptable ranges. The system should also continue to operate normally even in the case of credible contingencies. The operator should foresee such contingencies (disturbances) and take preventive control actions (as economically as possible) such that the system integrity and quality of power supply is maintained.

B. Emergency state: The power system enters an emergency state when some of the components operating limits are violated; some of the states wander outside the acceptable ranges, or when the system frequency starts to decrease. The control objective in the emergency state is to relieve system stress by appropriate actions.

C. Restorative state: Restorative state is the condition when some parts (or whole) of the system has lost power. The control objective in this state is to steer the system to a normal state again by taking appropriate actions.

1.2 Power system Security Assessment

Power system security assessment is used to determine whether, and to what extent, a power system is reasonably safe from serious interference to its operation. Important criteria for security assessment are violation of constraints for voltages, power flows. It can be divided into three major functions viz. system monitoring, contingency analysis and security control.

1. System monitoring- System monitoring supplies the power system operations or dispatches with pertinent up-to-date information on the conditions of the power system on real time basis as load and generation change. Telemetry systems measure, monitor and transit the data, voltages, currents, current flows and the status of circuit breakers and switches in every substation in a transmission network.
2. Contingency analysis - The second major security function is contingency analysis. Contingency analysis is the study of the outage of elements such as transmission lines and investigation of the resulting effects on line power flows and bus voltages of the remaining system. Contingencies referring to disturbances such as transmission element outages or generator outages may cause sudden and large changes in both the configuration and the state of the system. Modern operation computers have contingency analysis programs stored in them. These foresee possible system troubles

(outages) before they occur. They study outage events and alert the operators to any potential overloads or serious voltage.

3. Security control- The third major security function, corrective action analysis, permits the operators to change the operation of the power system if a contingency analysis program predicts a serious problem in the event of the occurrence of a certain outage. Thus this provides preventive and post-contingency control and permits the operator to change the operation of the power system.A simple example of corrective action is the shifting of generation from one station to another. This may result in change in power flows and causing a change in loading on overloaded lines.

There are two types of power system security assessments viz. static security assessment and transient security assessment. Static security assessment is the evaluation of steady state performance of the power systems for all possible contingencies and it also requires the steady state solution of the power system state equations in order to identify the voltages and powers in all the network nodes and the current flows in each power line. It helps to detect any potential overload of a system branch or an out-of-limit voltage following a given list of contingencies. Transient security assessment is used to determine the system dynamic behaviour in terms of rotor angle stability when subjected to disturbances.
In this project static security assessment of power system is done.

Chapter 2

PMUs and Load Flow Analysis

2.1 Phasor Measurement Units (PMUs)

A phasor is a complex number that represents both the magnitude and phase angle of the sine waves found in electricity. The phasors from different nodes, which refer to the same time–space coordinate, can improve performances of monitored control systems in various field of modern power systems, such as flow calculation, state estimation, transient stability analysis and frequency stability analysis. Phasor measurements that occur at the same time are called "synchro phasors". They are measured by high-speed monitors called Phasor Measurement Units (PMUs) that are 100 times faster than Supervisory Control and Data Acquisition (SCADA). PMU measurements record grid conditions with great accuracy and offer insight into grid stability or stress. Synchro phasor technology is used for real-time operations and off-line engineering analyses to improve grid reliability and efficiency and lower operating costs.

Synchronized measurement technology (SMT) facilitates the realization of the real-time wide area monitoring, protection, and control of a power system. The major advantages of using SMT are that the measurements from widely dispersed locations can be synchronized with respect to a global positioning system (GPS) clock, voltage phase angles can be measured directly, which was so far technically infeasible, and the accuracy and speed of state estimation increases manifold. Phasor measurement units (PMUs) are the most accurate and advanced instruments utilizing SMT available to the power system engineers and system operators. The PMUs, when placed at a bus, can offer time synchronized measurements of the voltage and current phasors at that bus. If we place the PMUs in all busses in a power system, it can be completely observable and so do not need any more calculation. But it is neither economical nor necessary to install PMUs at all node of a wide-area interconnected network. Since, due to the fact that each PMU can measure not only the bus voltage but also the currents along the lines incident to the buses, so selecting suitable buses and placing PMUs on them can make the entire system observable. A power system is considered completely observable when all the states in the system can be uniquely determined.

2.2 Load Flow Analysis -

It is a steady state analysis of an interconnected power system during normal operation. Single line diagram of power system contains hundreds of buses and branches with impedances per unit on a common MVA base. Load flow equations also known as power flow equations. Power flow calculation is very important for power system operation, economic scheduling and planning. A load flow study is normally implemented during the planning stage of future extension of power system network and when changes made to an existing network. The aim of the study is to specifically obtain information on the magnitude and phase angle of the voltage at each bus and the real and reactive power flowing in each line.

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \quad , (i = 1,2, \ldots \ldots , n)$$

Here I_i is injected current at i^{th} bus, and V_j is the voltage at j^{th} bus, Y_{ij} is the element of admittance matrix and n is total number of nodes in the system.

Power flow in i^{th} bus is

$$S_i = V_i I_i^* = P_i + jQ_j$$

So, we take

$$S_i^* = V_i^* I_i = P_i - jQ_i$$

$$P_i - jQ_i = V_i^* \sum_{j=1}^{n} Y_{ij} V_j$$

Here elements are in phasor form

$$V_i = |V_i| \angle \delta_i$$

$$V_j = |V_j| \angle \delta_j$$

$$Y_{ij} = |Y_{ij}| \angle \theta_{ij}$$

Now put these values in above equation, we get

$$P_i - jQ_i = V_i = |V_i||V_j||Y_{ij}| \angle - (\delta_i - \delta_j - \theta_{ij})$$

Now the real and reactive power flow equations are

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij})$$

$$Q_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij})$$

At each bus, 4 parameters are there $|V|, \delta, P, Q$.

If n number of buses are there then total 4n quantities to be found but only 2n quantities known, it is very difficult to solve this mathematical problem, so at each bus 2 quantities will be specified or assumed as constant, so number of quantities to be calculated are reduced to 2n which can be calculated by solving 2n equations.

There are three types of bus

Slack bus / Swing bus / Reference bus: -

We take this bus ad reference bus where voltage magnitude and phase angle of the voltage are specified. This bus provides additional real and reactive power to supply the transmission losses. It is generator bus.

Known quantities - $|V|, \delta$

Unknown quantities - P, Q

Generator bus or PV bus: -

Known quantities - $P, |V|$

Unknown quantities - Q, δ

Load bus / PQ bus: -

Unknown quantities - $|V|, \delta$

Known quantities - P, Q

There are many methods for solving load flow equations. These are given below

(1) Gauss Method
(2) Gauss Seidel method
(3) Newton Raphson Method

2.2.1 Newton Raphson Load Flow (NRLF) Method

However, due to nonlinear nature of the load flow problem, it requires numerical method to obtain the solution within a specified tolerance. Newton Raphson is one of the well-known method being employed for the study. In terms of accuracy and convergence, this method is comparatively better than the other load flow methods. The approach in Newton Raphson requires solving a number of formulation for each iteration of the load flow solution. The main formulation is being simplified in a matrix form of which the size of matrix is dependent on the numbers of buses in the system.

The Newton Raphson method was used to perform load flow analysis. This method has a faster solution for load flow analysis. It requires an initial condition and work well for heavily load system when compared to another method. The expected results for load flow are voltage magnitude, phase angle, real and reactive power.

$$P_i = P_i(|V|, \delta)$$
$$Q_i = Q_i(|V|, \delta)$$

Here i=2,3………n

total number of bus = n

total number of equations = (2n-2)

number of state to be find = (2n-2)

state vector $[X] = \left[\frac{\delta}{|V|}\right]$

$$\begin{pmatrix} P^{sp} - P^{cal} \\ Q^{sp} - Q^{cal} \end{pmatrix} = (J)\left(\frac{\delta}{|V|}\right)$$

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = \begin{pmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|} \end{pmatrix} \begin{pmatrix} \Delta \delta \\ \Delta |V| \end{pmatrix}$$

Or we can say

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = \begin{pmatrix} J_1 & J_2 \\ J_3 & J_4 \end{pmatrix} \begin{pmatrix} \Delta \delta \\ \Delta |V| \end{pmatrix}$$

Here $P^{sp} = supposed\ real\ power, P^{cal} = calculated\ real\ power$

$Q^{sp} = supposed\ reactive\ power, Q^{cal} = calculated\ reactive\ power$

$$\begin{pmatrix} J_1 & J_2 \\ J_3 & J_4 \end{pmatrix} = jacobian\ matrix\ and\ J_1, J_2, J_3, J_4\ are\ jacobian\ elements$$

$$\begin{pmatrix} \Delta\delta \\ \Delta|V| \end{pmatrix} = corrective\ vector$$

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix}\ is\ mismatch\ vector$$

Calculating Jacobian elements

For J_1

$$J_1(i,i) = \frac{\partial P_i}{\partial \delta_i} = |V_i|^2|Y_{ii}| \sin\theta_{ii} - Q_i$$

$$J_1(i,j) = \frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i)$$

For J_2

$$J_2 = \frac{\partial P}{\partial |V|}$$

$$|V_i|\frac{\partial P_i}{\partial |V_i|} = |V_i|^2|Y_{ii}| \cos(\theta_{ii}) + P_i$$

$$|V_i|\frac{\partial P_i}{\partial |V_i|} = |V_i||V_j||Y_{ij}| \cos(\theta_{ij} + \delta_j - \delta_i)$$

For J_3

$$J_3(i,i) = \frac{\partial Q_i}{\partial \delta_i} = P_i - |V_i|^2|Y_{ii}| \cos(\theta_{ii})$$

$$J_3(i,j) = \frac{\partial Q_i}{\partial \delta_j} = -|V_i||Y_{ij}| \cos(\theta_{ij} + \delta_j - \delta_i)$$

For J_4

$$J_4 = \frac{\partial Q}{\partial |V|}$$

$$|V_i|\frac{\partial Q_i}{\partial |V_i|} = Q_i - |V_i|^2|Y_{ii}| \sin(\theta_{ii})$$

$$|V_j|\frac{\partial Q_i}{\partial |V_j|} = -|V_i||V_j||Y_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i)$$

Now

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = \begin{pmatrix} J_1 & J_2|V| \\ J_3 & J_4|V| \end{pmatrix} \begin{pmatrix} \Delta\delta \\ \frac{\Delta|V|}{|V|} \end{pmatrix}$$

Or we can say

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = \begin{pmatrix} H & N \\ J & L \end{pmatrix} \begin{pmatrix} \Delta\delta \\ \frac{\Delta|V|}{|V|} \end{pmatrix}$$

Steps of solving NRLF

Step-1

Construct Y_{bus} matrix, take iteration count k=0 & set tolerance limit $\epsilon = 0.0001$

Total bus=n

Slack bus=1

2,3………m=PV bus

m+1, m+2……. n=PQ bus

and ε $is\ tollerence\ we\ take\ its\ value\ is\ 0.0005$

step-2

initial guess, assume $\delta_i = 0 \; \forall \; i = 2,3 \ldots \ldots n$

assume $|V| = 1 \; \forall \; i = m + 1 \ldots \ldots \ldots n \; (PQ\ bus)$

step-3

calculate $P_i \; \forall \; i = 2,3 \ldots \ldots \ldots n$

and $Q_i \; \forall \; i = m + 1, m + 2 \ldots \ldots \ldots \ldots n$

step-4

calculate

$$\Delta P_i = P^{sp} - P^{cal} \; \forall \; i = 2,3 \ldots \ldots \ldots \ldots n, all\ bus$$

$$\Delta Q_i = Q^{sp} - Q^{cal} \; \forall \; i = m + 1, m + 2 \ldots \ldots \ldots \ldots \ldots n, PQ\ bus$$

Step-5

Calculate Jacobian elements & Jacobian matrix which is equal to

$$J = \begin{bmatrix} H & N \\ J & L \end{bmatrix}$$

Step-6

Then corrective vector $= \begin{pmatrix} \Delta\delta \\ \frac{\Delta V}{|V|} \end{pmatrix} = \begin{pmatrix} H & N \\ J & L \end{pmatrix}^{-1} \begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix}$

Find $[\Delta\delta]_{(n-1)\times 1}$, $[\Delta|V|]_{(n-m-1)\times 1}$

Step-7

$$\left|V_i^{k+1}\right| = \left|V_i^k\right| + \Delta V_i^k \quad \forall\, i = m+1 \ldots \ldots \ldots \ldots n$$

$$\delta_i^{k+1} = \delta_i^k + \Delta\delta_i^k \quad \forall\ i = 2{,}3 \ldots \ldots \ldots \ldots n$$

Step-8

Calculate P_i, Q_i at each bus i=2,3………. n, using basic load flow equation.

And then calculate $\Delta P_i = P^{sp} - P^{cal}$

$$\Delta Q_i = Q^{sp} - Q^{cal}$$

Step-9

If $\Delta P > \varepsilon \ \ or \ \ \Delta Q > \varepsilon, \quad then\, iteration\, count\; k = k + 1$ and go to step-5, else

Load flow converged and the number of iteration k+1.

This is the method that we have used for data generation. Now we will see some details about our bus systems.

2.3 Feature selection techniques

Reducing the dimensionality of the vectors of features that describe each object presents several advantages. As mentioned above, irrelevant or redundant features may affect negatively the accuracy of classification algorithms. In addition, reducing the number of features may help decrease the cost of acquiring data and might make the classification models easier to understand.

Class separability

$$F_i = \frac{m^{(s)} - m_i^{(l)}}{\sigma_i^{(s)^2} - \sigma_i^{(l)^2}}, \quad \forall\, i, j \in n$$

$$m_i^{(s)} = \frac{1}{N^{(s)}} \sum_{j=1}^{N^{(s)}} X_{ij}{}^{(s)}$$

$$m_i^{(l)} = \frac{1}{N^{(l)}} \sum_{j=1}^{N^{(l)}} X_{ij}{}^{(l)}$$

$$\sigma_i^{(s)^2} = \frac{1}{N^{(s)}} \sum_{j=1}^{N^{(s)}} \left(X_{ij}{}^{(s)} - m_i^{(s)} \right)^2$$

$$\sigma_i^{(l)^2} = \frac{1}{N^{(l)}} \sum_{j=1}^{N^{(l)}} \left(X_{ij}{}^{(l)} - m_i^{(l)} \right)^2$$

$m_i^{(s)}$ and $m_i^{(l)}$ – Means of i^{th} variable corresponding to secure and unsecure class

$\sigma_i^{(s)^2}$ and $\sigma_i^{(l)^2}$ – variances of i^{th} variable corresponding to secure and unsecure class

$N^{(s)}$ and $N^{(l)}$ – number of secure and unsecure patterns

N and n – Total number of patterns and total number of variables in a pattern.

Correlation coefficient

$$C_{ij} = \frac{E(x_i x_j) - E(x_i)E(x_j)}{\sigma_i \sigma_j}, \forall\, i, j \in n$$

Where

$$E(x_i x_j) = \frac{1}{N} \sum_{k=1}^{N} X_{ik} X_{jk}$$

$$E(x_i) = \frac{1}{N} \sum_{k=1}^{N} X_{ik}$$

$$E(x_j) = \frac{1}{N} \sum_{k=1}^{N} X_{jk}$$

$$\sigma_i^2 = \frac{1}{N} \sum_{k=1}^{N} (X_{ik} - E(X_i))^2$$

$$\sigma_j^2 = \frac{1}{N} \sum_{k=1}^{N} \left(X_{jk} - E(X_j)\right)^2$$

2.4 Security index (SI)

Security index (SI) is used to determine the security status of the input training and testing patterns. We calculate SI for each training pattern and assign as secure or insecure class. SI assigns the security status of the PS which is either 0 (secure) or 1 (insecure).

$$SI = \left(\frac{VV + LOV}{100}\right)(1/4)$$

VV- voltage violation, LOV – line overloaded

$$LOV = \begin{cases} \sum_{l}^{nl} \left(\frac{S_l - S_l^{max}}{\Delta S_l}\right), & if\ line\ \ l\ \ is\ overloaded \\ 0, & otherwise \end{cases}$$

S_l- Actual power across l, S_l^{max}- maximum capacity of power

$$VV = \begin{cases} \sum_{l}^{nb} \left(\left(\frac{V_i - V_i^{max}}{\Delta V_i^{max}}\right) + \left(\frac{V_i - V_i^{min}}{\Delta V_i^{min}}\right) \right), & if\ V_i^{min} > V_i > V_i^{max} \\ 0, & if\ V_i^{min} \leq V_i \leq V_i^{max} \end{cases}$$

$$\Delta V_i^{max} = V_i^{max} - 1$$

$$\Delta S_l = S_l^{max} - S_l^{admissible}$$

$$\Delta V_i^{min} = V_i^{min} - 1$$

$$\Delta S_l^{admissible} = S_l^{max} - 10\% S_l^{max}$$

Classification of system OCs based on SI	
Static security Index	Class label
SI=0 SI>0	Secure Class Insecure Class

First we calculate the value of SI, if the value of SI is zero the class will be secure otherwise insecure.

2.5 Test systems

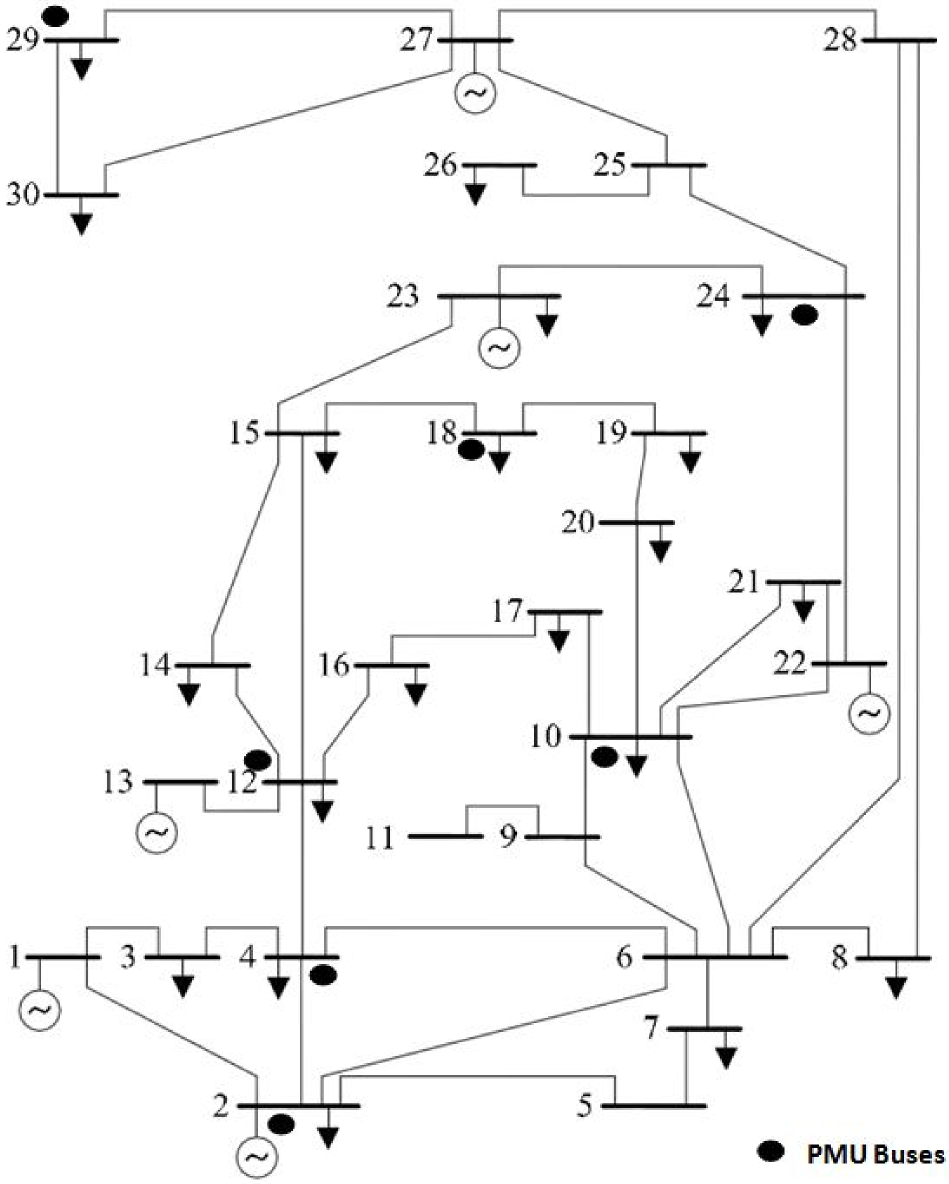

Figure 2 – IEEE 30 bus system

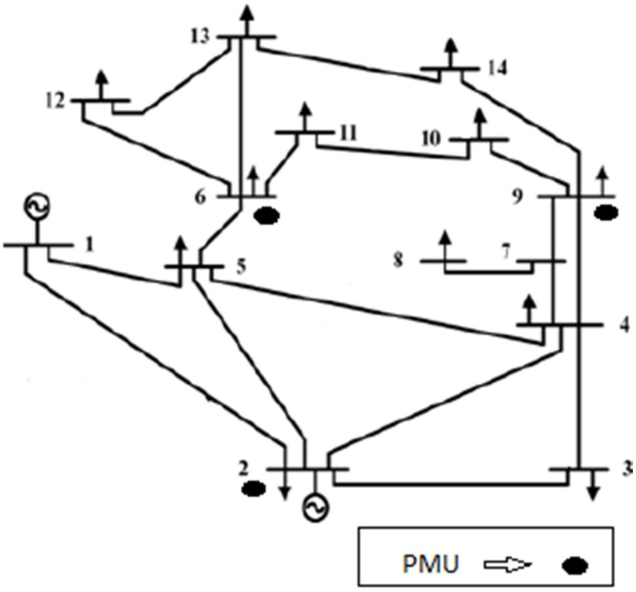

Figure 3 – IEEE 14 Bus System

For IEEE 14 bus system we can see in figure 3 there are 20 total numbers of branches and 3 PMUs are placed to make system observable. 12 branches are measured by PMUs and 18 contingencies are there. For each pattern there are 30 features but we choose those features which are relevant to our model.

Test System	IEEE 14 bus	IEEE 30 bus	Indian 246 bus
Number of branches	20	41	376
Number of PMUs	3	7	57
Number of contingencies	18	33	339
Number of branches measured	12	24	226
Number of features available	30	62	566
Number of features selected	5	6	96
Dimensionality reduction	16.67%	9.68%	16.96%

Table 1 – Data about buses

Chapter 3

Proposed Approach

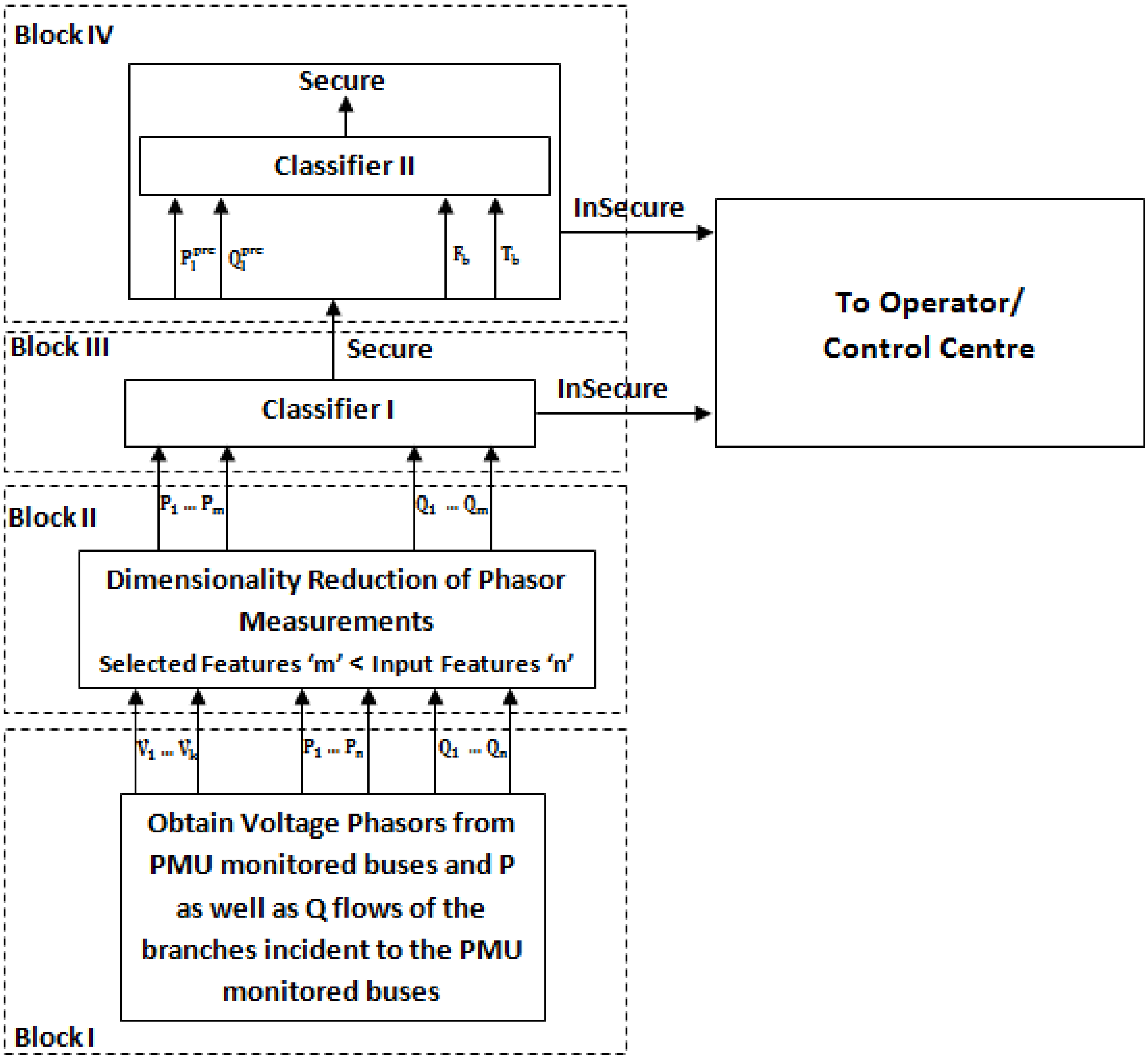

Figure 4 – Proposed Approach

Approach-

For this project we are proposing above approach which is shown in figure. First we get the real time synchro phasor measurements using PMUs. In data there are voltage angle, voltage magnitude, real power, reactive power. We get many patterns in data and each pattern has many features. In that features there are some features that are not useful for our work because actually those data are not important, they simply make the process complex and time consuming. So for reducing that useless data feature selection technique is used to select the more relevant feature for our model from synchro phasor measurements.

From that we find that real power and reactive power are the most suitable features for our model. Now we give that data to classifier-1 as input and it classifies our data to secure or insecure state. If the data is classified as secure that means our system is in secure condition and otherwise if data is in insecure state then it give the information to control centre and the operators take appropriate control action to get secure state. Now we take only secure data and give the contingency location and its respective pre-contingent steady state variables as inputs to classifier 2. In n-1 contingency analysis one line is removed at a time and checked whether the system is secure or insecure and repeat this process for all the line (one by one). Classifier 2 separates the data as secure or insecure. When state is insecure state then it again give the information to control centre to take preventive control action. If the state is secure then the power system is secure.

Chapter 4

Support Vector Machine

The conventional method of static security assessment is performed by solving load flow equation for all the possible contingencies. This makes the security assessment a trivial task due to huge computational burden associated with it. Hence there is a need to develop a fast technique to evaluate the security of power systems. To overcome the drawbacks of conventional methods, machine learning techniques have been predominately used for security assessment and classification. These techniques include Artificial Neural Network (ANN), Decision Tree (DTs), Support Vector Machine (SVM) etc. Drawbacks of ANN include greater computational burden, proneness to over fitting. Drawbacks of DTs are as a small change in input data can at times, cause large changes in the tree. Decision trees are easy to implement, when compared to other decision-making models, but preparing decision trees, especially larger networks are more complex and time-consuming.

Since, power system security assessment is a complex non-linear problem, SVMs have been extensively used for power system security evaluation. SVM uses a nonlinear mapping (support vector Kernel) to transform the original training data into a higher dimension and within this new dimension it searches for the linear optimal separating hyper plane. SVM finds the global optimum and the over fitting problem can be easily attenuated. However the choice of kernel, selection of kernel parameters, regularization parameter ‘C’ are its major limitations.

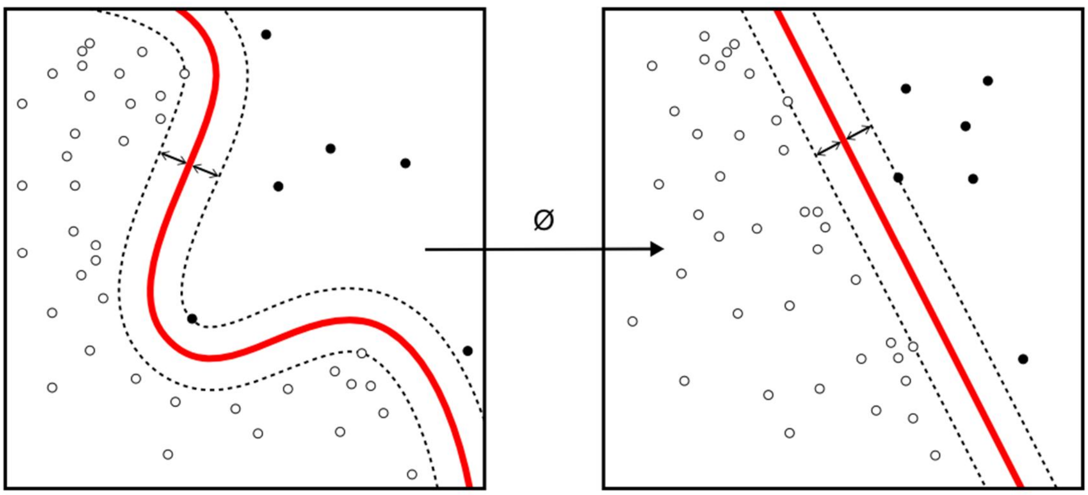

Figure 5 –Kernel Mapping

In above figure we can see that how the data transforms into higher dimensional space and non-linear data become linearly separable.

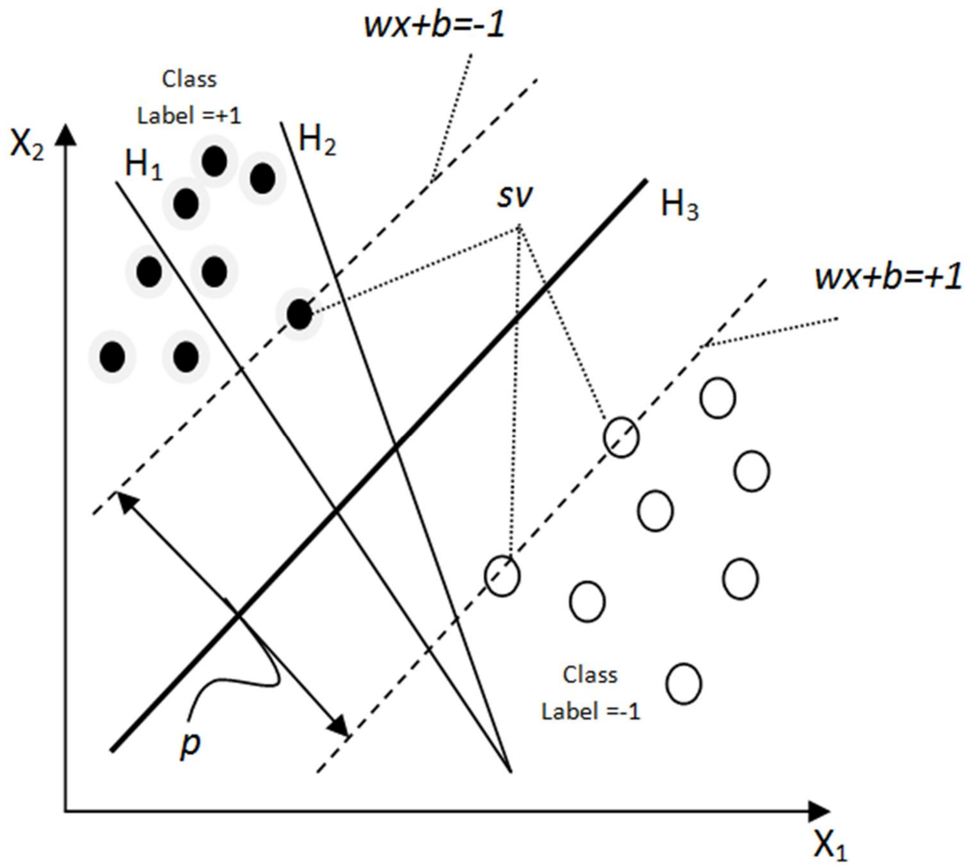

Figure 6– Selection of best hyperplane

Classifying data is a common task in machine learning. Suppose some given data points each belong to one of two classes, and the goal is to decide which class a new data point will be in. In the case of support vector machines, a data point is viewed as a p-dimensional vector (a list of p numbers), and we want to know whether we can separate such points with a (p-1) dimensional hyperplane. This is called a linear classifier. There are many hyperplanes that might classify the data. One reasonable choice as the best hyperplane is the one that represents the largest separation, or margin, between the two classes. So we choose the hyperplane so that the distance from it to the nearest data point on each side is maximized. If such a hyperplane exists, it is known as the maximum-margin hyperplane and the linear classifier it defines is known as a maximum margin classifier.

In fig we are draw three hyperplanes H_1, H_2 and H_3. Now we try to find maximum-margin hyperplane.

H_1 does not separate the class.

H_2 does, but only with the small margin.

H_3 separates them with the maximum margin.

Chapter 5

Wavelet Support Vector Machines

Wavelet analysis-

The proposed WSVM is based on wavelet analysis. The principle of wavelet analysis is to express or approximate a signal (or function) by a family of functions generated by dilations and translations of a mother wavelet as follows:

$$h_{a,c}(z) = |a|^{-1/2} h\left(\frac{z-c}{a}\right)$$

Where a is a dilation factor; c is a translation factor; and $h(z)$ is the mother wavelet, which satisfies the following condition [30], [31]:

$$W_h = \int_0^\infty \frac{|F(\omega)|^2}{|\omega|} d\omega < \infty$$

Where $F(\omega)$ is the Fourier transform of $h(z)$. The wavelet transform of a function $g(z)$ can be expressed

$$W_{a,c}(g) = \langle g(z), h_{a,c}(z) \rangle$$

Where $\langle \cdot,\cdot \rangle$ denotes the dot product. The right-hand side of above equation means the decomposition of the function $g(z)$ on a wavelet basis $h_{a,c}(z)$, and $W_{a,c}(g)$ are the coordinates of $g(z)$ in the space spanned by $h_{a,c}(z)$. Then the function $g(z)$ can be reconstructed as follows [30]:

$$g(z) = \frac{1}{W_h} \int_{-\infty}^{\infty} \int_0^\infty \frac{1}{a^2} W_{a,c}(g) h_{a,c}(z) da dc$$

Above equation can be approximated by taking the finite terms

$$\widehat{g(z)} = \sum_{i=1}^{N} W_i \cdot h_{a_i,c_i}(z)$$

Where W_i are the reconstruction coefficients.

Wavelet Kernels and WSVMS

Recently, wavelet SVMs (wavelet kernel for SVMs), which combines the wavelet technique with SVMs has been used for classification problems. The idea behind wavelet analysis is to express or approximate a signal or function by a family of functions generated by dilations and translations of a function called the mother wavelet. The goal of the WSVMs is to find the optimal approximation or classification in the space spanned by multidimensional wavelets or wavelet kernels. Wavelet is best for non-stationary signal analysis here original signal attach with mother wavelet signal and then makes analysis, means mother wavelet signal make zoom of basic signal, the analysis so result is coming best in comparison to other techniques. In this work, wavelet kernel is designed by considering this Morlet wavelet as the mother wavelet for this project.

A wavelet function can be written in the following form

$$h(Z) = \prod_{i=1}^{N} h(z_i)$$

Where $\{Z = (z_1, z_2, \dots, z_N) \in R^N\}$

Let $h(Z)$ be a mother wavelet, a and c let and denote the dilation and translation, respectively. $x, a, c \in R$. If $z, z' \in R^N$, then dot-product wavelet kernels are

$$K(z, z') = \prod_{i=1}^{N} h\left(\frac{z_i - c_i}{a}\right) h\left(\frac{z_i' - c_i'}{a}\right)$$

and translation-invariant wavelet kernels that satisfy the translation invariant kernel theorem are

$$K(z, z') = \prod_{i=1}^{N} h\left(\frac{z_i - z_i'}{a}\right)$$

In our project we are taking following wavelet as mother wavelet

$$h(z) = \cos(1.75z) exp\left(-\frac{z^2}{2}\right)$$

and the wavelet kernel of this mother wavelet is

$$K(z, z') = \prod_{i=1}^{l} \cos\left(1.75 \times \frac{z - z'}{a}\right) exp\left(-\frac{\|z - z'\|^2}{2a^2}\right), \quad z \epsilon \mathcal{R},\ z' \epsilon \mathcal{R}$$

Chapter 6

Results and Discussions

Detail of data generation for classifier-1 and lassifier-2

Here we are taking 1000 patterns for input of classifier 1 for IEEE 14 bus, IEEE 30 bus and Indian 246 bus. After that classifier 1 classifies the data as secure or insecure, we found that out of 1000 patterns there are 369 secure patterns and 631 insecure patterns for IEEE 14 bus system. Similarly for IEEE 30 bus 182 secure and 818 insecure patterns, for Indian 246 bus 263 secure patterns and 737 insecure patterns.

Now we go for classifier 2. We see there are 6642 total patterns for classifier 2 for IEEE 14 bus system. Actually there are 18 contingencies (from table) and 369 secure patterns for IEEE 14 bus system. We do n-1 contingencies analysis for 18 contingencies. We get 18*369=6642 total numbers of patterns for classifier 2 for IEEE 14 bus system. Similarly we can also see P_{total} for IEEE 30 bus system and Indian 246 bus system.

Test System	Classifier 1			Classifier 2		
	P_{total}	P_{secure}	$P_{insecure}$	P_{total}	P_{secure}	$P_{insecure}$
IEEE 14 bus	1000	369	631	6642	3521	3121
IEEE 30 bus	1000	182	818	6006	9	5997
Indian 246 bus	1000	263	737	24722	21755	2967

Table 2 - Details of classified pattern

Here,

P_{total} – Total Number of Patterns,

P_{secure} -Number of patterns belonging to secure class,

$P_{Insecure}$ -Number of patterns belonging to insecure class

Result of classifier-1 using the proposed approach

In this part we test the 20% patterns of total patterns by using traditional method and our proposed WSVM and see secure patterns and insecure patterns for both. After we see the prediction accuracy.

Test Systems	Traditional method		Proposed WSVM		
	P_{secure}	$P_{insecure}$	P_{secure}	$P_{insecure}$	PA (%)
IEEE 14 bus	72	128	72	128	100
IEEE 30 bus	47	153	47	153	100
Indian 246 bus	60	140	60	140	100

Table 3 – Result of classifier-1 using the proposed approach

Here,

PA = Prediction accuracy of the classifier

P_{secure} -Number of patterns belonging to secure class,

$P_{Insecure}$ -Number of patterns belonging to insecure class

Results of classifier-2 using the proposed approach

Test Systems	Traditional method		Proposed WSVM		
	P_{secure}	$P_{insecure}$	P_{secure}	$P_{insecure}$	PA (%)
IEEE 14 bus	779	549	777	551	98.19
IEEE 30 bus	1	1220	0	1221	99.92
Indian 246 bus	4387	557	4417	527	96.85

Table 4 – Result of classifier 2 using the proposed approach

Here,

PA = Prediction accuracy of the classifier

P_{secure} -Number of patterns belonging to secure class,

$P_{Insecure}$ -Number of patterns belonging to insecure class

Comparison of performance of the proposed WSVM with other kernel SVM classifiers

Here we are comparing the performance of our WSVM classifier with other classifiers. Clearly we can see that WSVM has the maximum prediction accuracy among all the classifiers. Another thing we can see that in most of the cases m-SVM has the maximum misclassification % because it is not a good classifier for non-linear data. We did this comparison for IEEE 14 bus, IEEE 30 bus and Indian 246 bus system.

SVM Classifiers	IEEE 14 Bus					
	Classifier I			Classifier II		
	PA (%)	Misclassification (%)		PA (%)	Misclassification (%)	
		Secure	Insecure		Secure	Insecure
l-SVM	99	2.7778	0	58.05	52.7599	26.5938
q-SVM	99	2.778	0	67.62	53.5302	2.3679
p-SVM	100	0	0	80.05	32.9910	1.4572
m-SVM	97.5	6.9444	0	49.77	46.8549	55.0091
r-SVM	99	2.7778	0	96.84	3.4660	2.7322
Proposed SVM	**100**	0	0	**98.19**	1.6688	2.0036

Table 5 - Comparison of performance of the proposed WSVM with other kernel SVM classifiers for IEEE 14 Bus system

SVM Classifiers	IEEE 30 Bus					
	Classifier I			Classifier II		
	PA (%)	Misclassification (%)		PA (%)	Misclassification (%)	
		Secure	Insecure		Secure	Insecure
l-SVM	100	0	0	99.92	100	0
q-SVM	99.5	0	0.6536	99.92	100	0
p-SVM	99.5	0	0.6526	99.92	100	0
m-SVM	76.5	61.7021	11.7647	99.92	100	0
r-SVM	100	0	0	99.92	100	0
Proposed SVM	**100**	0	0	**99.92**	100	0

Table 6 - Comparison of performance of the proposed WSVM with other kernel SVM classifiers for IEEE 30 bus system

SVM Classifiers	Indian 246 Bus					
	Classifier I			Classifier II		
	PA (%)	Misclassification (%)		PA (%)	Misclassification (%)	
		Secure	Insecure		Secure	Insecure
l-SVM	99.5	0	0.7143	89.75	0.2963	88.6894
q-SVM	97	0	4.2857	NC	-	-
p-SVM	100	0	0	17.33	92.9565	1.6158
m-SVM	81.5	55	2.8571	84.89	9.1406	62.1185
r-SVM	99.5	0	0.7143	94.60	2.0515	31.7774
Proposed SVM	**100**	0	0	**96.85**	1.4361	16.6966

Table 7 - Comparison of performance of the proposed WSVM with other kernel SVM classifiers for Indian 246 bus system

Chapter 7

Conclusions

In this report a wavelet support vector machine (WSVM) classifier has presented to solve the problems of power system static security assessment and compared with other SVM classifiers in terms of % prediction accuracy (PA) and after comparison it is found that WSVM classifier has the maximum % prediction accuracy among all SVM classifiers. This comparison is done on IEEE 14 bus, IEEE 30 bus and Indian 246 bus system.

Future scope- In this project static security assessment and classification in done, further this project can be extended for transient security assessment and classification in future.

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