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Computational Approaches for Monitoring Voltage Stability in Power Networks

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Abstract*- Voltage collapse and major blackouts have been repeatedly encountered in large power networks. The prime reason for this, is failure of systems ability to maintain synchronization. Under such condition system fails to maintain steady voltage at all buses and rapid growth in system collapse is assured. The basic work in this paper is to find the system stability by analyzing Jacobean determinant and Reactive Power in per unit. For this purpose we use Ward-Hale 6 Bus System with reactive power in per unit and Jacobean determinant. We compute critical value of reactive power by artificial neural network and Extrapolation through MS-Excel, where the system becomes unstable. We provide a computational framework which helps to analyze system stability limit.

Key words: - Ward Hale 6 bus System, Jacobean Determinant, Reactive Power, ANN, Extrapolation, EBPN, Blackout etc.

I. INTRODUCTION

Voltage stability refer to the ability of power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating point. The system state enters the voltage instability region when a disturbance or an increase in load demand or alteration in system state results in an uncontrollable and continuous drop in system voltage. A system is said to be in voltage stable state if at a given operating condition, for every bus in the system, the bus voltage magnitude increases as the reactive power injection at the same bus is increased. For Ward and Hale 6 bus system, there is one slack bus, one voltage controlled bus and remaining 4 are load buses.

A system is voltage unstable if for at least one bus in the system, the bus voltage magnitude decreases as the reactive power injection at the same bus is increased. It implies that if, V-Q sensitivity is positive for every bus the system is voltage stable and if V-Q sensitivity is negative for at least one bus, the system is voltage unstable.[1]

In the world, number of times condition of blackout occurs, by which a lot of consumers gets affected. Some of major blackouts from all over the world in the last few decades include a massive breakdown in **India** on *30-31/July/2012*, by which 7 states and approx. 620 millions peoples affected. This is called biggest ever power failure in the world. Another one is a fault in transmission line occurs at Uttar Pradesh state in **India** on *2/Jan/2001*, by which 230 millions peoples affected. On *1/Nov/2014* **Bangladesh** Suffered nationwide power outage for almost 10 hrs and almost 150 million peoples affected. On *26/Jan/2015* over 80% of **Pakistan** went power off due to some technical fault at power station in sindh, by which 140 million peoples affected. A transmission system failure occurs in Java-Bali, **Indonesia** on *18/Aug/2005*, approx. 100 million peoples get affected. [2]

When a power system is subjected to a sudden increase of reactive power demand following a system contingency, the additional demand is met by the reactive power carried by the generators and compensators. Generally there are sufficient reserves and the system settles to a stable voltage level. However, it is possible, because of a combination of events and system condition that the additional reactive power demand may lead to voltage collapse, causing a major breakdown of part or all the system. [3]

There are number of research scholars who have proposed their work on voltage collapse and voltage stability. In [4] authors represent a new approach of studying voltage stability in power systems at which voltage stability in transmission lines and system buses are carefully analyzed based on their V-Q and V-P relationships. In [5] authors derived the voltage stability margin of a power system with and without the FACTS devices under different loading conditions using Support Vector Machine (SVM) are determined. In [6] authors approach an analysis of reactive power control and voltage stability in power systems.

In [7] authors deal with the security aspects of power system by evaluating the severity of transmission line outage. Voltage security assessment is made by determining the power flow in the line using load flow for each contingency. In [8] authors represent how the SVC can regulate the power system stability. Due to its fast response and by which way it can control the reactive power in order to maintain the system stability.

The study done by the research scholars increased our curiosity to know more about voltage collapse and system stability and encourage us to try some effort in this area. In this paper, a simple ward and hale 6 bus system is used for which critical value of reactive power in per unit is evaluated by ANN and extrapolation through MS-Excel using data from a graphical representation. ANN via MATLAB generates a simulink model which is trained according to variation of previous data. Then model is ready to give an output for any specified input by testing the data number of times and result with minimum error. "TREND" function is used in MS-Excel to evaluate the peak demand by arranging the data in a table form. A comparative study is also provided between the results obtained by the two methodologies for obtaining better solutions. This paper further contains introduction to voltage collapse & system stability and literature review in section I, description of methodologies in section II, modeling and development of ANN in section III, results in section IV, conclusion in section V followed by references and bibliography respectively.

II.DESCRIBTION OF METHODOLOGY

2.1 ARTIFICIAL NEURAL NETWORK

An Artificial Neural Network, normally called a neural network, is a mathematical model stimulated by biological neural networks. A neural network consists of an interrelated group of artificial neurons, and it processes information using a connectionist approach to calculation. In most cases a neural network is an adaptive system that changes its prototype during a learning stage [9]. Artificial neural network is also considered as one of the modern mathematical-computational methods which are used to crack unexpected dynamic problems in developed behavioral systems during a time period By learning to discriminate patterns from data in which other computational and statistical method failed to answer them, artificial neural networks are capable to solve the problems [10]. Artificial neural networks, initially developed to emulate basic biological neural systems– the human brain particularly, are collected of a number of interconnected simple processing elements called neurons or nodes. Each node receives an input signal which is the total ‘‘information’’ from other nodes or external stimuli, processes it nearby all the way through an activation or transfer function and produces a transformed output signal to other nodes or external outputs.

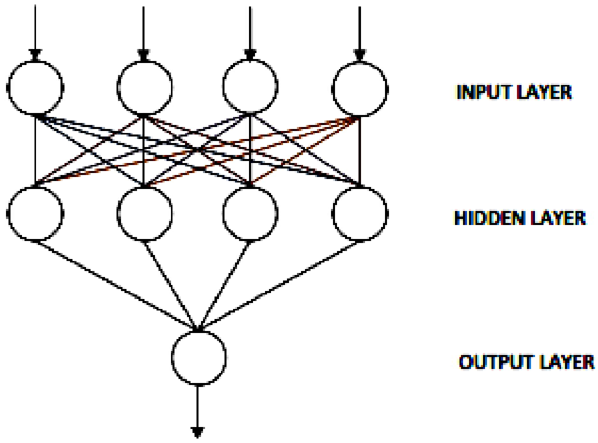

Fig.1 Feed Forward Neural Network

An MLP is naturally composed of numerous layers of nodes. The first or the lowest layer is an input layer where external information is received. The last or the uppermost layer is an output layer where the problem result is achieved. The input layer and output layer are separated by one or more inter- mediate layers called the hidden layers. The nodes in adjoining layers are usually completely connected by a cyclic arc from a lower layer to a higher layer [11]. **Back-propagation**, a reduction of expenditure for "backward propagation of errors", is a general method of training artificial neural networks used in consensus with an optimization method such as gradient descent. The method calculates the gradient of a loss function with respect to all the weights in the network. The gradient is fed to the optimization method which in turn uses it to revise the weights, in an attempt to minimize the loss function. Back-propagation requires a known, desired output for each input value in order to calculate the loss function gradient [12].

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2.2 EXTRAPOLATION THROUGH MS-EXCEL

The Excel TREND function calculates the linear trend line throughout a given set of y-values and (optionally), a given set of x-values. It returns values along a linear trend. Fits a straight line (using the method of least squares) to the arrays known_y's and known_x's. Returns the y-values along that line for the array of new_x's that you specify.

TREND (known_y's, [known_x's], [new_x's], [const])

New_X- *Required data point for which someone wants to envisage the value.*

Known_Y's- *Required. The dependent array or collection of data.*

Known_X's- *Required. The independent array or assortment of data.*

Const *– An optional logical argument that specifies whether the constant 'b', in the straight line equation y=mx+b, should be forced to be equal to zero. [13]*

III. MODELLING AND DEVELOPMENT OF ANN

The Jacobean determinant data for ward and hale 6 bus system for reactive power 0.0 per unit to -0.55 per unit is taken from [14] employed for the training of ANN to predict the critical value of reactive power where system is collapse. The proposed configuration of ANN is shown in below figure.

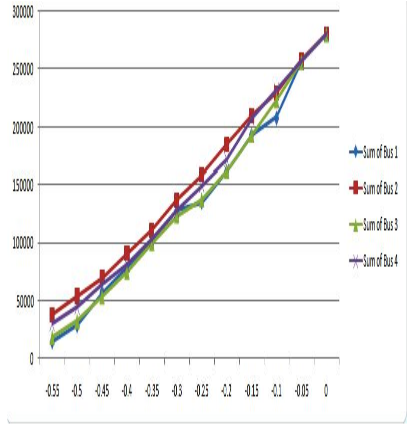


Fig.2 Reactive Power v/s Jacobian Determinant

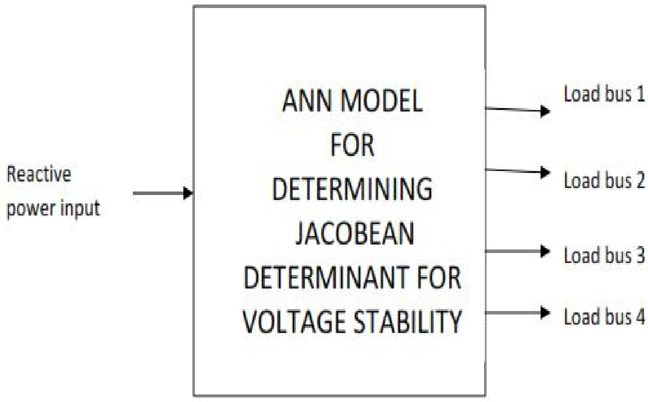


Fig. 3 Proposed ANN Model

MATLAB 2009 is used for ANN training and testing. The training data set for proposed ANN prediction contains all the four inputs. Hence the dimension of the developed for training is 20X4, i.e. it contains 12 rows and 4 columns.

TABLE 1. REFERENCE DATA

S.NO.	REACTIVE POWER	BUS 1	BUS 2	BUS 3	BUS 4
1	0	280500	280500	280500	280500
2	-0.05	256500	258500	256500	256500
3	-0.1	208000	230000	223300	232000
4	-0.15	193500	210000	193500	208000
5	-0.2	162000	185000	162000	172000
6	-0.25	135000	159000	137500	150000
7	-0.3	128000	137000	123400	128000
8	-0.35	102000	111000	99500	103000
9	-0.4	78000	91000	74600	81000
10	-0.45	56000	70000	53000	64000
11	-0.5	28000	54000	32000	45000
12	-0.55	14000	38000	18000	30000

Once the neural network has been structured for a particular function, that network is ready to be trained. To start the training process, the initial weights are chosen randomly. Then the training or learning begins. The training of ANN predictor is shown in Fig. 4. After training of ANN predictor, the error obtained is 5.05 X 10^{-22} in 8 iterations. The training performance, regression plot and training state representing gradient and validation check plot are also represented in Fig. 4.

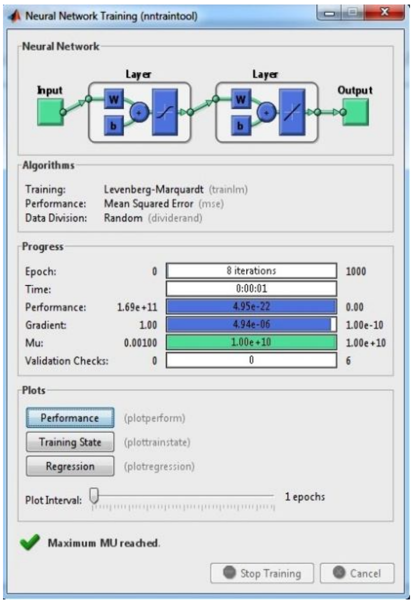


Fig. 4(a) Training Model

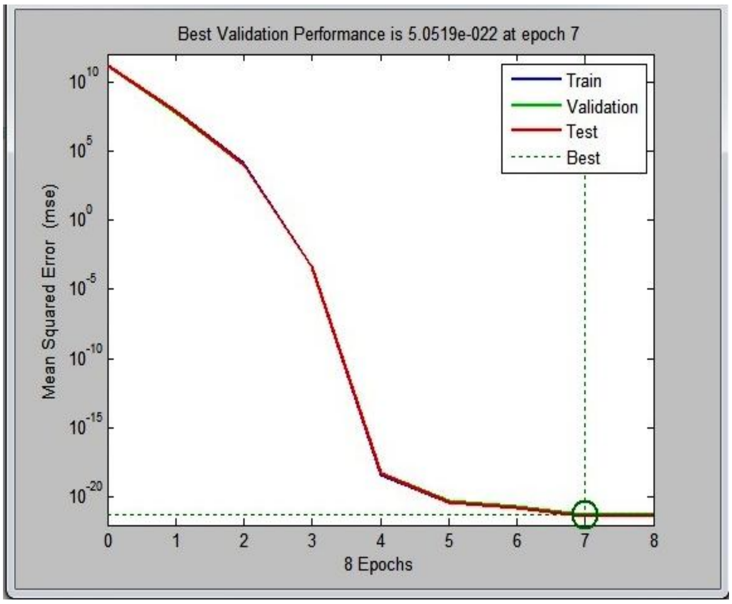


Fig. 4(b) Performance Plot

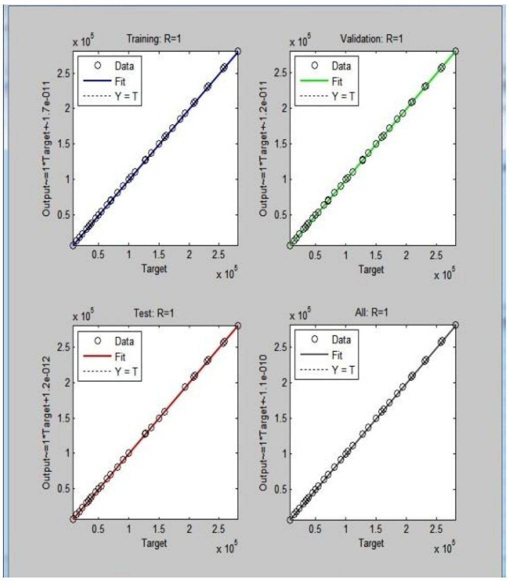


Fig. 4© Regression Plot

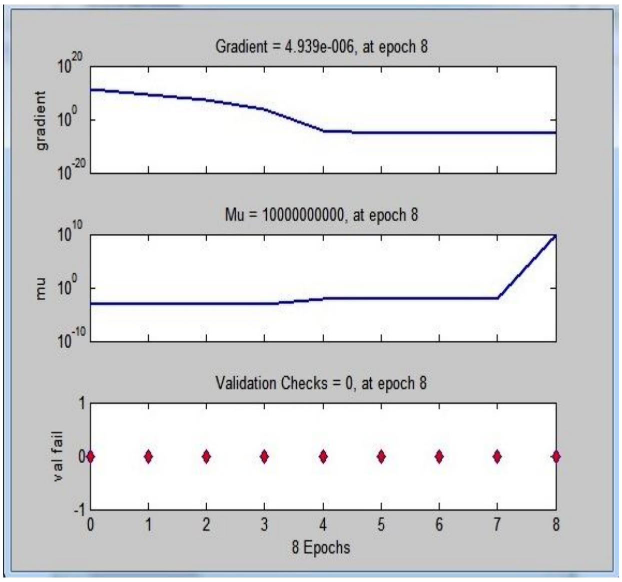


Fig. 4(d) Training State

IV.RESULT

Successful operation of ANN for analyzing system stability requires an appropriate training data set that can adequately covers the entire solution space with a view to recognize and generalized the relations among the problem variables. The result of ANN simulink model is representing in Fig.5 and Fig. 6. The critical value of reactive power for which jacobian determinant convert its sign from positive to negative for any one load bus is determined and also determined by Extrapolation. Almost same results are derived by both the methods which are presented in table-3.

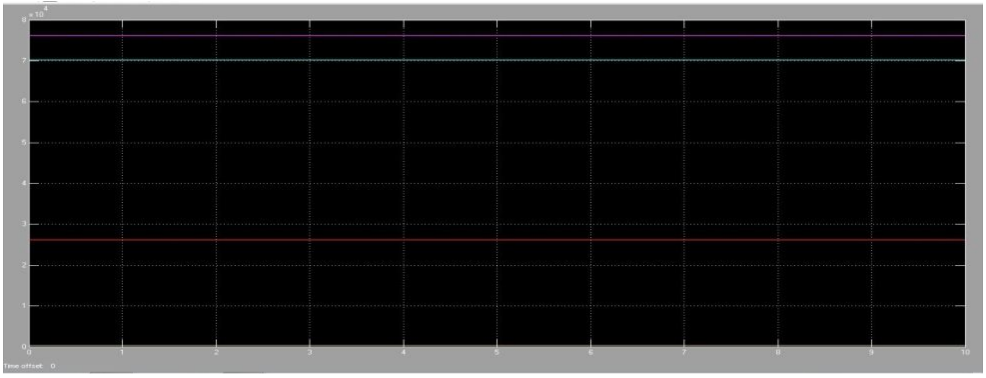


Fig. 5 ANN result at reactive power -0.56pu

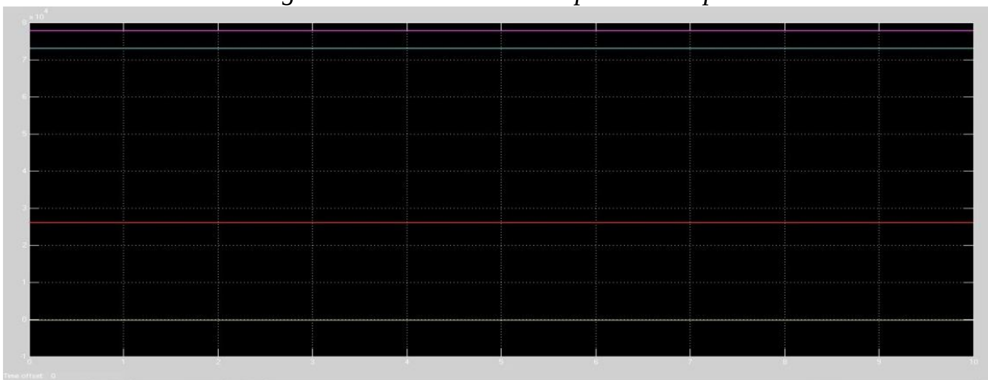
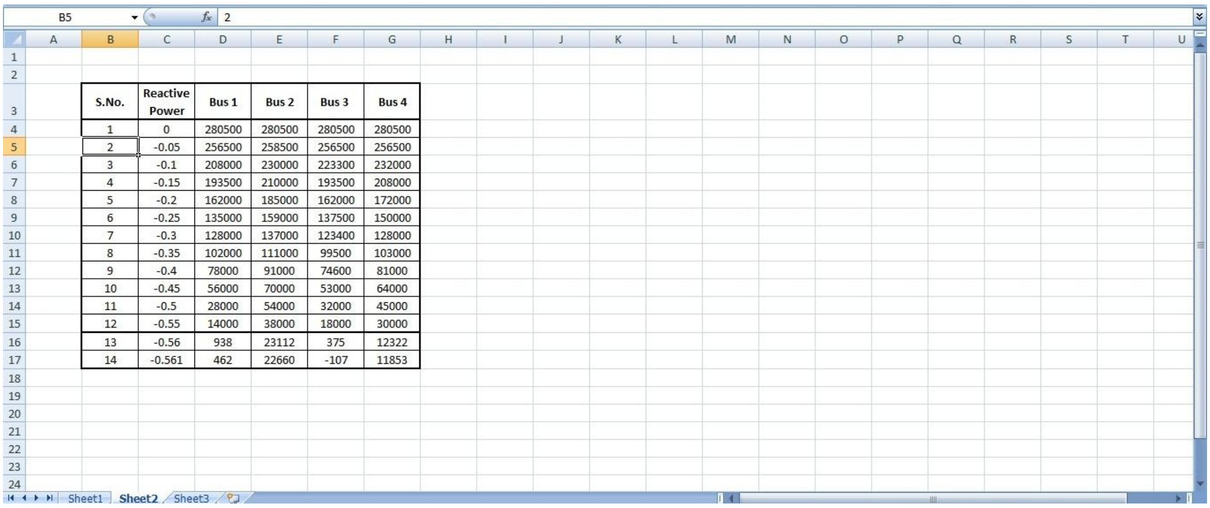


Fig. 6 ANN result at reactive power -0.561pu



S.No.	Reactive Power	Bus 1	Bus 2	Bus 3	Bus 4
1	0	280500	280500	280500	280500
2	-0.05	256500	258500	256500	256500
3	-0.1	208000	230000	223300	232000
4	-0.15	193500	210000	193500	208000
5	-0.2	162000	185000	162000	172000
6	-0.25	135000	159000	137500	150000
7	-0.3	128000	137000	123400	128000
8	-0.35	102000	111000	99500	103000
9	-0.4	78000	91000	74600	81000
10	-0.45	56000	70000	53000	64000
11	-0.5	28000	54000	32000	45000
12	-0.55	14000	38000	18000	30000
13	-0.56	938	23112	375	12322
14	-0.561	462	22660	-107	11853

Fig. 7 MS Excel result of jacobian determinant at reactive power -0.56 and -0.561

TABLE 2 RESULTS OF ANN AND EXTRAPOLATION

S. No.	Reactive Power (pu)	Extrapolation (Jacobian Det.)	ANN (Jacobian Det.)						
		Load Bus-1	Load Bus-2	Load Bus-3	Load Bus-4	Load Bus-1	Load Bus-2	Load Bus-3	Load Bus-4
1	-0.56	938.345	23112.24	374.9184	12321.79	26225	76176	334	70301
2	-0.561	461.6667	22660	-107.333	11853.33	26063	77817	-253	73021

V.CONCLUSION

**From the above results we can easily understand that when reactive power goes below to -0.56 per unit than jacobian determinant of one of the load bus goes negative and system will be unstable.In the current world scenario supply of electricity is much essential which performed by interconnection between number of grids for which it is also compulsory to compute system stability state. It is an imperative task to make entire system healthier. Stability depends upon a variety of factors from which one is reactive power. Reactive power is used for voltage control in the system and stability by reactive power can be determined by various methods one is relation between reactive power and jacobian determinant. The outcomes help the system operators to investigate the situation of system instability and keep up the reactive power within limit.

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