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Feed Forward Artificial Neural Network Based Modelling of SVC & Wind Farm System

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Abstract: *The concept of Var compensation embraces a wide and diverse field of both system and customer problems, especially related with power quality issues, since most power quality problems can be attenuated or solved with an adequate control of reactive power. In general, the problem of reactive power compensation is viewed from two aspects: load compensation and voltage support. Static voltage instability is mainly associated with reactive power imbalance. Thus, the load ability of a bus in a system depends on the reactive power support that the bus can receive from the system. As the system approaches the maximum loading point or voltage collapse point, both real and reactive power losses increase rapidly. Therefore, the reactive power supports must be locally adequate. With static voltage stability, slowly developing changes in the power system occur that eventually lead to a shortage of reactive power and declining voltage. The Flexible AC Transmission System (FACTS) technology is a promising technology to achieve complete deregulation of power system based on power electronic devices, used to enhance the existing transmission capabilities in order to make the system flexible and independent in operation then the system will be kept within limits without affecting the stability. Increased transmission demand is met where possible by increasing the existing transmission capacity. When trying to improve the transmission capacity, a key assumption is made that if the overall system reliability is not improved, at least the existing system reliability is maintained. The research work in this thesis is focused on FACTS Controllers and Artificial Neural Network. Concept of Artificial Neural Network is described in detail. In this paper, it is presented how a Feed-Forward Neural Network is trained through MATLAB Programs using a set of input values of a parameter obtained through running of developed simulations of FACTS Controllers in MATLAB/SIMULINK.*

Keywords: *Feed forward neural network, artificial neural network, Static Var compensator, Flexible AC transmission, FACTS controller*

I. INTRODUCTION

The worldwide concern about environmental pollution and a possible energy shortage has led to increasing interest in technologies for the generation of renewable electrical energy. Among various renewable energy sources, wind power is the most rapidly growing one in Europe and the United States. With the recent progress in modern power electronics, the concept of a variable-speed wind turbine (VSWT) equipped with a doubly fed induction generator (DFIG) is receiving increasing attention because of its advantages over other wind turbine generator concepts. In the DFIG concept, the induction generator is grid-connected at the stator terminals; the rotor is connected to the utility grid via a partially rated variable frequency ac/dc/ac converter (VFC), which only needs to handle a fraction (25%–30%) of the total DFIG power to achieve full control of the generator. The VFC consists of a rotor-side converter (RSC) and a grid-side converter (GSC) connected back-to-back by a dc-link capacitor. When connected to the grid and during a grid fault, the RSC of the DFIG may be blocked to protect it from over current in the rotor circuit. The wind turbine typically trips shortly after the converter has blocked and automatically reconnects to the power network after the fault has cleared and the normal operation has been restored.

II. STATIC VAR COMPENSATOR-SVC

The SVC has been used for reactive power compensation since the mid-1970, firstly for arc furnace flicker compensation and then in power transmission systems. One of the first 40 MVAR SVC was installed at the Shannon Substation of the Minnesota Power and Light system in 1978. The SVC results in the following benefits:

- A. Voltage support, and regulation,
- B. Transient stability improvement, and
- C. Power system oscillation damping,
- D. Reactive power compensation,
- E. Power transfer capacity increase and line loss minimization.

Fig. 1 shows these configurations: Thyristor Controlled Reactor (TCR), Thyristor Switched Reactor (TSR) and Thyristor Switched Capacitor (TSC) or a combination of all three in parallel configurations. The TCR uses firing angle control to continuously increase/decrease the inductive current whereas in the TSR the inductors connected are switched in and out stepwise, thus with no continuous control of firing angle.

Usually SVC's are connected to the transmission lines, thus having high voltage ratings. Therefore, the SVC systems have a modular design with more thyristor valves connected in series/ parallel for extended voltage level capability.

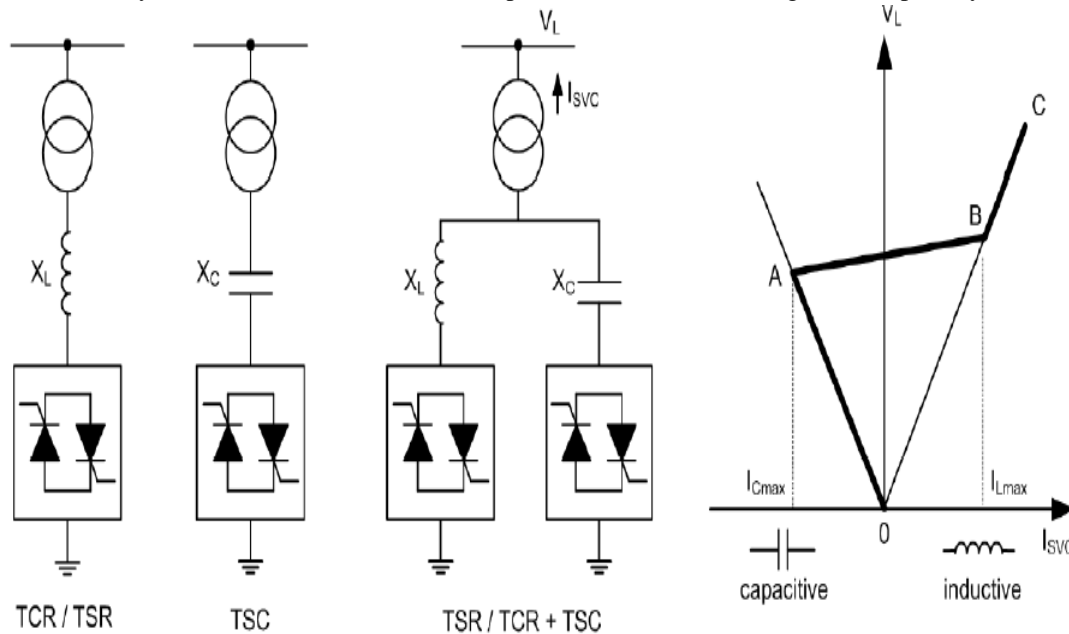


Fig. 1 SVC configurations and its I-V characteristics

III. REACTIVE POWER COMPENSATION

VAR compensation is defined as the management of reactive power to improve the performance of ac power systems. The concept of Var compensation embraces a wide and diverse field of both system and customer problems, especially related with power quality issues, since most power quality problems can be attenuated or solved with an adequate control of reactive power [1]. In general, the problem of reactive power compensation is viewed from two aspects: load compensation and voltage support. In load compensation, the objectives are to increase the value of the system power factor, to balance the real power drawn from the ac supply, to compensate voltage regulation, and to eliminate current harmonic components produced by large and fluctuating nonlinear industrial loads [2], [3]. Voltage support is generally required to reduce voltage fluctuation at a given terminal of a transmission line. Reactive power compensation in transmission systems also improves the stability of the ac system by increasing the maximum active power that can be transmitted. It also helps to maintain a substantially flat voltage profile at all levels of power transmission, it improves high-voltage dc (HVDC) conversion terminal performance, increases transmission efficiency, controls steady-state and temporary over voltages [4], and can avoid disastrous blackouts [5], [6]. Series and shunt Var compensation are used to modify the natural electrical characteristics of ac power systems. Series compensation modifies the transmission or distribution system parameters, while shunt compensation changes the equivalent impedance of the load [1], [7]. In both cases, the reactive power that flows through the system can be effectively controlled improving the performance of the overall ac power system. Traditionally, rotating synchronous condensers and fixed or mechanically switched capacitors or inductors have been used for reactive power compensation. However, in recent years, static Var compensators (SVCs) employing thyristor-switched capacitors (TSCs) and thyristor-controlled reactors (TCRs) to provide or absorb the required reactive power have been developed [7]– [9]. Also, the use of self-commutated pulse width modulation (PWM) converters with an appropriate control scheme permits the implementation of static compensators capable of generating or absorbing reactive current components with a time response faster than the fundamental power network cycle [10]– [12]. Based on the use of reliable high-speed power electronics, powerful analytical tools, advanced control and microcomputer technologies, flexible ac transmission systems (FACTS) have been developed and represent a new concept for the operation of power transmission systems [13], [14]. In these systems, the use of SVCs with fast

response times play an important role, allowing to increase the amount of apparent power transfer through an existing line, close to its thermal capacity, without compromising its stability limits.

IV. ARTIFICIAL NEURAL NETWORK

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of many highly interconnected processing elements (neurons) working in unison to solve specific problems. ANNs, like people, learn by example. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process. Learning in biological systems involves adjustments to the synaptic connections that exist between the neurons. This is true in case of ANNs as well. The basic building block of all biological brains is a nerve cell, or a neuron as shown in the Fig.2. Each neuron acts as a simplified numerical processing unit. In essence, the brain is a bundle of many billions of these biological processing units, all heavily interconnected and operating in parallel. In the brain, each neuron takes several input values from other neurons, applies a transfer function and sends its output on to the next layer of these neurons. These neurons in turn send their output to the other layers of neurons in a cascading fashion [14].

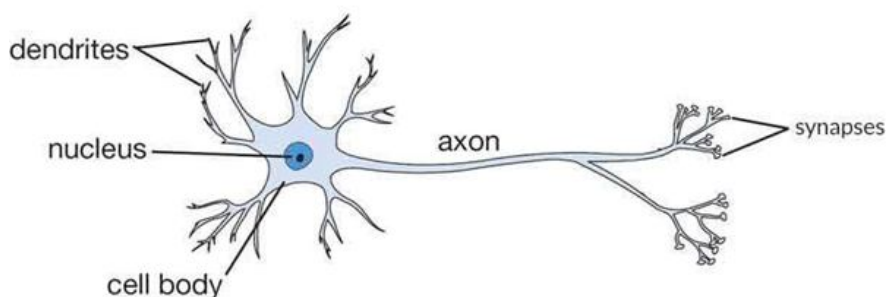


Fig. 2 A Biological Neuron

In similar manner, ANNs are usually formed from many hundreds or thousands of simple processing units, connected in parallel and feeding forward in several layers. In a biological neural network, the memory is believed to be stored in the strength of interconnections between the layers of neurons. Using neural network terminology, the strength or influence of an interconnection is known as its weight. ANN borrows from this theory and utilizes variable interconnections weights between layers of simulated neurons. ANNs were proposed early in 1960's, but they received little attention until mid-80's. Prior to that time, it was not generally possible to train networks having more than two layers. These early two layers networks were usually limited to expressing linear relationships between binary input and output characters. Unfortunately, the real world is analog and doesn't lend itself to a simple binary model. The real innovation in ANN research came with the discovery of the backpropagation method. Because of fast and inexpensive personal computers availability, the interest in ANNs has blossomed. The basic motive of the development of the neural network was to make the computers to do the things, which a human being cannot do. Therefore, ANN is an attempt to simulate a human brain. Hence, the ANN architecture can be easily compared with the human brain. An artificial neural network is a system based on the operation of biological neural networks, in other words, is an emulation of biological neural system.

A. Advantages

- 1) A neural network can perform tasks that a linear program can not.
- 2) When an element of the neural network fails, it can continue without any problem by their parallel nature
- 3) A neural network learns and does not need to be reprogrammed.
- 4) It can be implemented in any application.
- 5) It can be implemented without any problem.

B. Disadvantages

- 1) The neural network needs training to operate.
- 2) The architecture of a neural network is different from the architecture of microprocessors therefore needs to be emulated.
- 3) Requires high processing time for large neural networks.

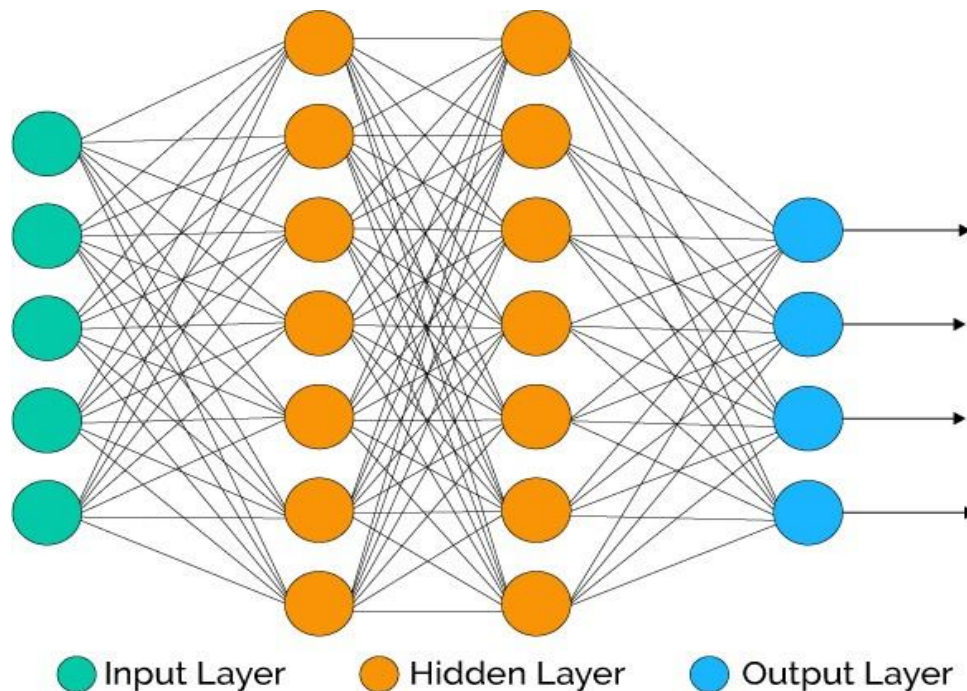


Fig. 3 Model of ANN

C. Model of Artificial Neural Network

The model of Artificial neural network is shown in fig. 3, which has input layer, hidden layer and output layer. The input layer contains those units (artificial neurons) which receive input from the outside world on which network will learn, recognize about or otherwise process. Output layer contains units that respond to the information about how it's learned any task. Hidden layers are in between input and output layers. The job of hidden layer is to transform the input into something that output unit can use in some way. Most neural networks are fully connected that means to say each hidden neuron is fully connected to every neuron in its previous layer (input) and to the next layer (output) layer. The neuron has following parts:

- 1) **Neuron:** A neuron (or cell or a unit) is an autonomous processing element. Neuron can be thought of a very simple computer. The purpose of each neuron is to receive information from other neurons, perform relatively simple processing of the combined information, and send the results to one or more other neurons. Generally, neurons are represented by circle or squares.
- 2) **Layers:** A layer is a collection of neurons that can be thought of as performing some type of common functions. These neurons are usually numbered by placing the numbers or letters by each neuron and are generally assumed that no neuron is connected to another neuron in the same layer.
- 3) **Synapses:** An arc or a synapse can be a one-way or a two-way communication link between two cells as shown in the Fig. 2. A feed-forward network is one in which the information flows from the input cells through hidden layers to the output neurons without any paths whereby a neuron in a lower numbered layer receives input from the neurons in a high numbered layer. A recurrent network, by contrast, also permits communication in the backward direction.
- 4) **Weights:** A weight w_{ij} is a real number that indicates the influence that neuron n_i has on neuron n_j . For example, positive weights indicate reinforcement, negative weights indicate inhibition and a weight zero (or the absence of weight) indicates that no direct influence or connection exists.
- 5) **Propagation Rule:** A propagation rule is a network rule that applies to all the neurons and specifies how outputs from cells are combined into an overall net input to neuron n . The term 'net', indicates this combination. The most common rule is the weighed sum rule wherein, adding the products of the inputs and their corresponding weights forms the sum,

$$\text{net } i = b_i + \sum w_{ij} n_{ij}$$

where, j takes on the appropriate indices corresponding to the numbers of the neurons that send information to the neurons n_i . The term in p_j represents the inputs to neurons n_i , from neuron n_j . If the weights are both positive and negative, then this sum can be computed in two parts: excitatory and inhibitory. The term b_i represents a bias associated with neurons n_i . Adding one or more special neuron(s) having a constant input of unity often simulates these neuron biases [14].

V. PROBLEM FORMULATION

The training algorithm of back propagation involves four stages [14], viz.

- A. Initialization of Weights
- B. Feed Forward
- C. Back Propagation of errors
- D. Updation of the weights and the biases.

During first stage which is the initialization of weights, some small random values are assigned. During feed forward stage each input unit (x_i) receives an input signal and transmits this signal to each of the hidden units z_1, \dots, z_p . Each hidden unit then calculates the activation function and sends its signal z_j to each output unit. The output unit calculates the activation function to form the response of the net for the given input pattern.

During back propagation of errors, each output unit compares its computed activation y_k with its target value t_k to determine the associated error for that pattern with that unit. Based on the error, the factor δ_k is computed and is used to distribute the error at output unit y_k back to all units in the previous layer. Similarly factor δ_j is computed for each hidden unit z_j .

During final stage, the weight and biases are updated using the δ factor and the activation,

- x: input training vector
- x: ($x_1, \dots, x_i, \dots, x_n$)
- t: Output target vector
- t: (t_1, \dots, t_i, t_n)
- δ_k = error at output unit y_k
- δ_j = error at hidden unit z_j
- α = learning rate
- V_{oj} = bias on hidden unit j
- z_j = hidden unit j
- w_{ok} = bias on output unit k
- y_k = output unit k

The training algorithm used in the back-propagation network is as follows. The algorithm is given with the various phases:

1) *Initialization of Weights*

- Step 1: Initialize weight to small random values.
- Step 2: While stopping condition is false, do Steps 3-10.
- Step 3: For each training pair do steps 4-9.

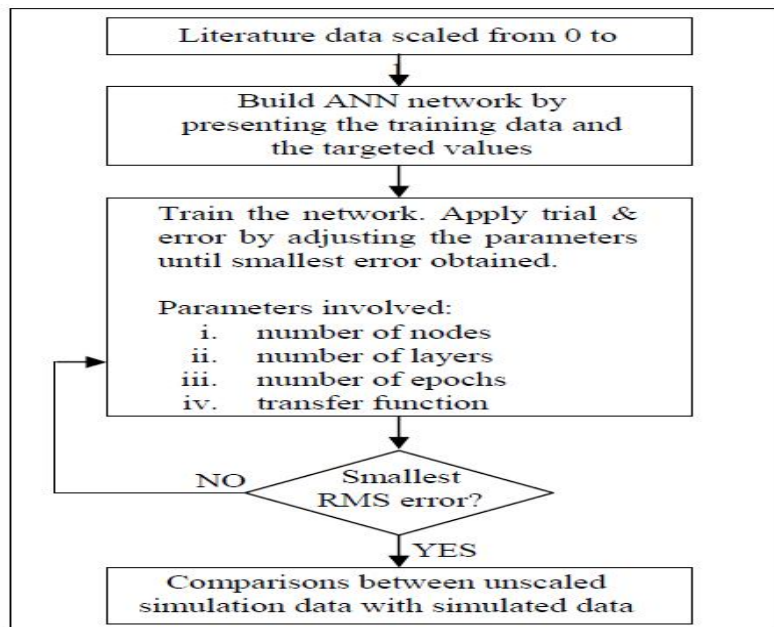


Fig. 4 Flow Chart of Training the Neural Network

2) *Feed Forward*

Step 4: Each input unit receives the input signal x_i and transmits this signals to all units in the layer above i.e hidden units.

Step 5: Each hidden unit ($z_j, j=1, \dots, p$) sums its weighted input signals.

$$z_{-inj} = v_{oj} + \sum x_i v_{ij} \tag{3.1}$$

applying activation function

$$z_j = f(z_{inj}) \tag{3.2}$$

and sends this signal to all units in the layer above i.e. output units.

Step 6: Each output unit (y_k) sums its weighted input signals.

$$y_{-ink} = w_{ok} + \sum z_j w_{jk} \tag{3.3}$$

and applies its activation function to calculate the output signals.

$$y_k = f(y_{-ink}) \tag{3.4}$$

3) *Back Propagation of Errors*

Step 7: Each output unit receives a target pattern corresponding to an input pattern, error information term is calculated as

$$\delta_k = (t_k - y_k) f'(y_{-ink}) \tag{3.5}$$

Step 8: Each hidden unit (z_j) sums its delta inputs from units in the layer above

$$\delta_{-inj} = \sum \delta_j w_{jk} \tag{3.6}$$

The error information term is calculated as

$$\delta_j = \delta_{-inj} f'(z_{inj}) \tag{3.7}$$

4) *Updation of Weight and Biases*

Step 9: Each output unit (y_k) updates its bias and weights ($j=0, \dots, p$). The weight correction term is given by:

$$\Delta W_{jk} = \alpha \delta_k z_j \tag{3.8}$$

and the bias correction term is given by

$$\Delta W_{ok} = \alpha \delta_k \tag{3.9}$$

$$W_{jk}(\text{new}) = W_{jk}(\text{old}) + \Delta W_{jk}, \quad W_{ok}(\text{new}) = W_{ok}(\text{old}) + \Delta W_{ok} \tag{3.10}$$

Each hidden unit ($z_j, j=1, \dots, p$) updates its bias and weights ($i=0, \dots, n$)

The weight correction term

$$\Delta V_{ij} = \alpha \delta_j x_i \tag{3.11}$$

The bias correction term

$$\Delta V_{oj} = \alpha \delta_j \tag{3.12}$$

$$\text{Therefore, } V_{ij}(\text{new}) = V_{ij}(\text{old}) + \Delta V_{ij}, \quad V_{oj}(\text{new}) = V_{oj}(\text{old}) + \Delta V_{oj} \tag{3.13}$$

Step 10: Test the stopping condition.

The stopping condition may be the minimization of the errors, number of epochs etc.

VI. SIMULATION AND MODELLING

The investigated power system network is modeled and simulated in MATLAB / SIMULINK as shown in Fig. 5, to study the steady state behavior with SVC and STATCOM. The fault is initiated between 10 and 10.1 sec from starting of the simulation. The purpose of running simulation in this mode is to verify the dynamic reactive power compensation capability of SVC during the event of fault, while integrating wind power in a distribution network. The network consists of a 132 kV, 50 Hz, grid supply point, feeding a 33-kV distribution system through 132/33 kV, 62.5 MVA step down transformer. There are two loads in the system; one load of 20 MW and another load of 4 MW at 50 Km from the transformer. The 33 kV, 50 km long transmission line is modeled as line. A 9 MW wind farm consisting of six 1.5 MW wind turbines is to be connected to the 33- kV distribution network at 4 MW load point. Dynamic compensation of reactive power is provided by a SVC located at the point of wind farm connection. The 9 MW wind farm have conventional wind turbine systems consisting of squirrel-cage induction generators and variable pitch wind turbines. To limit the generator output power at its nominal value, the pitch angle is controlled for winds exceeding the nominal speed of 9 m/s. Each wind turbine has a protection system monitoring voltage, current and machine speed. Test system is simulated in MATLAB/Simulink. Fig.5 shows the Simulink model of the test system. Phasor simulation is used to simulate the test system; to make it valid for intended purpose. Variable-step ode23tb solver is used for simulation. The simulation time is 20 sec. figure 6

shows the voltage at 33 KV at bus 1 during static voltage control. Figure 7 shows the voltage at 33 KV at bus 2 during SVC. Figure 8 shows the Reactive power supplied by SVC to the network. Results are presented in table 1, which shows the Values of voltage at bus 1 and 2 and Reactive power by SVC between 1 to 20 s. The results obtained are voltages V1 and V2 and the reactive power. The reactive power at bus 1 for the different time period is obtained. Table 2 shows the comparison of voltage values on Bus 1 and 2, the results have been obtained by simulation using MATLAB and through Artificial Neural Network.

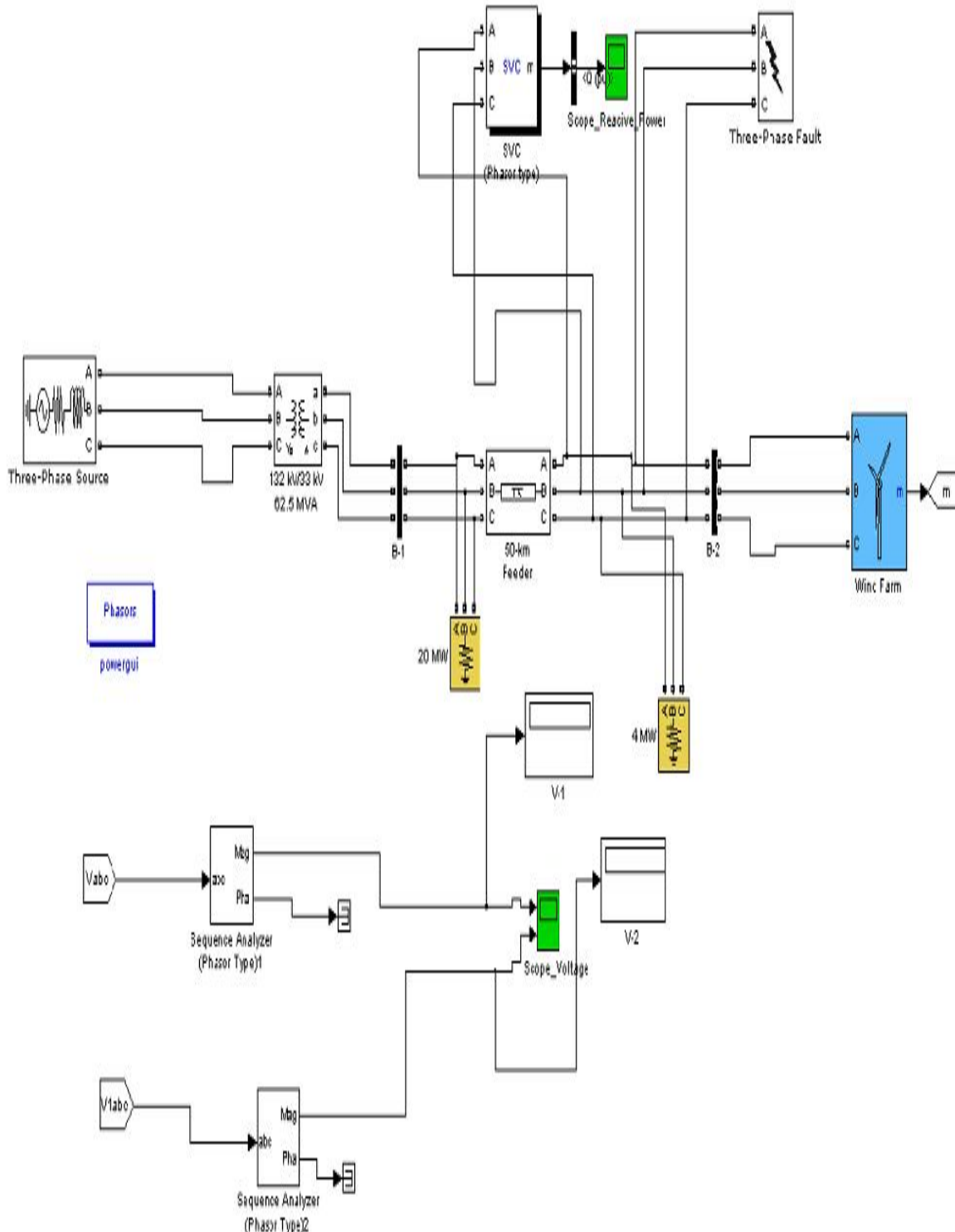


Fig. 5 Simulation model of transmission line in MATLAB

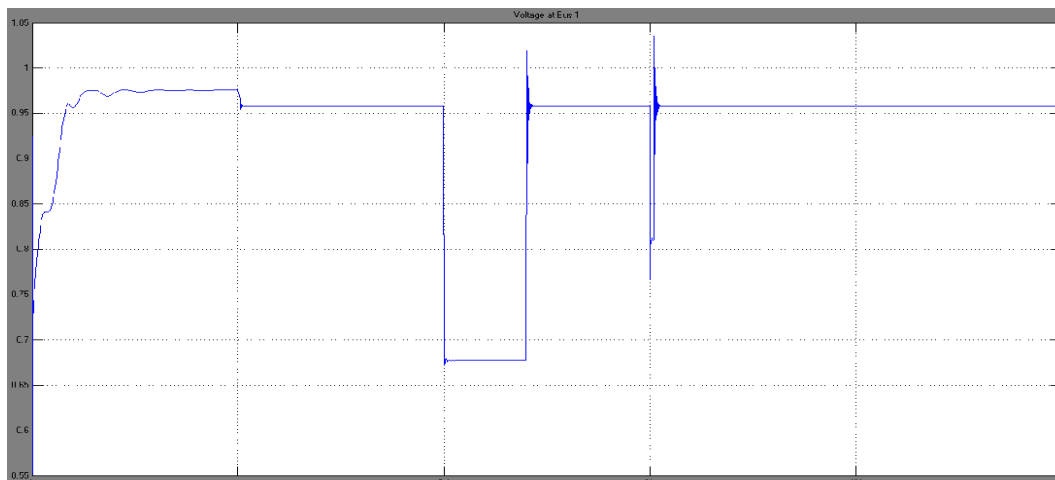


Fig. 6 Voltages at 33 KV Bus-1 during SVC

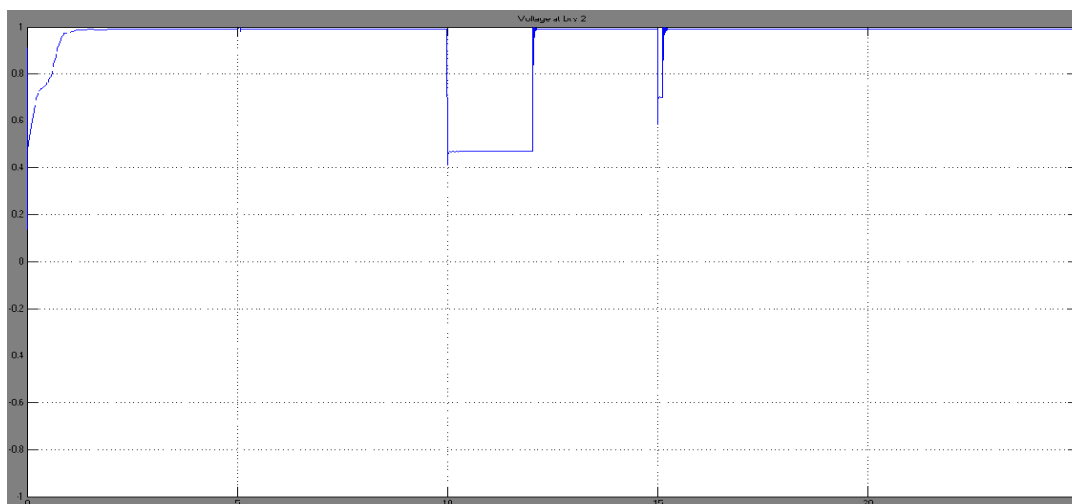


Fig. 7 Voltages at 33 KV Bus-2 during SVC

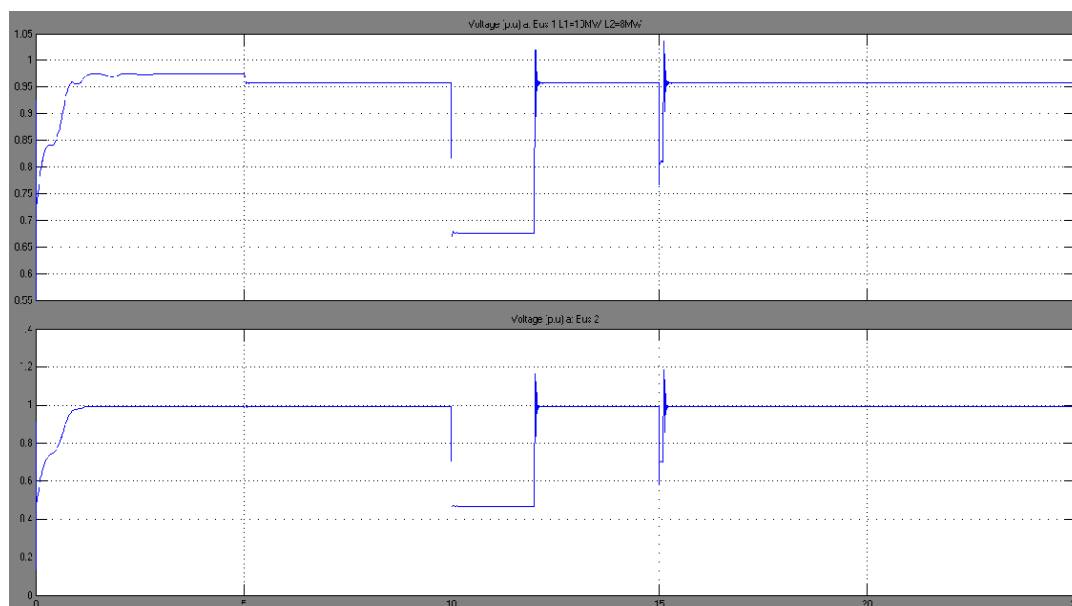


Fig. 8 Reactive power supplied by SVC to the network

TABLE I
VALUES OF VOLTAGE AT BUS 1 AND 2 AND REACTIVE POWER BY SVC BETWEEN 1 TO 20s

Time (s)	V ₁ (p.u.)	V ₂ (p.u.)	Reactive Power by SVC (MVAR)
1	.9265	.9663	-1.501
2	.9379	.9752	-.8471
3	.9378	.9737	-.8373
4	.9373	.9732	-.8702
5	.9377	.9728	-.8815
6	.9213	.9769	-.7522
7	.9213	.9769	-.7522
8	.9213	.9769	-.7522
9	.9213	.9769	-.7522
10	.9213	.9769	-.7522
10.125	.8491	1.0	-3.861
10.150	.8491	1.0	-3.861
10.199	.8491	1.0	-3.861
10.2	.9196	.9727	-.6692
10.3	.9213	.9769	-.7522
10.5	.9213	.9769	-.7522
11	.9213	.9769	-.7522
12	.9213	.9769	-.7522
13	.9213	.9769	-.7522
14	.9213	.9769	-.7522
15	.9213	.9769	-.7522
16	.9213	.9769	-.7522

17	.9213	.9769	-.7522
18	.9213	.9769	-.7522
19	.9213	.9768	-.7524
20	.9209	.9759	-.7498

TABLE III

VALUES OF VOLTAGE ON BUS 1 AND BUS 2 OBTAINED THROUGH MATLAB/SIMULINK AND THROUGH NEURAL NETWORK

Sr. No.	Value of Load L1 and L2 (MW)	Time (s)	Voltage at Bus 1 and Bus 2 obtained through SIMULINK (p.u)		Voltage at Bus 1 and Bus2 obtained through ANN (p.u)		Error (%)	
1	L1=20, L2=4	5	.9458	.9904	.9558	.9507	-1.05	4
2	L1=20 , L2= 4	10	.9272	.9916	.9360	.9420	-.9	5
3	L1= 20 , L2= 4	15	.9272	.9916	.9360	.9420	-0.94	5
4	L1= 15 , L2= 6	5	.9616	.9914	.9611	.9554	.05	3.63
5	L1= 15 , L2= 6	10	.9432	.9918	.9415	.9475	.180	4.46
6	L1=15 , L2= 6	15	.9432	.9918	.94155	.9475	.18	4.46
7	L1= 40 , L2= 10	5	.8163	.9512	.81882	.5162	-.30	4.57
8	L1= 40 , L2= 10	10	.7078	.8435	.7104	.4692	-.36	44
9	L1= 40 , L2= 10	15	.7078	.8435	.7104	.4692	-.36	44
10	L1= 4 , L2= 15	5	.9836	.9866	.9464	.9292	3.78	5.8

VII. CONCLUSION AND FUTURE SCOPE OF WORK

For the proposed work stability improvement of wind generation system using induction generators is investigated. The wind farms supply the active power to the grid when the wind turbines are connected to the grid, but at the same time, the reactive power is absorbed from grid. Induction machines are mostly used as generators in wind power based generations. Induction generators draw reactive power from the system to which they are connected, which is undesirable for the transmission system. Particularly in the

case of large turbines and weak distribution system. Without reactive power compensation, the integration of wind power in a network causes voltage collapse in the system and under-voltage tripping of wind power generators. Therefore, it is necessary to compensate the reactive power for grid-connected wind farm to eliminate the effects of voltage fluctuations which is caused by reactive power loss in grid. With the rapid development of power electronics technology, traditional reactive power compensation shows some obvious drawbacks and connecting the Flexible AC Transmission System (FACTS). Static Var Compensator (SVC) is proposed in this study to compensate the reactive power & improve the stability of the system. An additional active voltage support produced by a SVC can significantly improve the recovery of wind turbines from the fault due to faster restoration of the voltage, improving the stability of the induction generator. Since some other FACT Controllers are cheaper than SVC for the same rating, it is desirable to study the effect of other FACTS in a wind energy system.

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