Restoration of Normal Frequency Affected by Small Load Variations Through HVDC Link Using Neuro-Fuzzy Approach

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Abstract— **HVDC power transmission is coming up with merits to replace the EHV-AC systems. The controller inverter operation can successfully regulate the power in HVDC link leading to fulfillment of power demand in A.C. networks caused by sudden rise in loading. Since overloading and unloading both lead to the departure of operating frequency below or above normal, its control for normalization is exercised through control of power flow in HVDC Link. Also the same is achieved by adjusting firing delay angle intelligently. This paper aims at providing automation to frequency normalization after it has undergone changes from normal value of 50 Hz, due to sudden and sustained increase in load or due to working of generators at increased loads in H.V.D.C transmission systems. It is planned to automate the restoration of departed frequency to normal value by arranging the change in firing delay angle i.e. α of the converter of H.V.D.C. link, till the increased load demand is met with. An adaptive control system has been devised which controls the firing delay angle on the basis of decisions given by a fuzzy controller. Also the fuzzy controls are decided by the departure in frequency from normal. The results have been found to be encouraging.**

Keywords- HVDC Transmission, Power Frequency, Fifing Delay Angle, Converter, Bipolar DC Link, Fuzzy Control.

I. INTRODUCTION

Associated with numerous advantages, HVDC is emerging as a superior methodology for transmission of power over long distance viz-a-viz EHV-AC transmission technique of transmitting the power. Further no interconnected A.C. system can operate without the effective operation of HVDC link. At either end of HVDC link there exists a converter. Once it is a rectifier and the other time it is an inverter. Also in each stage the involved SCRs are required with power ratings and therefore need special care during selection and design. Moreover the power flow in HVDC link has direct impact on the frequency of the A.C network. Thus by modulating the power flow in D.C. link by means of adjusting firing delay angle, it is possible to meet the changes in power demand in A.C. networks. Also the elimination of mismatch of power supplied by the HVDC link and the power demanded by the A.C. network leads to restoration of power frequency in the A.C. networks. It is important to point out that the power frequency undergoes a loss due to sudden loading of generators. Further its restoration requires the feeding of extra power demand. The feeding of extra power demand may be done by the sending end A.C. network. But In the present case the modulation of power is being carried out at the HVDC link level. This could be possible by regulating in the power flow in D.C. link by controlling the firing delay angle and extinction angle of the thyristor. Having appreciated the above model, efforts have been made in the present paper to provide the desired increase in power of D.C. link till the frequency in the A.C. network is restored to power frequency. For this purpose a feedback controller has been proposed to be developed. In order to make its results close to reality it is proposed to support the control action by a fuzzy approach. Since A.C. network are prone to sudden loading dependent on consumer, the loss of frequency in A.C. network interconnected through HVDC link is a recurrent & regular and an all the time requirement. It therefore needs an automatic controller to restore the power frequency in A.C. network. Further this involves a rich application of electronic device in power sector. The Bipolar model of HVDC transmission under consideration is shown in Fig.1.

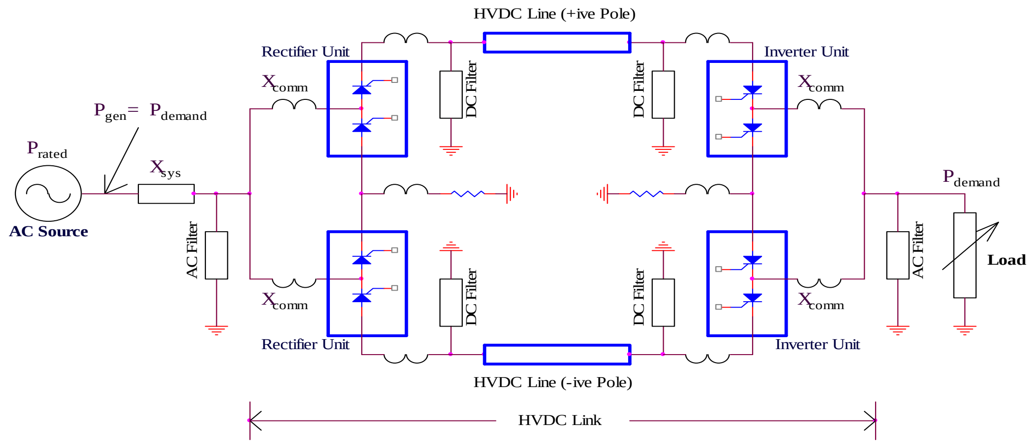

Figure 1. Bipolar model of HVDC Transmission

II. PROBLEM IDENTIFICATION AND PROPOSED SOLUTION

It has been found that due to sudden loading in A.C. network, the power frequency fails to be a power frequency. It can be restored by supplying extra power demand though HVDC link. This needs to control the firing delay angle and extinction angle of the thyristors in the 3-phase controlled converter. The problem is therefore;

- To sense the loss of frequency.
- To decide the firing delay angle & extinction angle for raising the power flow through HVDC link till the power frequency is restored in the A.C. network i.e. the problem requires to develop a controller for restoration of power frequency.
- To introduce the concept of fuzzy approach to make the things more realistic.

In order to obtain a real time working model for developing a frequency restorer, an adaptive control system has been proposed. The model has been first tested on Simulink, made available by MATLAB. The fuzzy approach is being used to act as decision box producing the desired firing delay angle. It is obvious that both overloading and underloading to loss of frequency from its normal value of 50 Hz. This is a direct degradation in power quality of AC supply and is responsible for undesired heating with consequential damages in the distribution network. Under this condition the only option left is to restore the disturbed frequency back to its normal value. But it is not possible unless and until the extra power is fedback to the load demand. Also the same requires power supply to be increased which in turn needs the advancing of firing delay angle of the thyristors woking at the inverter end by keeping the rectifier end with full passage of power flow in the HVDC link. The adaptive feedback controller will cause the feeding of load demand with the consequential restoration of frequency in AC network. The instantaneous value of frequency in the AC network is measured using frequency meter and the same is compared against the reference (i.e. 50 Hz.). The error frequency ($f = f_{actual} - f_{ref}$) is given to a fuzzy controller, giving the output which is some new value of α. The new value of α is adjusted on the thyristor with the help of square gate pulse, which does the role of turning on of thyristor. Due to continuous monitoring the firing delay angle keeps on changing until the normal frequency is regained. The control of frequency through HVDC link works more successfully and yields the restoration of power frequency in the load affected A.C. network.

III. DEVELOPMENT OF FREQUENCY CONTROLLER USING POWER MATCHING CONCEPT

The work is centered on available capacity. The load demand should be so regulated that load $\leq$ rated capacity of the generator. The concept is that for a given load utilize the full equivalent capacity of generator i.e. adjust the firing delay angle, α to meet the load demand then further adjust the governor setting. The governor setting shall be changed after fullest utilization of power pending in HVDC link. When HVDC link feeds for no blockage & load demand gets increased then, the governor throttle will be given more opening, thus increasing the fuel supply and therefore meeting the increased load demand. The basic concept of firing a thyristor by delaying or advancing the power angle α has been used in this approach. It decides the conduction time and non conduction time i.e. ON & OFF time of the thyristor. This in turn determines the amount of power flow through thyristor unit from source to the load. However the setting of α_{min} to α_{max} enables the power to flow form P_{max} to P_{min}. Since the control of P_{demand} lies in the hands of consumer, it affects the frequency of power supply adversely. Also because the uncontrolled and divergent departure of frequency from power frequency level is dangerous for sustained delivery of power and may not only lead to unit shutdown but may prove to be uneconomical. It is therefore aimed to provide a comprehensive control of restoration of power frequency in such a manner that under generation of power by Governor Action is stopped. For the purpose it is suggested to obtain power matching between power demanded and power supplied in three steps.

- Power matching through Load shedding Control
- Power matching through α- control
- Power matching through Governor control

The comprehensive frequency controller which is developed in the present work is shown in Fig.2.

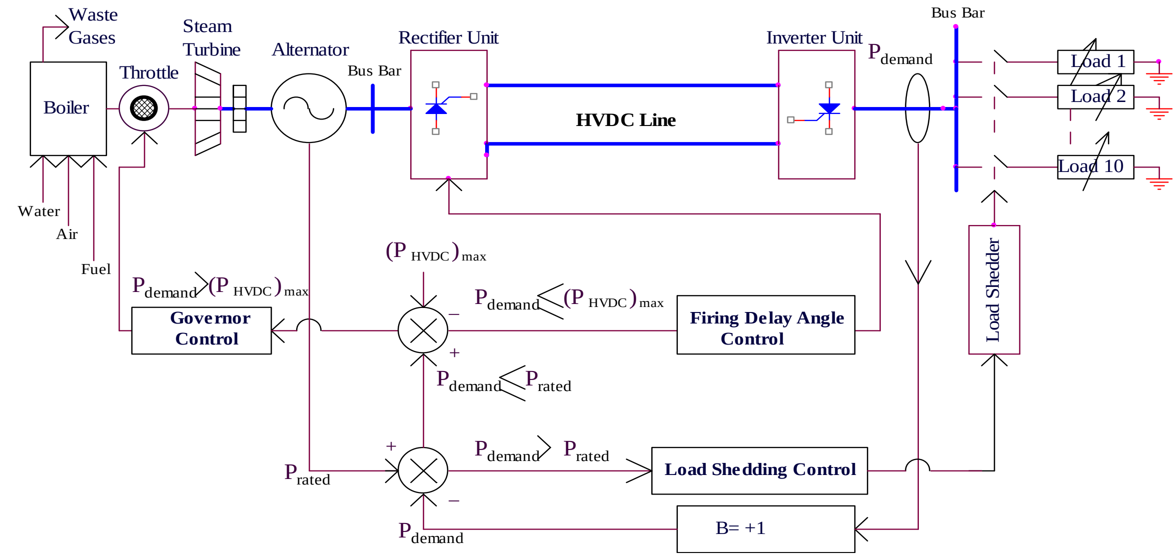

Figure 2. Proposed Comprehensive Frequency Controller using Power Matching Concept

The power demand ($P_{demand)}$ is sensed at the output and compared with generation capacity (P_{rated}). If $P_{demand} > P_{rated}$ the control gives command for load shedding. Then If $P_{demand} \leq P_{HVDC}$ the controller adjust the firing delay angle α to ensure $P_{demand} = P_{HVDC}$. This is done to arrange power matching and therefore restoration of power frequency without raising through Governor setting power import at generator level. As a result the generator capacity is utilized to optimum level thus this facility can be employed till P_{demand} is $\leq (P_{HVDC})_{max}$. In order to make the controller more effective and realistic, the theory of Neuro-Fuzzy control has been used. If the power demand is such that $(P_{HVDC})_{max} < P_{demand} \leq P_{rated}$, the Governor control is executed to establish power matching leading to restoration of power frequency.

The P_{HVDC} output has been obtained for given α by mathematical approach. Also the ANN has been developed, to give the power angles α, so that the desired power output can be ensured on the basis of P_{demand}. Further because the variation of α would follow the momentary change due to variation in P_{demand}, the system will suffer oscillatory changes in output power leading to over heating and fluctuation in size of power flow at a very rapid rate. Thus to avoid these draw backs a fuzzy rule base has been developed and applied upon a neural network, thus giving us a definite α for a given class of power range. Thus a neuro-fuzzy controller provides a smooth control of power flow and lesser changes in the values of α. These values of α are provided by Fuzzy Inference System (FIS) ridden upon ANN. The output of α so provided by FIS is then used for application on thyristor-3 phase bridge, which than enables power matching such that the frequency which got disturbed due to load variation is restored to power frequency again. The load shading is the way out for power matching which is the basis for restoration of power frequency. The load shading unit is activated on the command of expert system and it is made to operate till $P_{demand} \leq P_{rated}$. For execution the over current relay and circuit breaker system is made the basis of execution. However some smart instrumentation is provided for assured operation. The variation of P_{HVDC} on varying the firing delay angle, α has been depicted in the graph shown in Fig.3.

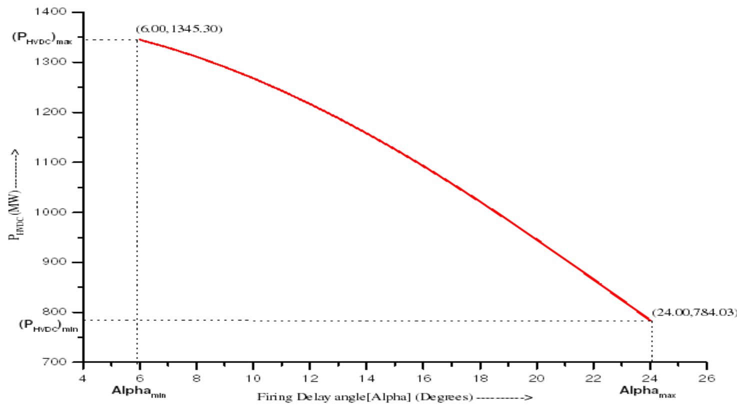

Figure 3. Firing Delay Angle α Vs P_{HVDC} Characteristic for Rectifier

The ANN for determination of α has been obtained by following specifications on MATLAB.
Network Type = Feedforword, Train Function = TRAINLM, Adaption Learning Function = LEARNGDM
Performance Function = MSE, Numbers of Layers = 2, epochs =1000, goal = 0.000000000000001, max_fail= 50.
The MATLAB view of ANN are as shown in Fig. 4 to 7.

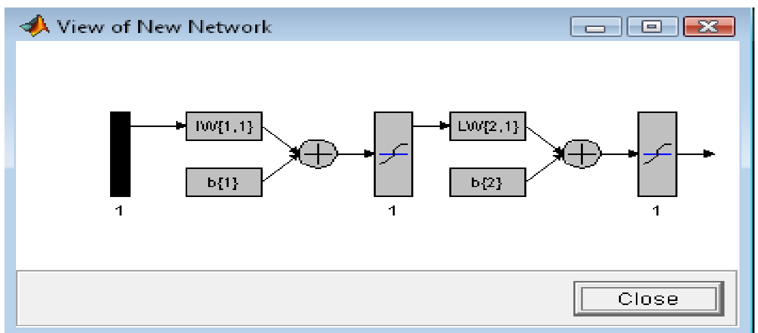

Figure 4. MATLAB view of Network

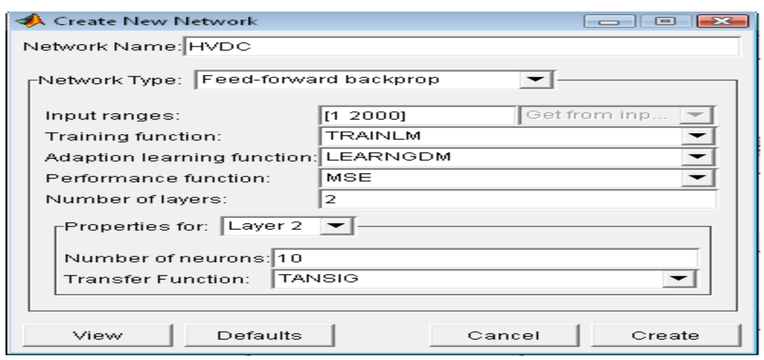

Figure 5. View of Parameter Selecting for Network

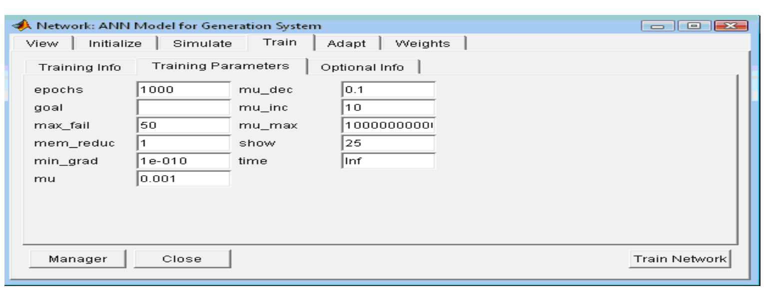

Figure 6. View of Selecting Other Parameters for Network

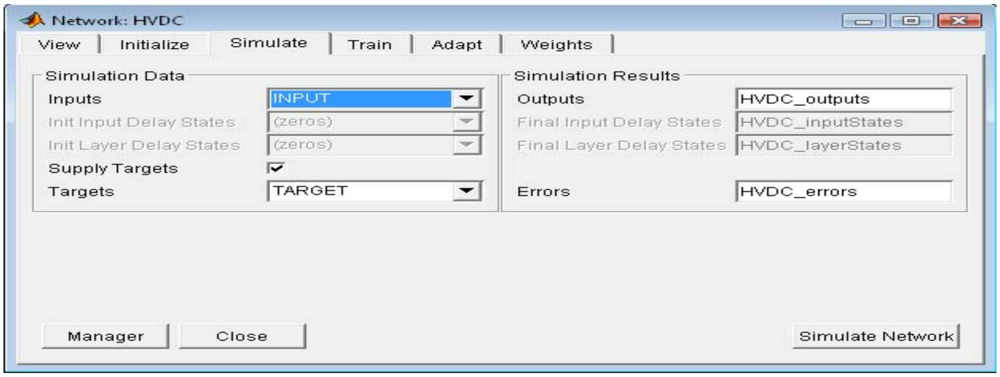

Figure 7. View of Selecting Input and Output Targets for Network

Governor control is basically the control for rate at which the steam is to be injected on the blades of turbine so that mechanical output of turbine raises the speed of generator and thus restores the power frequency on the basis of power matching. This control achieved through the command issued by expert system. For these it is ensured that the rise in throttle opening is stopped soon the $P_{generated} = P_{demand}$. The flow chart for the Expert System is shown in Fig.8.

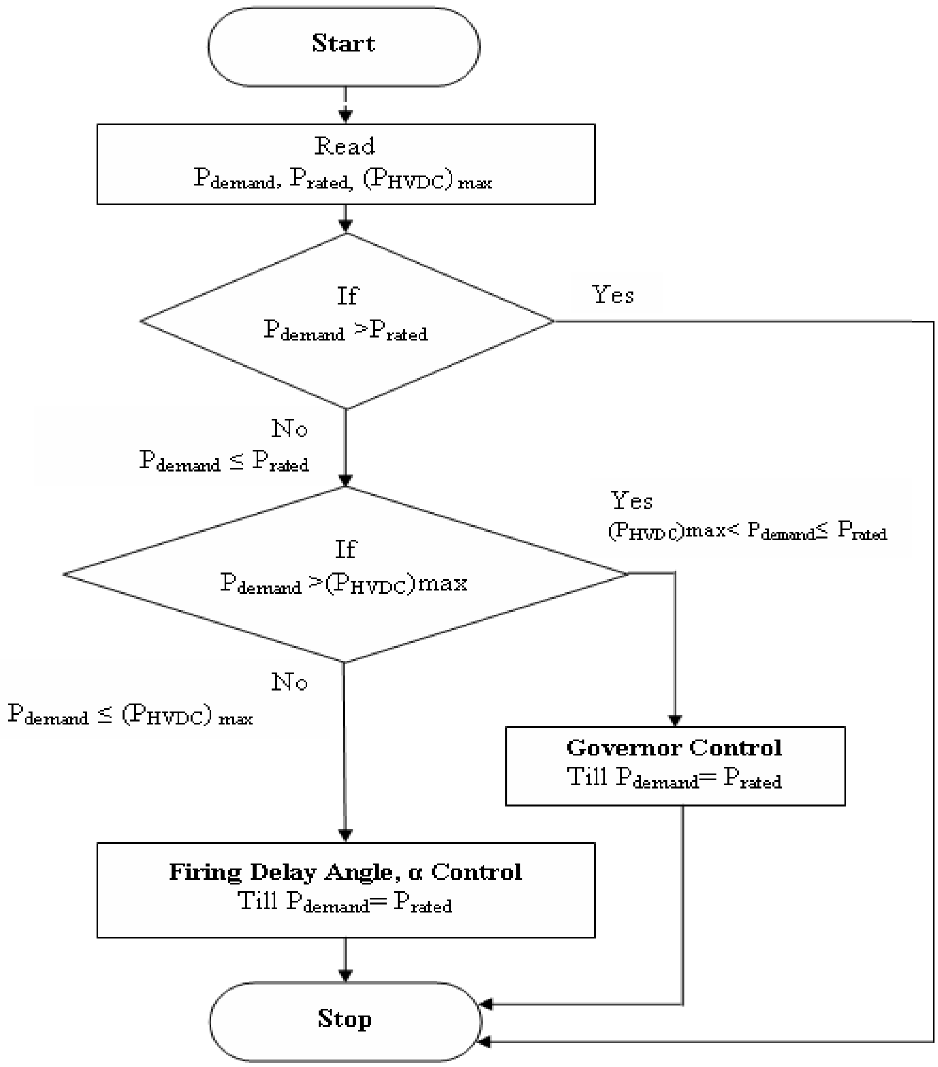

Figure 8. Flow Chart for the Expert System

IV. ILLUSTRATION AND RESULTS

We have tested the developed comprehensive frequency controller for 100 samples of daily load curves and suggest the applicability of each of the 3-stages of control action provided for matching power conditions, so that the system is restored back to normal operation at power frequency after having undergone perturbations due consumer controlled load demand. The comprehensive controller for restoration of power frequency is reproduced in Fig. 9. The value of firing angle (α) has been obtained by using ANN model with 24 inputs of P_{demand} Vs 24 values of α for 1-day. The ANN considered in present case is as below.

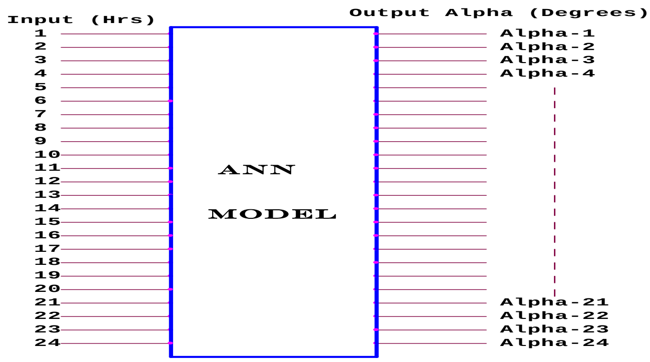

Figure 9 ANN Model for calculating 24 values of α

Out of 100 load curves, the first 75 load curves which provide for P_{HVDC} and α_{math} have been used for training the ANN as shown in Fig. 10. Also the second 25 load curves which provide for output ANN for given input of P_{HVDC}, have been used to obtain α_{ANN}. The error curves have been plotted for α_{math} & α_{ANN} as shown in Fig.11.

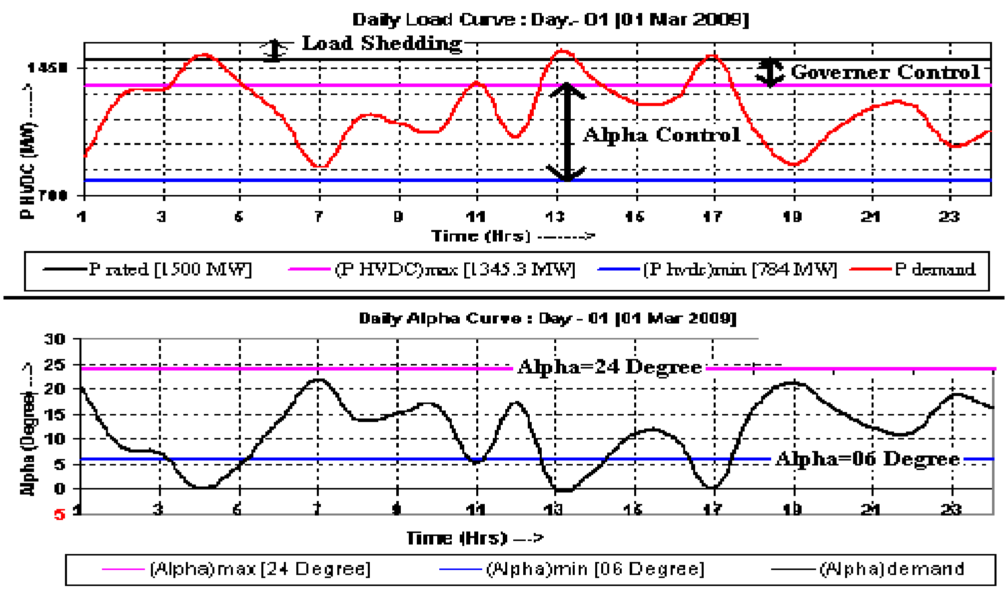

Figure 10 Illustrations of Daily Load Curve and α Curve

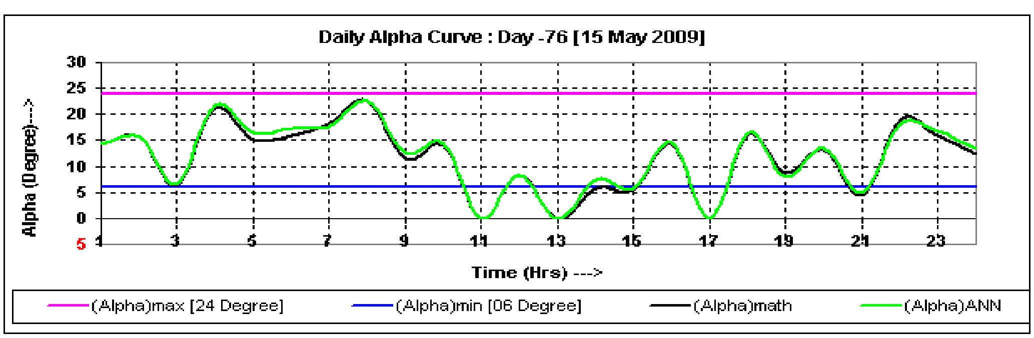

Figure 11 Illustration of Error Curve for α_{math} & α_{ANN}

Since applying the instantaneous value of α makes the system unstable and is also not desirable for reliable operation hence the cut off value of α is applied to the rectifier end corresponding to a small power sub-band. For this implementation, the entire range of P_{demand} is divided into 8 subparts. The power bands and associated values of α have been derived by fuzzy rule base as given in Table 1. Also Fig.12 shows the ANN Model for calculating 24 values of α.

TABLE I. POWER SUB-BANDS VS A DEMAND

Sl. No.	P_{HVDC} (MW)		α (Degree)	
	Power Sub-Band	**Range**	**α -Sub band**	**Cut off value of α demand**
1	$\Delta P_1 = (P_{min} - 0)$	(784.033-0)	α_{max}	24
2	$\Delta P_2 = (P_{VL} - P_{min})$	(906.189-784.033)	α_{VH}	21
3	$\Delta P_3 = (P_L - P_{VL})$	(1021-906.189)	α_H	18
4	$\Delta P_4 = (P_{mid} - P_L)$	(1126.233-1021.498)	α_{mid}	15
5	$\Delta P_5 = (P_H - P_{mid})$	(1216.969-1126.233)	α_L	12
6	$\Delta P_6 = (P_{VH} - P_H)$	(1290.794-1216.969)	α_{VL}	09
7	$\Delta P_7 = (P_{max} - P_{VH})$	(1345.305-1290.794)	α_{min}	06
8	$\Delta P_8 = P_{max} +$	(P_{rated} (1500)-1345.305)	α_{min} (+ Governer Setting)	06

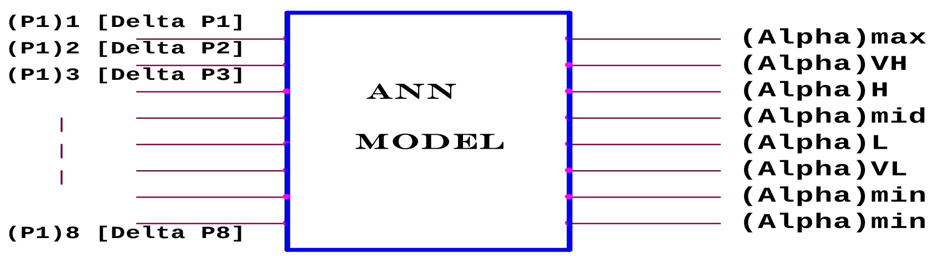

Figure 12 ANN Model for calculating 24 values of α

V. CONCLUSION AND FUTURE SCOPE

Bulk power transmission and interconnection of two A.C. networks, working even at two different frequencies could be possible through HVDC link/transmission system. In this work the power matching concept has been used to restore power frequency which suffers deviation in increasing or decreasing mode due to consumer controlled loading conditions. A comprehensive controller has been developed which enables power matching in three manners. In 1st manner when the load demand is less than $(P_{HVDC})_{max}$, the transmission capacity is not fully utilized. In such a case the hidden power of HVDC link is released by readjusting the firing delay angle (α) till the power demand is met with. This approach is known as firing angle control or α- control. Also α-control is performed though Neuro-fuzzy controller wherein α is decided on the basis of power demand. In Neuro-fuzzy controller the ANN gives point by point value of α. Also because the load demand remains in continuously variable mode, smart changeover is not possible and is also not advisable. Thus in order to achieve this and also to reduce the number of fluctuations (i.e. corrective adjustments), α-control has been exercised through fuzzy controller. In 2nd manner when load demand is more than $(P_{HVDC})_{max}$ rating of HVDC link but less than P_{rated} of the generator i.e. when, $(P_{HVDC})_{max} < P_{demand} \leq P_{rated}$, The Governor control is used for obtaining power matching and thus restoring the power frequency to normal. In 3rd manner when the load demand is more than P_{rated} of the generator, the control action is activated by Load shedding control. An expert system has been developed to exercise the above control actions in a sequential approach. The important outcome of the work is thus the restoration of power frequency can be achieved even without the help of only Governor Control thus saving the cost of production of energy. The load shedding beyond the rated capacity of the generator works to reduce the ageing of machines and prevents overstressing of machines due to electromechanical stresses. Advantages of Expert System are:

- Control is smooth & power generation is utilized point by point, thus sparing addition of units.
- Further it is possible to interconnect 2-AC networks operating at different frequencies.
- It enables bulk power transmission system.
- Introduction of Neuro-Fuzzy approach serves against the losses and imperfections resulting form hard computing.

In future proposed model can be extended to meet the power supply conditions through National/International Grid to extend power to areas of non-power generations. Further the model can be tried for interconnection of more than two A.C. networks.

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