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A novel ANN based UPFC for voltage stability and reactive power management in a remote hybrid system

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Abstract

This paper gives a novel idea of application of ANN based UPFC controller for Reactive Power compensation in a standalone hybrid power system and thereby enhances the stability of the system .For the Isolated WECS a linear small signal transfer function model of the hybrid wind Diesel model is considered with different loading conditions. The reactive power compensation and stability analysis have been carried out with UPFC Controller with an IEEE exciter I. A feed forward neural network with back propagation technique is designed to tune the parameters of UPFC controller. From the matlab Simulation it is clear that the system parameters attend steady state value with lesser time and complexities.

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Keywords Reactive power compensation;ANN Controller;Isoalated WECS;SG;IG;UPFC

I. Introduction

Standalone hybrid systems are small power systems located at remote places to cater the local power demands of those particular places which are situated far away from the main grid. Generally two or more renewable sources are combined to form a hybrid system where shortfall of one source is recovered by the other. [1]-[2]. Wind Diesel system is often used as hybrid power system where a diesel generator works as a backup with a wind turbine to

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transmit power to isolated areas. SGs function as diesel Genset and SCIG/DFIG/PMIG are preferred in Wind Turbine for an better performance and for their rugged characteristics [3]-[5].In case of a hybrid WECS, Induction generator requires reactive power for its operation which is generally met by the_Synchrous machine. The SG fails to meet the demand of reactive power in many instance and leads to problems like voltage fluctuation and instability
Nomenclature

P_{IG} Q_{IG}	Real Power, Reactive by Induction Generator based Wind Turbine	K_a and K_v	Exciter Gain, Gain of Energy balance loop
P_{SG} Q_{SG}	Real Power, Reactive Power delivered by Synchronous Generator based DG	Ta, T_r, T_s	Exciter time constant, rising time constant, settling time constant
E_M	Electromagnetic energy stored in the Induction Generator (DFIG)	X_d and X_d'	Synchronous generator reactance under steady state and transient state
ΔE_M	Incremental Change in the Stored Electromagnetic Energy of Induction Generator (DFIG)	Teand Tm	Change in electro magnetic torque and mechanical torque
$\Delta QUPFC$	Reactive generated by UPFC	$\Delta\alpha$	small Change in Phase angle of Compensators
ΔQ_{COM}	small Change in Reactive Power supplied by UPFC.	ΔE_q	Small Change in Internal Armature Voltage
K_A and K_E and K_F	Voltage Regulator, Exciter and Stabilizer s gain constants.	ΔE_{fd}	Incremental Change in the Voltage of the Exciter
ΔV	Small Change in System Voltage	η	Performance Index

Generally capacitor banks are utilised to control reactive power in the hybrid power system. As renewable like wind is unpredictable and loads are constantly changing fixed capacitors cannot meet the challenge to compensate reactive power. [7]-[8].The challenges of power quality issues like voltage instability and reactive power compensation are generally compensated by the FACTS(Flexible AC Transmission System) devices [9]-[11].UPFC like SVC and STACOM is used for controlling reactive power of the hybrid power system. It is extensively utilised for voltage, angle stability studies in the hybrid power system. Management of reactive power has become a necessary aspect of hybrid power system and deficiency of adequate reactive power forces the hybrid system to go through voltage instability and fluctuations. Many a times UPFC has been projected as a reactive power compensating device in several literatures. This work proposes an ANN for the UPFC Controller to manage reactive power and voltage instability in a standalone wind diesel hybrid system. The proposed ANN controller tunes the gains of the PI Controller and enhances the dynamic voltage stability.Numerous problems are easily solved with the application of ANN controller in power system. The working of ANN is similar to working of biological nervous systems. ANN consists of a number of processing elements (neurons) working together to solve a problem. It is designed for a specific application through learning process which adapts the synaptic connections of the neurons. The main merits of ANN are the relationship between the input and output data s for an unknown relationship or complex function. The gains of the PI controller depend upon the type of reactive power load for optimum performance. Due to the variable nature of the load, the PI gains setting of UPFC are adjusted after proper tuning. The paper focuses the ANN based approach to tune the PI gains of the UPFC controller over a wide range of load characteristics. For the simulation the multi-layer feed-forward ANN tool box of MA TLAB with the error back-propagation training method is used. The dynamic responses of the hybrid system are shown for 5 % step increase in load reactive power with and without 5% step increase in input wind power.

This paper discusses a small signal model of wind-diesel system for analysis of transient stability and reactive power compensation with introduction of ANN based UPFC controller for 5% load change. Section II describes the whole system and the detailed mathematical model of it. Detailed work with application of of ANN controller for tuning the gains of PI controller is discussed in section III. Finally the simulation results with detailed descriptions are represented in section IV and conclusion part in Section V.

II. **System configuration and its mathematical modelling**

The main constituents of this standalone hybrid power system are Induction machine driven wind turbine, synchronous machine driven diesel power and UPFC Controller. The typical block diagram clearly shows the reactive power exchange between the sources and loads. To meet the reactive power deficiency in the hybrid system and to enhance the voltage stability an UPFC with ANN controller is provided. UPFCs are always considered relatively better reactive power compensators than other FACTS devices like SVC and STATCOM. The hybrid system parameters are mentioned in Table1.

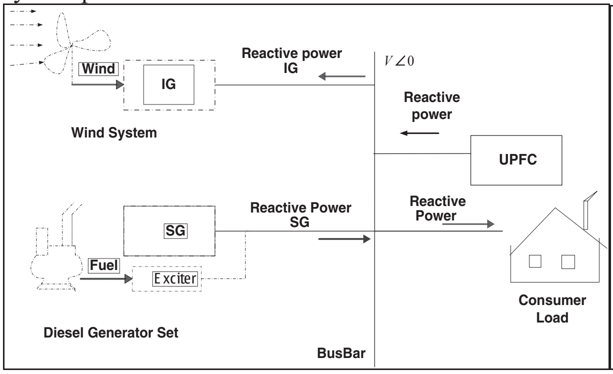

Fig.1.Block diagram of WECS with UPFC

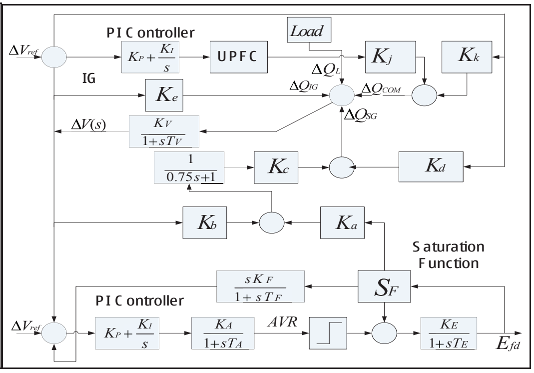

Fig.2. Transfer Function model with UPFC

In the hybrid system Reactive power balance equation is obtained as [13]

$$\Delta Q_{SG} + \Delta Q_{UPFC} = \Delta Q_L + \Delta Q_{IG} \tag{1}$$

Because of small reactive power load change ΔQ_L, terminal voltage output of the system varies that influences the reactive power requirement of other elements of the hybrid system. The mathematical expression of reactive power balanced equation is $\Delta Q_{SG} + \Delta Q_{UPFC} - \Delta Q_L - \Delta Q_{IG}$ and the value deviates the system output voltage. The real power exchange equation of the system is $P_{IG} + P_{SG} = P_L$ (2)

Reactive power exchange equation is $Q_{SG} + Q_{COM} = Q_L + Q_{IG}$ (3)

$$\Delta V(S) = [\Delta Q_{SG}(S) + \Delta Q_{COM}(S) - \Delta Q_L(S) - \Delta Q_{IG}(S)] \tag{4}$$

The synchronous generator equation is $Q_{SG} = \frac{(E_q' V\cos\delta - V^2)}{X'd}$ (Transient condition) (5)

with small change $\Delta Q_{SG} = \frac{V\cos\delta}{X'd\Delta E'q} + \frac{E'q\cos\delta - 2V}{X'd\Delta V}$ (6)

Taking the Laplace Equation we get the relation $\Delta Q_{SG}(s) = K_a \Delta E_q'(s) + K_b \Delta V(s)$ (7)

$$\Delta Q_{svc}(s) = K_c \Delta V(s) + K_d \Delta B_{svc}(s) \tag{8}$$

UPFC Controller:-The UPFC controller consists of two inverters where the first Inverter provides or absorbs real power while the reactive power is either produced or absorbed by the second inverter. In a SMIB the injected powers depend on the injected voltages and are explained as

$$P_{sh} = \frac{V_i V_{sh}}{x_{sh}} \sin(\delta_i - \delta_{sh}) \quad , Q_{sh} = \frac{V_i^2}{x_{sh}} - \frac{V_i V_{sh}}{x_{sh}} \cos(\delta_i - \delta_{sh})$$

The reactive power delivered by UPFC varies with V_{m2p} and δ that becomes proportional to the voltage for the isolated hybrid system the reactive power supplied by the UPFC in the above mentioned system is

$$\Delta Q_{UPFC} = K_j \; \Delta\delta(S) + K_k \Delta V(S) \tag{9}$$

III. Artificial Neural Network

ANN is basically based upon the neural structure of the brain. It tries to imitate the functioning of the brain. As we know that brain stores information and ANN provides a new field of computing which involves the creation of massive parallel networks to solve specific problems. As neurons provide the ability to remember and apply the previous experiences, ANN works on a similar pattern to achieve high computational rates due to massive parallelism fault tolerance capability. The controller uses back propagation algorithm for the training process.

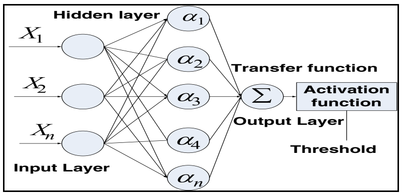

Fig3 - Shunt Controller of UPFC

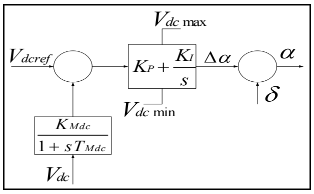

Fig 4-Structure of ANN Controller

III A. Back Propagation Algorithm:-

This algorithm is the most popular and widely accepted algorithm.

First step-Initialization- In this network weights and threshold levels are randomly distributed in small range.

Second step-Activation Here the outputs of the neuron in the hidden layers are calculated. $y_j(p) = sigmoid\left[\sum_{i=1}^{n} x_i(p).w_{ij}(p) - \theta_i\right]$ n is equal to the number of inputs of the neurons j in the hidden layer. So the output of the neuron in the outer layer $y_k(p) = sigmoid\left[\sum_{i=1}^{m} x_{jk}(p).w_{ik}(p) - \theta_k\right]$

Third step- Training of weights-The error gradient for the neurons in the output layer is calculated.

$\delta_k(p) = y_k(p)\left[1 - y_k(p)\right].e_k(p)\,, e_k(p) = y_{dk}(p) - y_k(p)$ corrections weights $\Delta w_{jk}(p) = \alpha.y_j(p)\delta_k(p)$

then the weights at the output neurons are updated as $\Delta w_{jk}(p+1) = w_{jk}(p) + \Delta w_{jk}(p)$ The error gradient of the hidden layer neurons can be calculated $\delta_j(p) = y_j(p)\left[1 - y_j(p)\right]\sum_{k=1}^{l}\delta_k(p)w_{jk}(p)$ and the weight corrections are $\Delta w_{jk}(p) = \alpha x_i(p)\delta_j(p)$ when updated the weights at the hidden neuron $w_{jk}(p+1) = w_{jk}(p) + \Delta w_{jk}(p)$

Fourth step-Iteration -An increase of iteration *p* by one step and the process should be repeated until the selected error Criterion is satisfied.

III.B. Training of parameters by ANN

The value of the reactive power load voltage characteristics (n_q) is used as input of the ANN and the outputs are the proportional and integral gains k_p and k_i of UPFC controller. The ANN uses the normalised values of n_q as input and produces output in normalised way and is converted to actual one. Determination of weights is known as training of the learning process. An input output pairing is first prepared prior to the conducting of training process. Based on the loading conditions the set is first developed by calculating the desired PI controller gains. A typical range between 0.0 to 4.0, taking the exponent of load voltage characteristics is prepared to cover all typical loads of the power system. The network is trained repeatedly till an optimum agreement between predicted gains and actual gains is achieved. The network is again tested to predict the actual gain settings of the load model. The performance index η is based on integral square error (ISE) and is equal to $K_i^{\min} \le K_i \le K_i^{\max}$ and by minimising the performance index optimised values of k_p and k_i are determined. ΔV Is the voltage deviation, subject to the constraints $K_p^{\min} \le K_p \le K_p^{\max}$ and $K_i^{\min} \le K_i \le K_i^{\max}$ and the testing is performed for n_q, 1.25 and 3.25.

Table 1-Optimum gain settings UPFC for different values of exponent of reactive-load voltage char.

nq	0.5	1	1.5	2	2.5	3	3.5	4
Kp	35	38	41	45	47	49	50	54
Ki	4985	5100	5405	5600	5807	6008	6234	6458

IV. Simulation Results

MATLAB based simulation has been carried out taking an ANN based UPFC Controller for the wind diesel hybrid power system. The ANN controller for compensating reactive power and voltage of the hybrid system was taken with a step load change of 5%. The variation of all the system parameters such as small variation in reactive power of Synchronous generator, Induction generator, Reactive Power Change of UPFC, Variation in firing angle, Variation in terminal voltage, Variation in field excitation, Variation in armature voltage, and change of armature voltage under transient, etc., as shown in Fig. 3, are studied for the above mentioned disturbance using traditional PI Controller and the ANN controller.

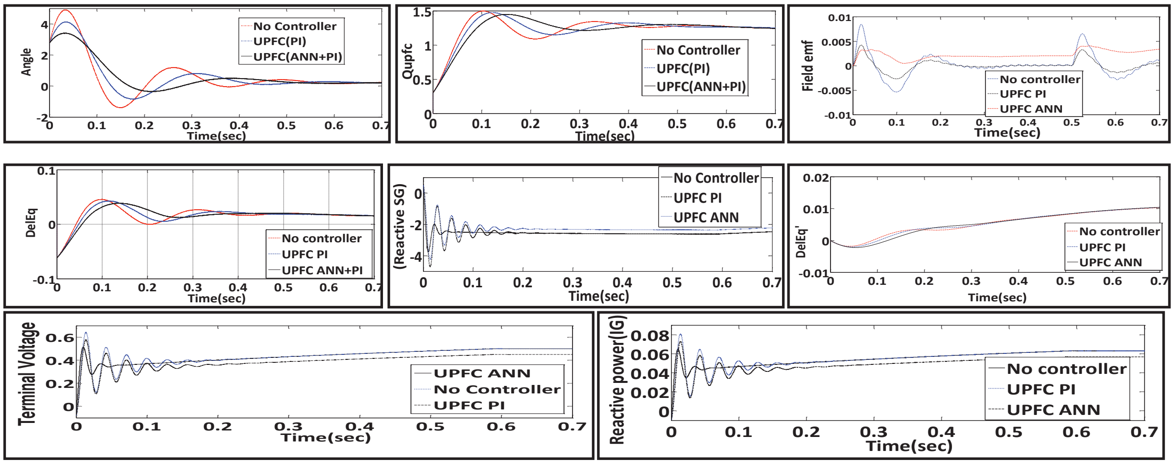

Fig 3 (a) Change in firing angle (b) Reactive Power change of UPFC (c) Field excitation change (d) Eq change with time (e) Reactive power change in DG (f) Eq' change with time(g) Terminal voltage change in Wind Diesel System (h) Reactive power change in Induction Generator

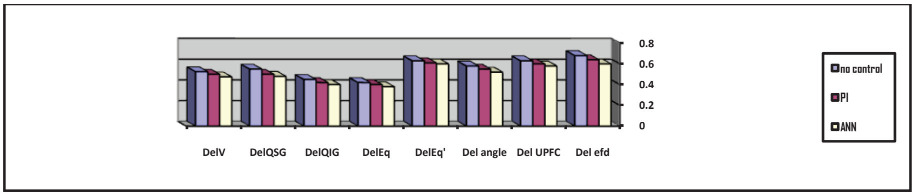

Figure 4(b)-Settling time of different parameters with time

During study it is quite evident that the ANN Controllers show better performance and the settling time with peak overshoots are found to be less in comparison to the conventional PI Controller. The firing angle in case of TCR improves in case of UPFC with decrease in the value of wind input. The ANN Controller has shown robustness in its approach

V. Conclusions

This paper gives a novel solution for the dynamic voltage stability and reactive power management issue in the isolated hybrid power system with the incorporation of ANN based UPFC controller. Results show the positive changes in the system parameters with the change of load and it is quite evident that the reactive Power management of the hybrid system is achieved .The compensation in case of back propagation based ANN controlled system is more robust than the conventional power system. The proposed ANN controller based hybrid system shows better results and rising time, overshoot and settling time get improved by the proposed controller. Furthermore it is found that the said system with ANN Controller demonstrates robustness and stability to wide changes of wind input and loading condition.

Appendix

Table 2: Comparison between two controllers for 5% load change

	PI Controller		ANN Controller	
	Maximum Deviation	Settling Time	Maximum Deviation	Settling Time
DelV	0.05	0.5	0.048	0.475
Del UPFC	1.5	0.6	1.48	0.58
Del QSG	0.52	0.5	0.515	0.48
Del QIG	0.0052	0.42	0.0051	0.4
Del E_q	0.048	0.4	0.047	0.38
Del $E_{q'}$	0.01	0.61	0.009	0.6
Del Alpha	4.1	0.55	3.4	0.52
Del Efd	0.049	0.64	0.048	0.6

Table 3- wind-diesel hybrid system parameters

System Parameter	**WECS**		
Wind Power (KW)	200	**UPFC**	
Diesel Power(KW)	200	T_α(S)	0.05
Load (KW)	300	T'_{do}	5.044
Base Power KVA	300	X'_d	0.3
Synchronous Generator(SG)		**Induction generator**	
$P_{SG,}$ in Kilowatt	0.4	$P_{IG,}$pu Kilowatts	0.6
Q_{SG} Kilowatt	0.2	$Q_{IG,}$pu KVAR	0.189
$E_{q(}$ per unit	1.113	$P_{IN,}$pu Kilowatts	0.75
E_q' per unit	0.96	r1=r2(pu)	0.19
V per unit	1.0	X1=X2(pu)	0.56
$X_{d,}$ per unit	1.0	**LOAD**	
$T'_{do,}$s	5	$P_{L(}$pu) in KW	1.0
		Q_L(pu) in KVAR	0.75
		α in Radian	2.44

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