Impact of Fuzzy Logic Based UPFC Controller on Voltage Stability of a Stand-Alone Hybrid System

Asit Mohanty and Meera Viswavandya

Abstract The main focus of the paper is to compensate the Reactive Power generated in the isolated wind–diesel hybrid system and enhancement of the Voltage stability by the use of Fuzzy PI based UPFC Controller. Linearised small signal model of the wind-Diesel System with different loading conditions is taken with IEEE Excitation system. In this paper the compensation has been carried out with UPFC Controller for different loading conditions. A self tunned Fuzzy PI controller is designed to tune the parameters of PI Controller Kp and Ki. Simulation result shows that the parameters of the system attend steady state value with less time due to the proposed controller.

Keywords Stand-alone hybrid system · UPFC · Fuzzy logic · Voltage stability

1 Introduction

Though renewables like wind, solar fuel cell are plentily available in the nature, they are intermittent and non-predictable in nature. Therefore Researchers have gone for combining one or more renewable energy sources to make a hybrid system so that any shortage due to one source can be compensated by the other. Small Hybrid systems not only provide power to the remote places, they are many times connected to the main grid to supply excess generated power.

One or more renewable sources are combined to form a Hybrid system where the shortage due to one

source is compensated by the other [1, 2]. Wind Diesel system is the most commonly used hybrid system in which a wind turbine combines with a diesel

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L.C. Jain et al. (eds.), *Computational Intelligence in Data Mining - Volume 3*,
Smart Innovation, Systems and Technologies 33, DOI 10.1007/978-81-322-2202-6_13

generator to provide power in remote places. Normally a Synchronous generator is used as Diesel Generator and Induction Generator is used in Wind Turbine for an improved performance [3, 5]. Though Induction generators are advantageous in comparison to Synchronous generator due to its rugged characteristics, they need reactive power for their operation. In a hybrid power system having both synchronous generator and Induction generator, the Induction generator needs the reactive power and it is provided by the Synchrous generator. But the reactive power supplied by the synchronous generator is not sufficient and therefore a big gap is created between the demand and supply of reactive power. Because of these gap problems like voltage fluctuation and instability occur in the hybrid power system.

In the literature survey [6] authors have emphasized the use of capacitor banks to improve voltage stability and to compensate the reactive power in the system. [6–8]. But due to the uncertain nature of wind and wide variation of load the fixed capacitors fail to deliver the required reactive power to the system. [7]. To meet the challenge of these power quality issues like voltage instability and reactive power compensation researchers have advocated the use of FACTS (Flexible AC Transmission System) devices [9].

UPFC [10] is one of the important member of FACTS devices which is used like SVC and STACOM to compensate the reactive power of the power system. This device is used for voltage and angle stability studies of power system. In the absence of reactive power, the system goes through a wide voltage variations and unnecessary fluctuations. Papers have projected UPFC as a reactive power compensating device with PI controllers. This work proposes a fuzzified UPFC Controller for reactive power control in a wind diesel hybrid system. The proposed controller tunes the gains of the PI Controller to enhance the transient stability and reactive power compensating capability of the system.

Here in this paper a SIMULINK based Fuzzified wind diesel model (Fig. 2) with IEEE exciter 1 (Fig. 3) is taken to analyze the transient stability and reactive power compensation issue with the application of UPFC for 1 % change in load disturbance. In Section no II the complete description of the system and the mathematical modeling is depicted. The detailed work of self tuned fuzzy logic for tuning the gains of PI controller is mentioned in Sect. 3. The model simulation output results with description are represented in Sect. 4. The conclusion part is clearly represented in Sect. 5.

2 System Configuration and Its Mathematical Modeling

This hybrid system consists of one Induction generator (IG), a Synchronous generator (SG), electrical loads and Reactive power control in the form of UPFC supported by its control strategy. The block diagram is clearly depicted in Fig. 1. The hybrid system parameters are mentioned in Table 3.

The reactive power balance equation of the system as mentioned in Fig. 2 having (SG, UPFC, IG, and LOAD) is $\Delta Q_{SG} + \Delta Q_{UPFC} = \Delta Q_L + \Delta Q_{IG}$.

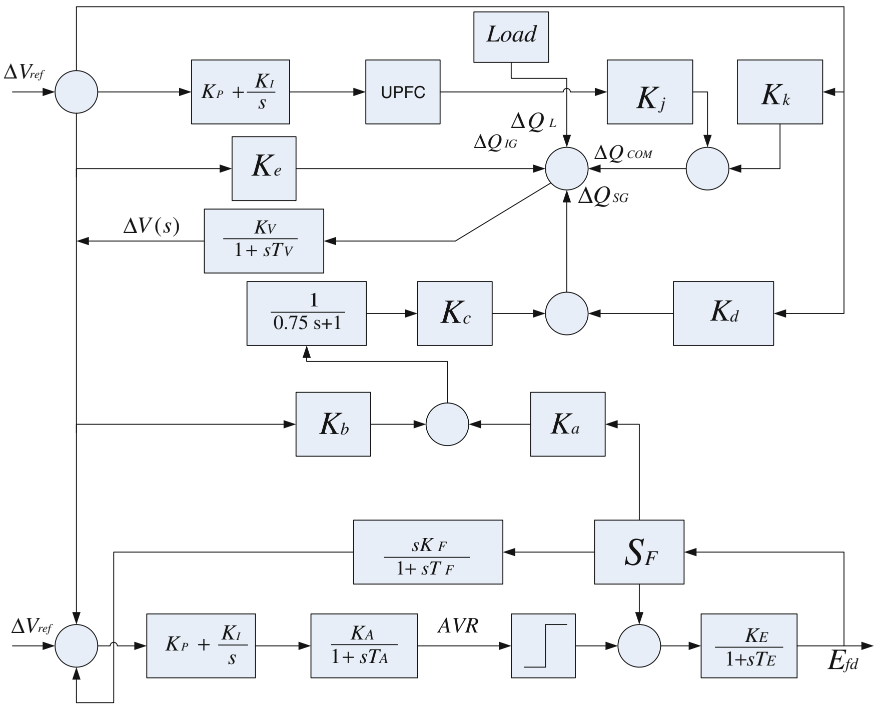

Fig. 1 Wind-diesel hybrid power system with UPFC

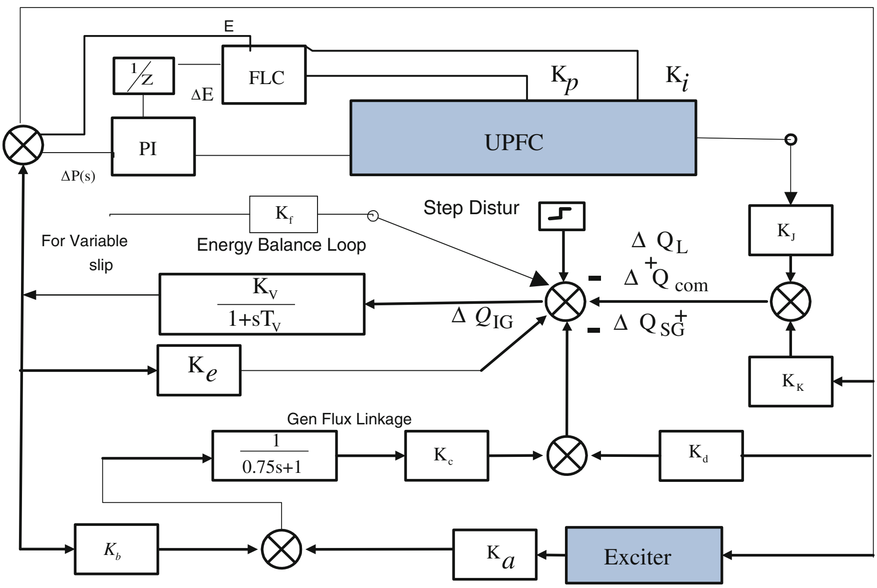

Fig. 2 Transfer function model with fuzzy logic based UPFC controller

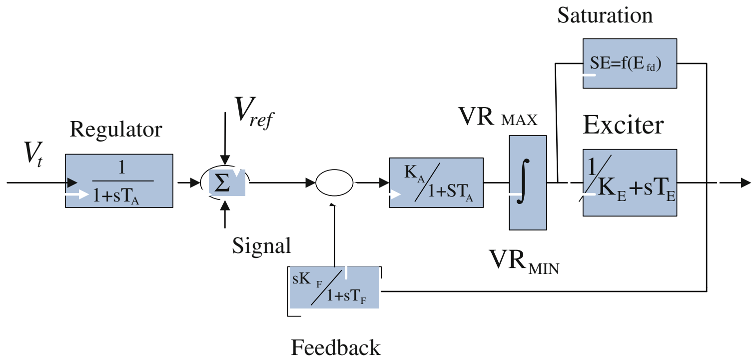

Fig. 3 Excitation system 1

Due to abrupt change in reactive power load ΔQ_L, the system terminal voltage varies accordingly and affects the reactive power balance equation of the whole system. Final reactive Power balance equation of the said system is $\Delta Q_{SG} + \Delta Q_{UPFC} - \Delta Q_L - \Delta Q_{IG}$ and this value deviates the system output voltage.

$$\Delta V(S) = \frac{K_V}{1 + ST_V}[\Delta Q_{SG}(S) + \Delta Q_{COM}(S) - \Delta Q_L(S) - \Delta Q_{IG}(S)] \tag{1}$$

$$\Delta Q_{SG} = \frac{V\cos\delta}{X'd\Delta E'q} + \frac{E'q\cos\delta - 2V}{X'd\Delta V} \text{ For small change} \tag{2}$$

$$\Delta Q_{SG}(S) = K_a \Delta E'q(s) + K_b \Delta V(s) \tag{3}$$

In case the controlling device is SVC, then the Laplace Transform of the said equation for a small perturbation [16]

$$\Delta Q_{SVC}(s) = K_c \Delta V(s) + K_d \Delta B_{SVC}(s) \tag{4}$$

2.1 UPFC Controller

The Structure of UPFC helps to control Reactive power and Active Power by injecting AC Voltage in series with amplitude and a phase angle to the Transmission Line. The role of first Inverter is to provide or absorb real power while the second Inverter produces and absorbs reactive power and there by provides shunt compensation. The injected powers depend on the injected voltages and bus voltages also. Buses *i* and *j* are taken as load buses in the load flow analysis as clearly shown in Figs.4 and 5. The injected powers are given as follow:

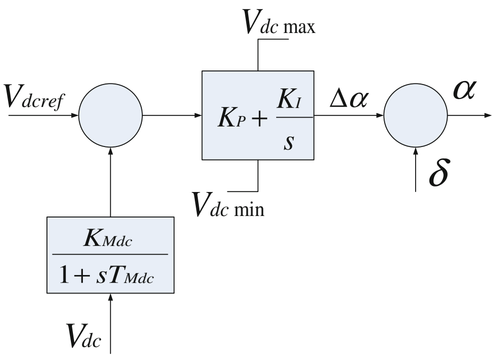

Fig. 4 Shunt controller of UPFC

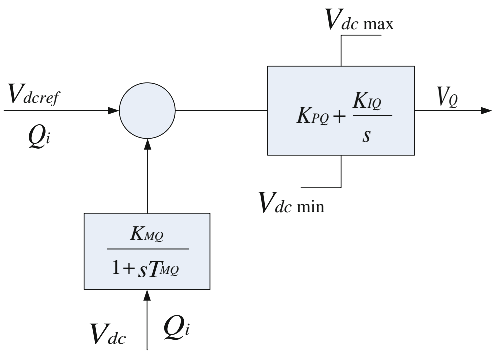

Fig. 5 Series controller of UPFC

$$P_{sh} = \frac{V_i V_{sh}}{x_{sh}} \sin(\delta_i - \delta_{sh}) \text{ and } Q_{sh} = \frac{V_i^2}{x_{sh}} - \frac{V_i V_{sh}}{x_{sh}} \cos(\delta_i - \delta_{sh}) \tag{5}$$

$$P_i = \frac{-V_i V_{pq}}{x_{ij}} \sin(\delta_i - \delta_{pq}) \text{ and } Q_i = \frac{V_i V_{pq}}{x_{ij}} \cos(\delta_i - \delta_{pq}) \tag{6}$$

$$P_j = \frac{V_J V_{pq}}{x_{ij}} \sin(\delta_j - \delta_{pq}) \text{ and } Q_j = \frac{-V_j V_{pq}}{x_{ij}} \cos(\delta_j - \delta_{pq}) \tag{7}$$

Multiplying V_j to the above two equations we can get

$$P_j = \frac{V_i V_j}{x_{ij}} \sin\delta - \frac{V_j V_{m2p}}{x_{ij}} \text{ and } Q_j = \frac{V_i V_j}{x_{ij}} \cos\delta - \frac{V_j V_{m2q}}{x_{ij}} - \frac{V_j^2}{x_{ij}} \tag{8}$$

$V_{m2p} = V_j \gamma(t)$ and $V_{m2p} = V_j \beta(t)$ where $\gamma(t)$ and $\beta(t)$ are control variables

$$\text{After partial derivative } \frac{dP_j}{dt} = \frac{dP_j}{d\delta}\frac{d\delta}{dt} + \frac{dP_j}{dV_{m2p}}\frac{dV_{m2p}}{dt} \tag{9}$$

$$\frac{dQ_j}{dt} = \frac{dQ_j}{d\delta}\frac{d\delta}{dt} + \frac{dQ_j}{dV_{m2p}}\frac{dV_{m2p}}{dt} \tag{10}$$

It can be said that the reactive power injected by UPFC depends upon V_{m2p} and angle δ,proportional to the voltage at the point of connection of UPFC.

3 Fuzzy Logic Controller (FLC)

Fuzzy control is a control mechanism based on Fuzzy Logic. Fuzzy Logic can be defined as a logic that are based on If-Then rules. A Fuzzy control uses rules that are used in operator controlled plants. A Fuzzy controller can work in three stages that are fuzzification, rule based and defuzzification.

Fuzzification is defined as the conversion of Crisp values to Fuzzified values. These are expressed by linguistic expressions and consists of membership functions like triangular, trapezoidal and rectangular etc.

Rule Base or Inference-This consists of all fuzzy IF-THEN rules in relation to the fuzzy sets.

Defuzzification- The last stage of Fuzzy controller is defuzzification where the fuzzy sets are again defuzzified and converted into crisp sets. There are several methods for defuzzification which includes Centre of gravity, Centroid method, bisector of area etc.

3.1 Self-Tuning Fuzzy PI Controller

The proposed Auto tuned Fuzzy logic PI controller is designed based on the concept of PI controller.

$$U(s) = KpE(s) + Ki \int E(s) \text{ and } E{*}Ki{*} \int E = U$$

The system performance can be improved by Changing the value of parameters Kp and Ki of the PI controller. The PI parameters (Kp and Ki) are slowly changed using fuzzy inference engine. This provides a mapping which is not linear with having inputs as error and change in error and ouputs Kp and Ki. Figure 6 shows the block having Fuzzy PI Controller.

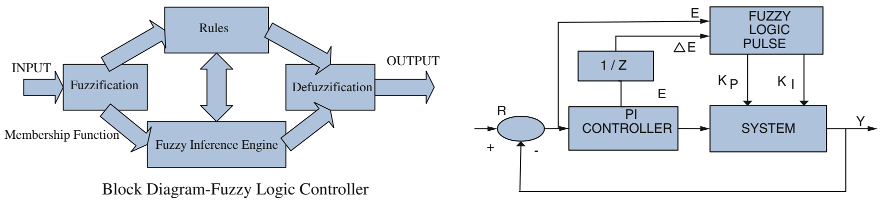

Fig. 6 Fuzzy PI controller block

$$\mu Pi = \min(\mu(E), \mu(\Delta E)), \mu Ii = \min(\mu(E), \mu(\Delta E))$$

Two input variables, error and change in error and two output variables Kp and Ki of the PI controller with seven linguistic variables of Triangular membership function is used for the proposed self tuning Fuzzy logic PI controller. The input membership functions are error(E) and change in error (ΔE) and output membership functions are Kp and Ki and are shown in Table 1 and 2.

Table 1 Fuzzy rule for Kp

E/ΔE	NL	NM	NS	Z	PS	PM	PL
NL	VL	VL	VB	VB	MB	M	M
NM	VL	VL	VB	MB	MB	M	MS
NS	VB	VB	VB	MB	M	M	MS
Z	VB	VB	MB	M	MS	VS	VS
PS	MB	MB	M	MS	MS	VS	VS
PM	VB	MB	M	MS	VS	VS	Z
PL	M	MS	VS	VS	VS	Z	Z

Table 2 Fuzzy rule for Ki

E/ΔE	NL	NM	NS	Z	PS	PM	PL
NL	Z	Z	VS	VS	MS	M	M
NM	Z	Z	VS	MS	MS	M	M
NS	Z	VS	MS	MS	M	MB	MB
Z	VS	VS	MS	M	MB	VB	VB
PS	VS	MS	M	MB	MB	VB	VL
PM	M	M	MB	MB	VB	VL	VL
PL	M	M	MB	VB	VB	VL	VL

Table 3 Parameters of wind-diesel hybrid system

System parameter	Wind diesel system
Wind capacity (KW)	150
Diesel capacity	150
Load capacity	250
Base power (KVA)	250
Synchronous generator	
$P_{SG,}$ (KW)	0.4
Q_{SG} (KW)	0.2
E_q (pu)	1.113
$E_{q,}$ (pu)	0.96
V (pu)	1.0
$X_{d,}$ (pu)	1.0
$T'_{do,}$s	5
Induction generator	0.6
$P_{IG,}$pu (KW)	
$Q_{IG,}$pu (Kvar)	0.189
$P_{IN,}$pu (KW)	0.75
r1 = r2(pu)	0.19
X1 = X2(pu)	0.56
Load	1.0
P_L(pu) (KW)	
Q_L(pu) (Kvar)	0.75
α (Rad)	2.44
UPFC	
T_α(S)	0.05
T'_{do}	5.044
X'_d	0.3

4 Simulation Results

The complete Simulation was carried away taking the Fuzzy Logic PI Controller (Table 1 and Table 2)in the wind diesel hybrid power system in MATLAB/Simulink environment. Application of Fuzzy controller for reactive power and voltage control of the isolated hybrid system was taken with a step load change of 1 %. The variation of all the system parameters such as ΔQ_{SG}, ΔQ_{IG}, ΔQ_{UPFC}, $\Delta Q\alpha$, ΔV, ΔE_{fd}, ΔE_q and $\Delta E'_q$ etc., as shown in Fig. 7(a–h) are studied for the above disturbance using traditional PI Controller and the advanced Fuzzy PI Controller. In the study, The settling time and peak overshoot in the case of Fuzzy based UPFC controller is observed to be less as comparison to traditional PI Controller. The (FLC) shows better result by increasing the diesel power generation. Simulation results clearly show the output of Fuzzy PI Controller is better than the traditional PI Controller.

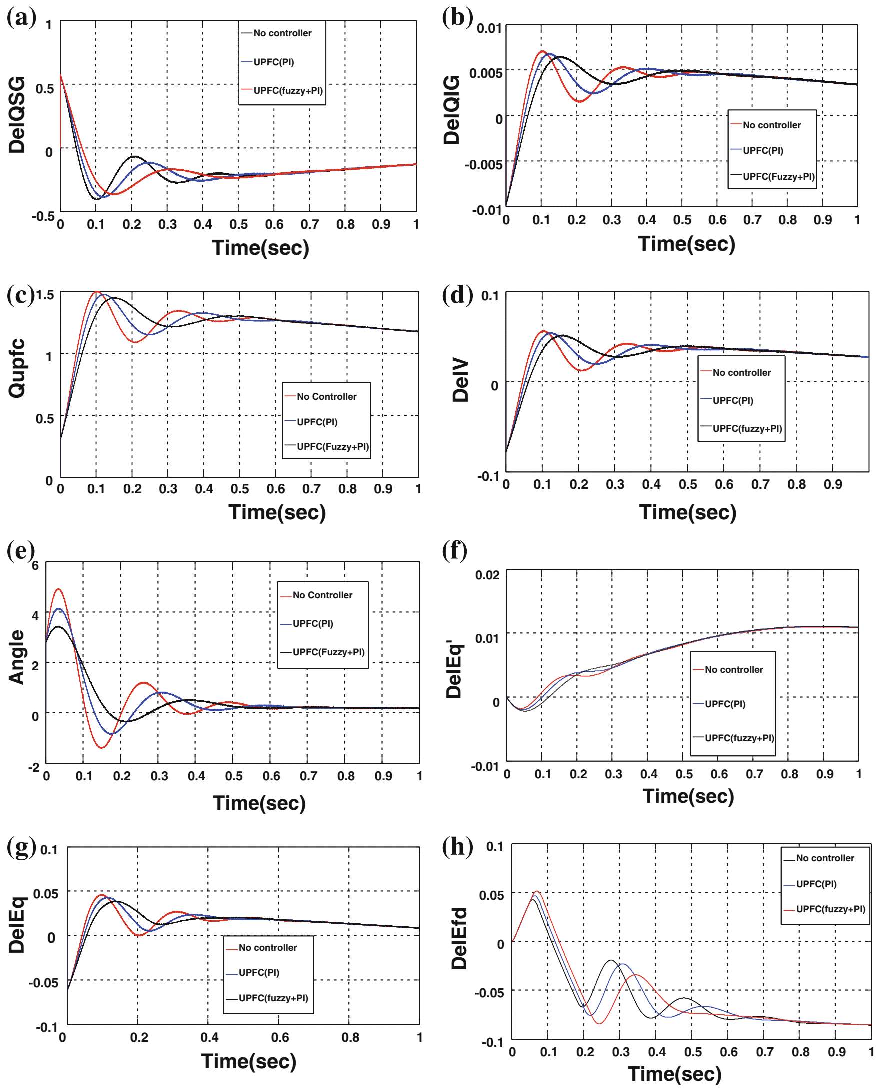

Fig. 7 Output of wind diesel hybrid system using UPFC for 1 % load change during transient condition (comparison with fuzzy controller).**a** Change in reactive power of DG, **b** Change in reactive power of IG, **c** Change in Reactive Power of UPFC,**d** Change in terminal voltage of WECS, **e** Thyristor change in angle (Δα), **f** Change in internal emf, **g** Change in internal armature emf, **h** Change in voltage of Exciter.

5 Conclusion

Here in this paper the transient stability analysis has been done in the hybrid system of wind diesel with the incorporation of Fuzzy PI controller Reactive Power compensation of the model has been done and after comparing the performances of the proposed paper it can be said that the compensation in case of Fuzzified system is better than the conventional system having simple PI system. The proposed Fuzzified system shows better results in settling time and overshoot. The Fuzzified Controller shows effective improvement and changes in the output by tunning the values of Kp and Ki than the conventional PI controller. The Fuzzified system with UPFC seems Robust and effective in its approach.

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