Fuzzy Logic Based UPFC Controller for Voltage Stability and Reactive Control of a Stand-Alone Hybrid System

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Abstract This paper is mainly focused on the implementation of fuzzy logic based UPFC controller in the isolated wind-diesel-micro hydro system for management of reactive power and enhancement of voltage stability. For better analysis a linearised small signal transfer function system is considered for different load inputs. The fuzzy based UPFC controller has been tunned to improve the reactive power of the off grid system. Simulation in MATLAB environment has been carried out and the effectiveness of fuzzy tuned controller is established..

Keywords Reactive power compensation · Standalone wind-diesel-micro hydro system · UPFC

1 Introduction

Renewable energy sources by nature are intermittent and non predictable though they are plentily available in the nature. Hybrid energy sources combining multiple energy sources mitigate this problem to a great extent as because shortfall due to one source is replenished by other. Generally standalone hybrid models exist near the place of consumption and can be connected to the main grid. One or more renewable sources are combined to form a Hybrid system where the inadequacy of generation of power because of one source is met by the other source [1, 2]. Wind Diesel Micro hydro system is quite popular choice of combined energy source where a combined network of wind, micro hydro and diesel system work to provide

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continuous power supply to the load, Turbines used in this particular model are Induction generators and they use the Synchronous generator based Diesel engine as back up [3–5]. Turbines having Induction generators have some operational difficulties as they require reactive energy for its smooth working. The much needed reactive energy is provided by the Synchronous machine to a small extent but the real compensation is impossible without the FACTS devices who not only manages the reactive power but enhances the overall stability of the system.

Capacitor banks [6–8] which is mentioned in many articles fail to assist in the compensation of reactive energy and improve voltage stability. Its because the wind is intermittent and load change is unavoidable. The voltage problem and reactive power mismatch are mitigated by the FACTS devices [9–11].

UPFC is one of the important member of FACTS devices which has been utilized like SVC and STACOM for compensation of reactive power. UPFC acts as a better compensator and increases the voltage stability and angle stability. Management of reactive energy is extremely essential as shortfall of reactive power. makes the system voltage varying. The importance of reactive power can be accessed from the fact that the shortfall of reactive power makes the whole system unstable. UPFC like other FACTS members has proven its ability in compensating reactive energy and improving the stability margin. Furthermore a Fuzzy logic controller can be added to the UPFC Controller to tune the parameters and improve the stability status of the system to a great extent.

A simulink based Fuzzy logic tuned wind diesel micro hydro system is discussed with reactive power compensator like UPFC with step change in load, for better transient stability. For better analysis the mathematical model has been derived. The proportional and integral constants are finely tuned by the Fuzzy controller.

2 System Configuration and Its Mathematical Modeling

The wind-diesel-micro hydro hybrid system essentially takes the generating devices like wind turbine and micro hydro turbine to supply power to the loads. The backup is provided by the Diesel generator. The synchronous based Diesel genset also helps the system in improvement of reactive power. The single line system block with UPFC controller is shown in Fig. 1. The system parameter table is shown in this paper and is mentioned as Table 3 (Fig. 2).

The balanced equation of Reactive power of (SG, UPFC, IG, and LOAD) is expressed as [13].

The reactive power balance equation of the system for uncertain load ΔQ_L is

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

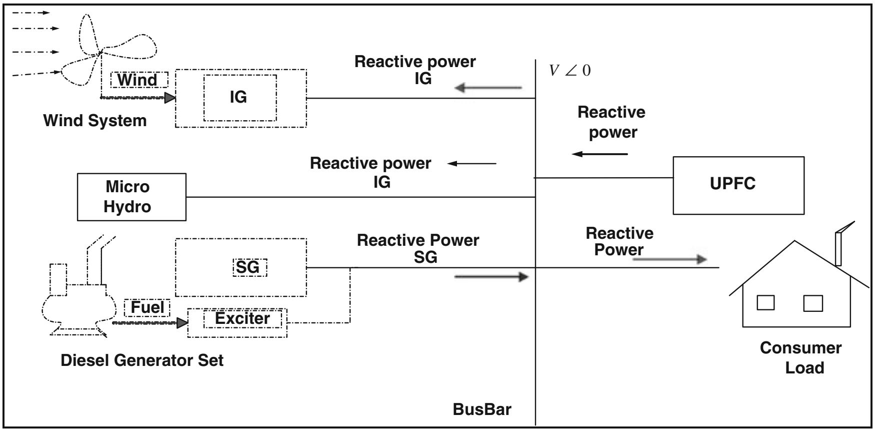


Fig. 1 Wind diesel micro hydro hybrid system block

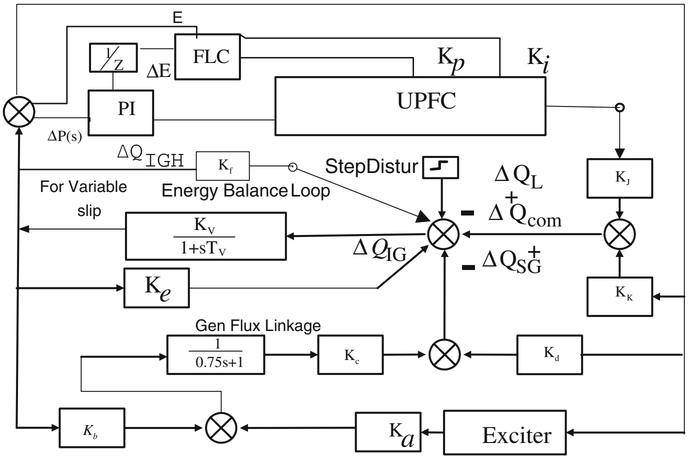


Fig. 2 Transfer function of fuzzy logic based UPFC controller

$\Delta Q_{SG} + \Delta Q_{UPFC} - \Delta Q_L - \Delta Q_{IG} - \Delta Q_{IGH}$ deviates the system output voltage.

$$\Delta V(S) = \frac{K_V}{1 + ST_V}\left[\Delta Q_{SG}(S) + \Delta Q_{COM}(S) - \Delta Q_L(S) - \Delta Q_{IG}(S) - \Delta Q_{IGH}\right] \quad (2)$$

$$Q_{SG} = \frac{\left(E'_q V \cos\delta - V^2\right)}{X'd} \text{ and } \Delta Q_{SG} = \frac{V\cos\delta}{X'd\Delta E'q} + \frac{E'q\cos\delta 2V}{X'd\Delta V} \quad (3)$$

Using SVC as compensator

$$\Delta Qsvc\,(s) = K_c\,\Delta V(s) + K_d\,\Delta B_{svc}(s) \quad (4)$$

2.1 UPFC Controller

The work of UPFC is to compensate Reactive power as well as Active Power by supply of AC Voltage. It may act in series with the amplitude and phase angle with that of Transmission network. In this case one Inverter either supplies or absorbs real power and the second Inverter also sends or gets reactive power. In this way shunt compensation has been done. The supplied powers completely rely on the injected voltages and bus voltages. The injected reactive energy by the UPFC Controller depends on V_m and angle δ (Figs. 3 and 4). So the small change in reactive power is equal to

$$\Delta Q_{UPFC} = K_j\,\Delta\delta(S) + K_k \Delta V(S) \quad (5)$$

Fig. 3 Shunt controller

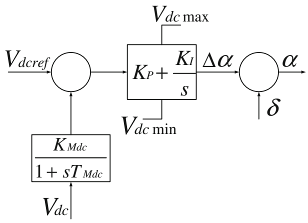
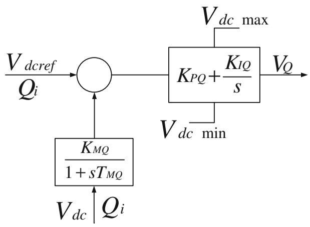


Fig. 4 Series controller



3 Fuzzy Logic Controller (FLC)

A fuzzy set has much more generalised approach than the ordinary sets. The proposed self tuned Fuzzy controller operates in 3 stages i.e. Fuzzification inference engine and defuzzification. These three stages with the help of membership functions tune the parameters of UPFC controller (Fig. 5).

3.1 Self-Tuning Fuzzy PI Controller

As power system is non linear a self tuned Fuzzy controller is designed to tune the proportional and integral controllers.of the PI controller. A PI controller can be explained as U(s) = KpE(s) + Ki ∫ E (s) and E*Kp + Ki * ∫ E = U. The design of Fuzzy controller is such that the inputs and outputs are taken into account. Kp and Ki of the PI controller are tuned by the inference engine of FLC. For this Fuzzy controller error and change in error work as inputs and the output as proportional and integral constants.

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

The fuzzy controller uses seven linguistic variables so that there are 49 rules and it uses triangular membership function for tuning the Kp and Ki. An auto tuned fuzzy controller has input membership functions as error (E) and change in error (Del E) and in the output it gives tuned values of Kp and Ki (Tables 1 and 2).

Fig. 5 Fuzzy PI controller block

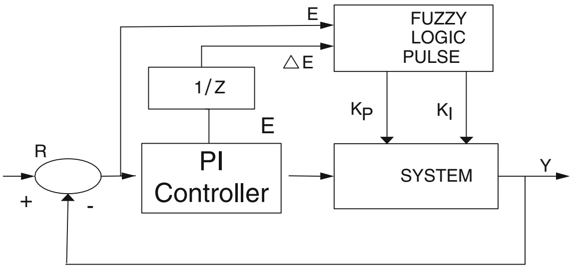


Table 1 Fuzzy rule for Kp

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

4 Simulation Results

From the simulation based on UPFC controller with fuzzy logic performances of different parameters are noticed. The wind diesel micro hydro hybrid power system is simulated in MATLAB/Simulink environment. With a step load change of (1–5) % and variable input parameters like wind and hydro energy, Variation of all existing system parameters are noticed and plotted as shown (Fig. 6). During observation it is found that UPFC provides good performance with increase size of synchronous generator than induction generator. Vital parameters such as settling time and peak overshoot are found reduced in case of fuzzy controller with respect to traditional PI Controller. The Control signal is noticed after fuzzification, rules creation and defuzzification. It provides good damping but it has some Negatives like creation of membership function, making of rules and suitability of scaling factors which is done by trial and error method (Fig. 7).

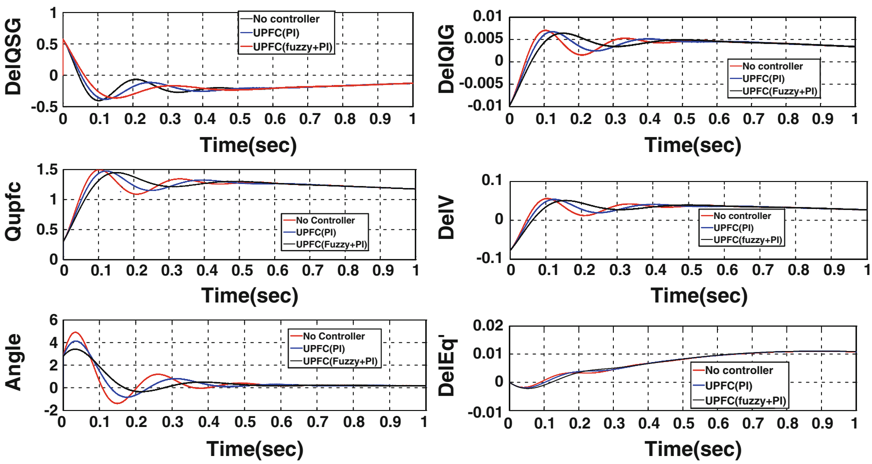


Fig. 6 Comparative results of wind diesel micro hydro hybrid system

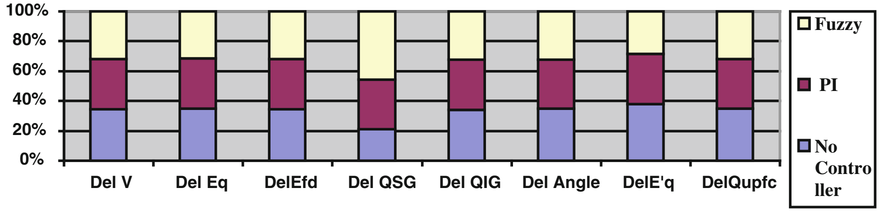


Fig. 7 Settling time of different parameters

5 Conclusion

This work has described a fuzzy logic tuned UPSC controller in the DG based hybrid system and discusses its impact in the management of reactive power and voltage stability. The parameters of the wind-diesel-micro hydro system perform in a better manner after proper tuning of the PI controller is done by Fuzzy controller. The simulated results show less settling duration and better overshoots. This particular hybrid system after the inclusion UPFC controller with soft computing approach performs robustly and takes the entire model to a more stable level.

Appendix

Table 3 Parameters of wind-diesel system

System Parameter	WindDieselSystem
Wind (IG)Capacity (Kilowatt) Diesel(SG) Capacity Load Capacity	100 KW 100 KW 200 KW
Base Power in KVA	200KVA

$P_{SG,=}$ 0.4 in KW $P_{IG,=}$ 0.6 in Kilowatts $P_{L(}$pu)= 1.0 in KW
Q_{SG} = 0.2 in KW $Q_{IG,}$pu=0.189 in KVAR Q_{L}(pu)= 0.75 in KVAR
$T'_{do} =$ 5.044
$E_{q(}$ pu) = 1.113 $P_{IN,}$pu in Kilowatts =0.75 α in Radian= 2.44
X'_{d} =0.3
E_q'(pu) = 0.96 r1=r2(pu)=0.19 $X_{d,(}$pu)=1.0
V(pu) = 1.0
X1=X2(pu) = 0.56 $T'_{do,}$S= 5 T_{α}(S)= 0.05

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