Improvement of Voltage Stability of Renewable Energy Sources-Based Microgrid Using ANFIS-Tuned UPFC

S. Gandhar, Jyoti Ohri and Mukhtiar Singh

Abstract The paper proposed an impact strategy to stabilize the reactive power variations in islanded microgrid, which results in the control over voltage instability. The required voltage compensation is achieved by injection of an accurate synchronous voltage supply into the microgrid through the power electronics-based converters. This work is accomplished by using advanced flexible AC transmission (FACTS) device and unified power flow controller (UPFC) connected to the microgrid. This compensation reference is obtained through a synchronous voltage management, avoiding the load frequency control loop. In this paper, the improvement in the voltage stability of power system during the transient period in the integrated renewable energy sources (RES)-based microgrid using the unified power flow controller (UPFC) is investigated. Furthermore, the proportional–integral controller of the control system is tuned by adaptive neuro-fuzzy inference system (ANFIS) technique. The ANFIS-tuned UPFC yields the better control on the bus voltages of the test system. This strategy does not require any hardware modification. This strategy is simulated in MATLAB/Simulink to prove its effectiveness.

Keywords Microgrid · RES · FACTS · UPFC

1 Introduction

In India, the renewable energy sources-based industries are growing exponentially. In the coming years, there will be very significant growth in RES-based power systems. There are many locations in the world which are still deprived of electrical

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energy. The grid connection to those areas is not viable solution as it requires a hefty investment. So, the best solutions are isolated microgrids. This solution also becomes better when it is driven by renewable energy sources' microgrids that can provide continuous and cost-effective electric power to such areas. For such microgrids, the hybrid combination of nonconventional and conventional energy sources is advisable solution because it produces cost-effective and pollution reducing power. But power quality is the decisive concern in such types of microgrids, and a typical disadvantage is the voltage imbalance. Lots of analysis and research work have been done on this subject. Such microgrids feed a variety of constant loads, dynamic loads, and randomly variable loads. Thus, the currents transported by the dispersed generations are generally not balanced [1, 2]. Therefore, the voltages beyond the load impedances and thereupon different load voltages convert to unbalanced. Unbalanced voltages resulted in maloperation, especially for dynamic loads, and increase losses in connecting machines. Although every distributed generation (DG) unit among the microgrid is trying to enforce balanced voltages in the system, the presence of non-conventional energy sources brings a lot of voltage variations in the system. Therefore, power electronics-based converter management strategies are implemented in the power system to maintain the output voltage balance. The inverters equipped with high-rating thyristors will do balanced voltages; as a result, this plan of action controls the converter output voltage and frequency [3]. However, few unsteady and fluctuating sources such as random electrical contingencies can require rigorous power electronic converters' arrangement to deliver the required power. This paper proposes a technique to compensate reactive power to maintain the voltage variations within the system. Consequently, it enhances the power system quality despite connecting dynamic loads. The compensation is usually achieved for hybrid power system because the voltage imbalance is quite evitable in the islanding mode of microgrid caused by the increment in unbalanced load currents [4]. The compensation is required in islanding mode of microgrid, but this strategy also depends on the injection of synchronous voltage provide to supply locally, it requires the reactive power for maintaining the voltage imbalance [5]. In this paper a simulation model of the microgrid in islanded mode is presented to characterize the reactive power balance analysis to maintain the voltage stability of the system.

2 Unified Power Flow Controller

FACTS controller is a family of power electronics based on different devices. Among the group of these controllers, unified power flow controller (UPFC) is termed as the best FACTS controller. It acts like a multitasking controller, which can perform several functions at any instant, such as controlling the transmission voltage, impedance, and active and reactive power [6], providing benefit to the power system. It is an advanced power electronic device, which has two converters: One is connected in shunt, and other is connected with the transmission line. It is a combination of a static compensator (STATCOM) and static series synchronous compensator (SSSC). It can
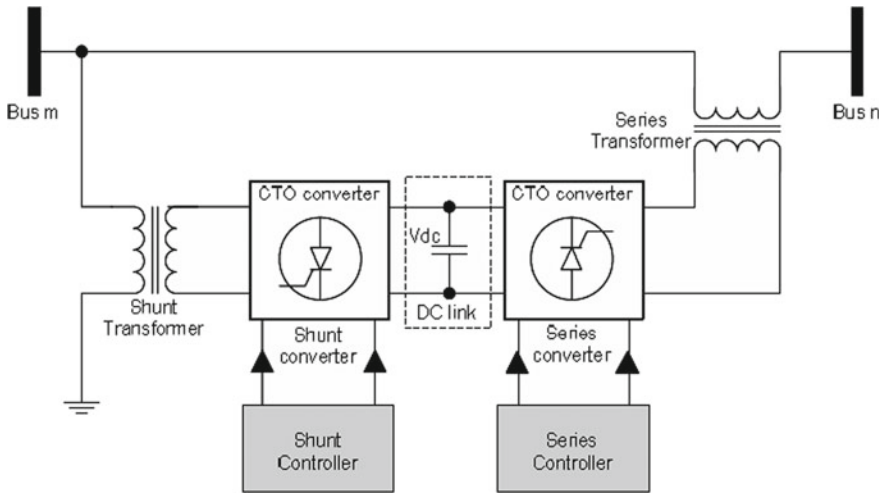
Fig. 1 Schematic diagram of the UPFC

be used for controlling many problems of the power system like managing power flow by enhancing transient stability and voltage (reactive power) control [7, 8]. The UPFC comprises of two voltage-source converters (VSCs), connected antiparallel and a DC electrical condenser is placed between those VSCs (Fig. 1). It feeds contemporary voltage supply of the needed amplitude into the system. The objective of series converter is to feed synchronous voltages, V series with the line, which leads to the flow of active power and the creation of the required reactive power into the system. The reactive power is created by the series converter, while the active power is carried to or from the line over the DC electrical condenser. Meanwhile, the shunt converter creates the need of this DC terminal power to or from the line, thereby maintaining the flow of active power of system. The total real power consumed by UPFC is account of losses of the converters and the coupling transformers. The creation of reactive power is directly done by series and shunt converters like a STATCOM. Therefore, reactive power compensation methodology of the shunt converter is similar to standard STATCOM.

An approximate identical circuit of the induction machine is examined for the state-space modeling of the induction generator as shown in Fig. 2. It is desirable that the model must have the least number of factors, and furthermore, it can be easily remodeled into multi-machine control framework. In perspective of this, the power conditions are expressed in terms of bus voltage and induction machine parameters, steady voltage lagging the equivalent impedance is E (like voltage behind the synchronous reactance if there should arise an occurrence of alternator) as shown in Fig. 2.
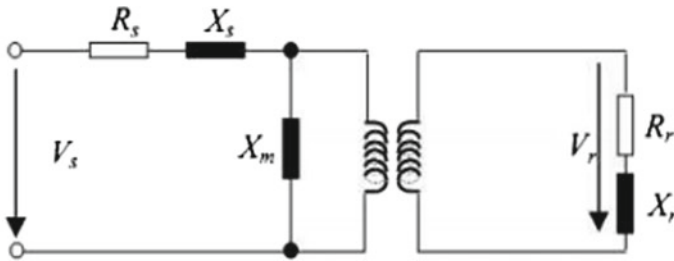
Fig. 2 An approximate equivalent circuit of the induction machine

3 Modeling of the Test System

The proposed test system shown in Fig. 3 comprises of 14 buses (six 22 kV buses, six 230 kV buses, and two 345 kV buses). The designed system is divided into three specific regions. Area 1 is termed as generation area, which is modeled by a three-phase generating source and a doubly-fed induction generator (DFIG) representing the renewable energy source in the system. Area 2 is placed between generation area (Area 1) and load center area (Area 3). It has the most advanced FACTS controller, i.e., UPFC. Area 3 consists of different types of loads, which are connected to different bus locations in the circuit as shown in Fig. 3, i.e., resistive–inductive, resistive–capacitive, purely capacitive loads, and a combination of both inductive and capacitive loads [9]. Power balance equations are considered for the simulation studies. Because of the presence of many inductive loads and the reactive power demand of DFIG, it is highly desirable to connect the condensers in the system. But after observing the transient responses of the system, it is really impossible to balance the reactive powers of the system with these fixed capacitors, and this results in the drop in bus voltages' profiles. Therefore, a very powerful FACTS controller is connected in between the Bus-7 and Bus-8 and responses are collected and presented in the next section.
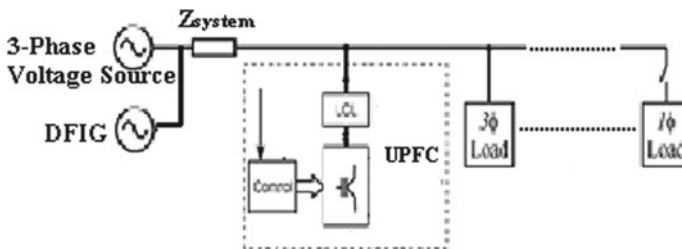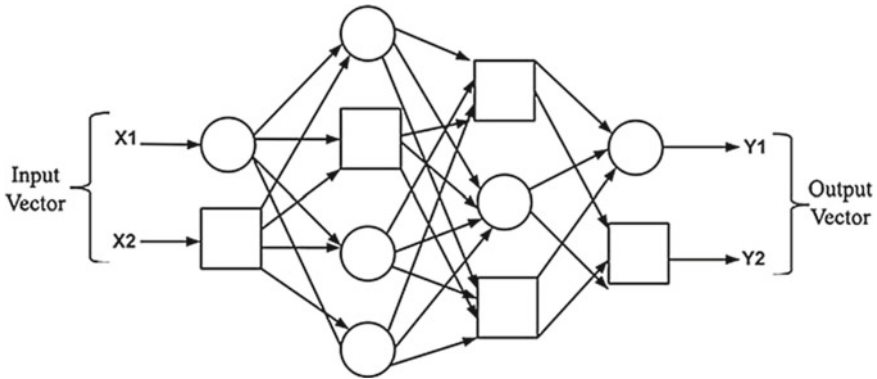

Fig. 3 Simulation set up

Fig. 4 Adaptive network

4 ANFIS Adaptive Network

In this section, a basic overview of ANFIS adaptive technique has been discussed. Here, Fig. 4 shows the rules for tuning of the ANFIS methodology additionally, which presented the online self-building neural fuzzy inference network technique. Adaptive network is one of the cases of feed-forward neural system with many layers [10, 11]. In this learning procedure, these systems frequently utilize supervised learning algorithm. In addition, adaptive networks have the architecture characteristics that it comprises of various adaptive hubs interconnected straightforwardly with no weights in between them. This system describes that every hub/node has different functions and tasks, and the output relies upon the incoming signals and parameters that are accessible in the hub. A learning rule that was used can influence the parameters in the hub, and it can lessen the event of errors at the output side of the adaptive network. The fundamental adaptive system utilizes gradient descent or backpropagation, and therefore, the chain rule frequently such as the way over learning calculations had been proposed by Werbos in 1970.

5 Simulation Test System and Results

Simulation studies are carried out in this section to demonstrate the transient performance of the test system with renewable energy sources using the UPFC and with ANFIS-tuned UPFC. IEEE 14-bus system is examined for the test analysis. It is attached with two generating systems as shown in Fig. 5. In this paper, the examination is studied on the supposition that renewable energy sources are controlling at a constant speed. The DFIG of Area 1 is of rating 1.5 KVA nominal power and jointed at bus '1'. The second source is having nominal power of 3 KVA and connected at bus '4'. Different types of loads are connected with this 14-bus test system. The

crest values of bus voltages are reviewed as indices to evaluated to assessed voltage stability and therefore the IEEE 14-bus test system shown in Fig. 5 is used to conduct the transient stability simulation. A UPFC is to be installed at the point of common coupling (PCC), wherever the wind energy facility is integrated with the utility system. Time simulation studies are carried out for 10 s on the test system. The UPFC has been inserted in these time simulations at 05 s. The voltage profiles of the most affected buses are presented in Figs. 7, 8, 9, 10, and 11. It is clearly presented that the UPFC is helping the turbulent energy system for the stabilization. The UPFC is also improving the voltage profiles of the buses in test system as presented in Figs. 7, 8, 9, 10, and 11, whereas the time simulation before 5 s shows the transient behavior of the system without the UPFC. Thus, the UPFC is playing a pivotal role of a dynamic compensator of the given test system and to be proved as an important FACTS controller of the family. The ANFIS-tuned UPFC is even producing better responses than the untuned UPFC, and the results shown in Figs. 7, 8, 9, 10, and 11 clearly prove the fact that the system is stabilizing in better manner with ANFIS-tuned UPFC (Fig. 6). Table 1 has been used to compare the bus voltages responses of test system without the UPFC and with the ANFIS-tuned UPFC.

Table 1 Bus voltages (pu) of IEEE 14-bus test system

| S. No.	Buses	Bus voltages without UPFC (p.u.)	Bus voltages with UPFC (p.u.)	Bus voltages with ANFIS-tuned UPFC (p.u.)
1	Bus '1'	0.9217	0.9462	0.9658
2	Bus '2'	0.9042	0.9338	0.9598
3	Bus '3'	0.9102	0.9262	0.9475
4	Bus '4'	0.8517	0.9461	0.9658
5	Bus '5'	0.8456	0.9405	0.9603
6	Bus '6'	0.8464	0.9426	0.9626
7	Bus '7'	0.9042	0.9399	0.9598
8	Bus '8'	0.8426	0.9396	0.9599
9	Bus '9'	0.8438	0.9422	0.9628
10	Bus '10'	0.9137	0.9261	0.9247
11	Bus '11'	0.9134	0.9338	0.9438
12	Bus '12'	0.9011	0.9039	0.9339
13	Bus '13'	0.9197	0.9309	0.9397
14	Bus '14'	0.9093	0.9150	0.9153
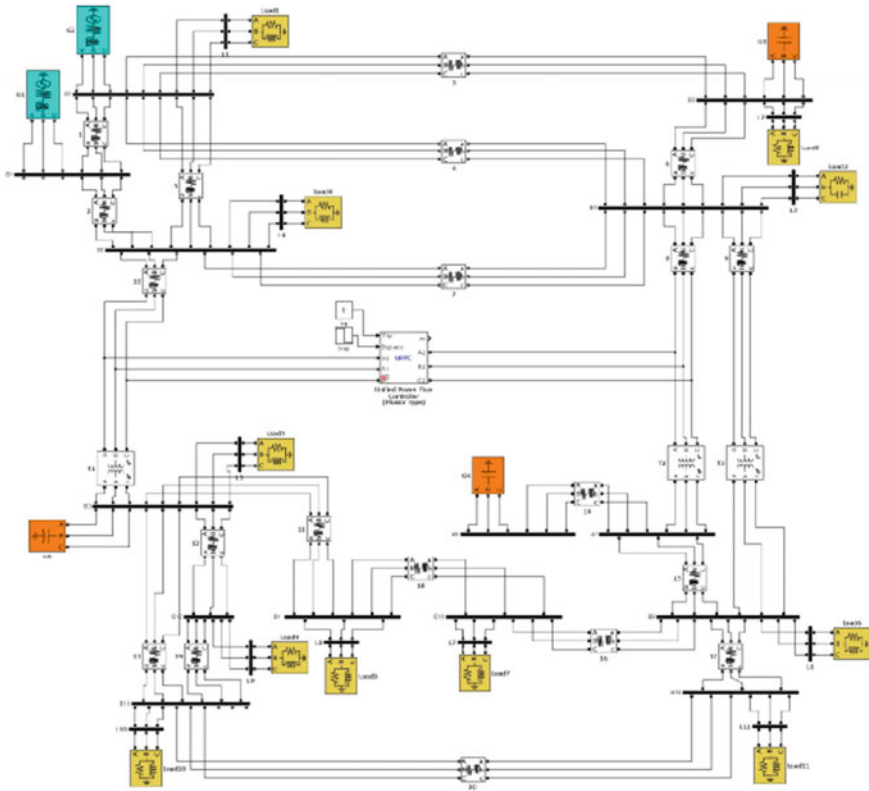
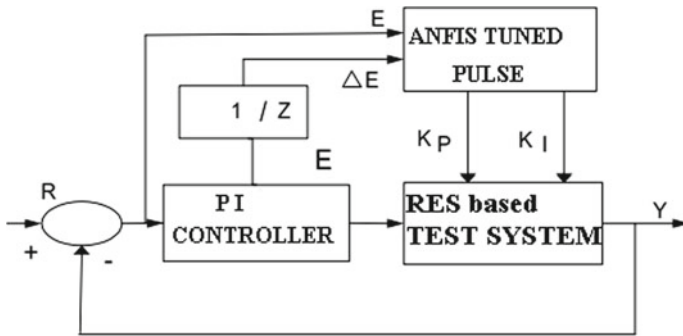**Fig. 5** Simulation test system

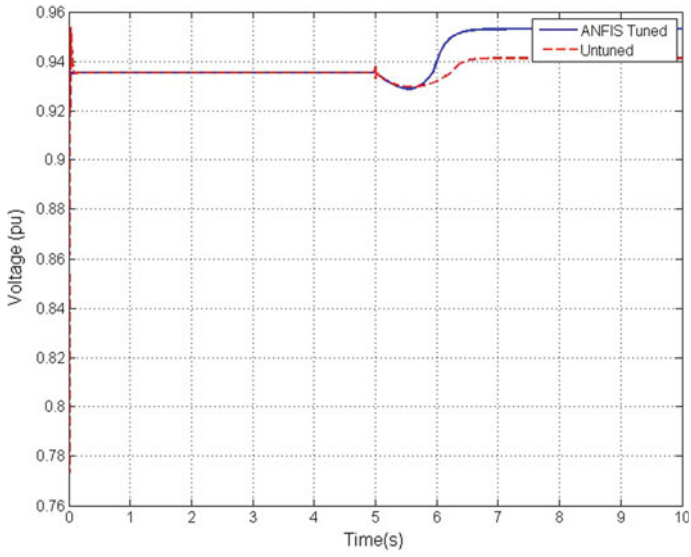**Fig. 6** ANFIS-tuned PI controller of the UPFC

Fig. 7 Bus-5 voltage (pu) of test system with ANFIS-tuned UPFC
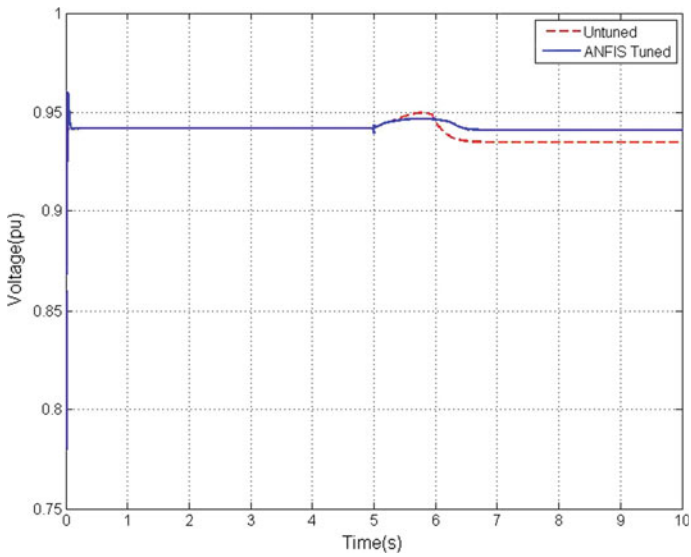

Fig. 8 Bus-8 voltage (pu) of test system with ANFIS-tuned UPFC
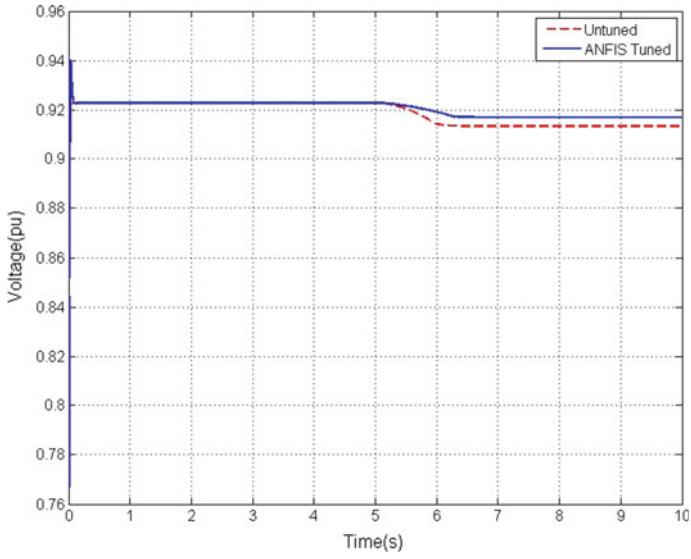
Fig. 9 Bus-10 voltage (pu) of test system with ANFIS-tuned UPFC
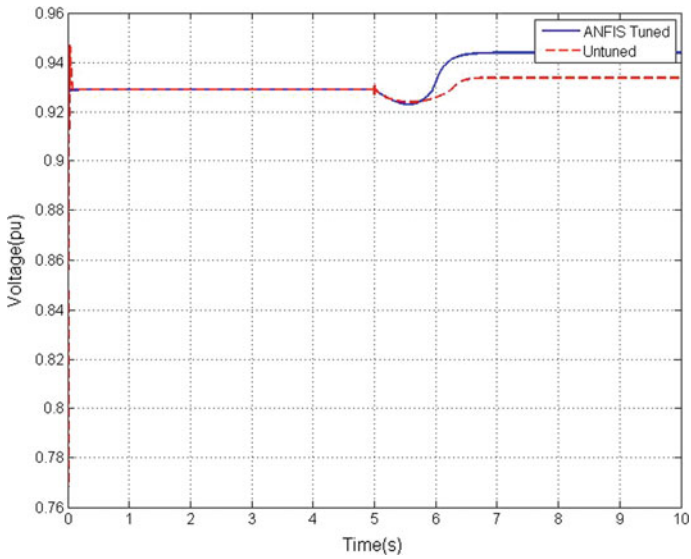

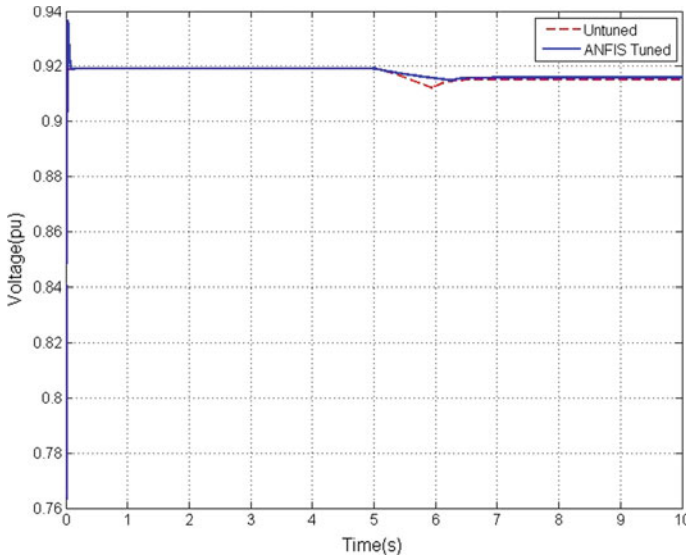**Fig. 10** Bus-11 voltage (pu) of test system with ANFIS-tuned UPFC

Fig. 11 Bus-14 voltage (pu) of test system with ANFIS-tuned UPFC

6 Conclusion

Renewable energy sources are gaining popularity around the globe, but it brings power and voltage instability in the system. Herein, the voltage stability improvements of a renewable energy sources-based system with the help of an ANFIS-tuned UPFC have been analyzed and presented. The nonconventional generators considered are the doubly-fed induction generators (DFIGs) with IEEE 14-bus system. A UPFC is placed in multi-machine power system with this test system. The obtained results show the improvement in voltage profiles of buses of the test power system using the ANFIS adaptive technique. The results reveal that, in such cases, the deployment of the shunt capacitor banks is incapable, so adequate VAR compensation may be attained by using the FACTS controllers, viz. UPFC only. Therefore, the need of compensating controller for the proposed wind energy sources-based power system has been discussed.

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