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Performance and Analysis Stable Operation in Hybrid Wind and Fuel Cell Based Distributed Generation System with FACTS Controller

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Abstract: This paper proposes a steady operation of hybrid distributed generation (DG) system composed of dual renewable energy sources, a wind turbine (WT) and a fuel cell with the Flexible AC Transmission System (FACTS) controller. Recently more number of small scale renewable energy sources such as (WT) are connected to the national grid and the number counts on. However maintaining stable operation has become a challenge because of the practical difficulties in mitigating, harmonics, managing reactive power and balancing the unbalanced load are concerned. The proposed system uses a FACTS controller, specifically the Unified Power Quality Conditioner (UPQC) with Neural Network model is designed for steady operation that guarantee improved quality of power at their point of installation of hybrid DG system. The UPQC is one of the family of FACTS controllers which offer a variety of options including series and shunt active (P), and reactive (Q) power compensation to improve power quality. In this effort, the off line trained ANN with training data collected from the operating conventional PI controller has been developed. The collected conventional data is used in a novel control system with an Integrated Neural Network (INN) controller instead of the traditional multi PI controllers. The performance of INN controller is compared with proportional integral (PI) controller and the system performance is analyzed using simulation with Matlab/Simulink.

Keywords: Distributed generation (DG), FACTS, fuel cell, Integrated Neural Network Controller (INN), Unified Power Quality Conditioner (UPQC), wind turbine (WT)

1 Introduction

The growing concern on climate changes and the ever present oil crisis have recently increased the interest in (DG) from renewable [1–4] and traditional sources. Among the renewable resources wind, and fuel cells are growing in significance and have gained the interest of energy researches. As green renewable energy resources, wind and fuel cell have gained substitution for conventional fossil fuels. The cost declines are due to new built-up technologies, large size, more effective and more consistent wind turbines [5–7]. However, the wind speed variation depend on ecological condition. Therefore in order to make sure the availability of renewable energy additional renewable energy source are pooled to form a hybrid energy system [8]. Present development in the fuel cell technology significantly enhanced the nominal and reasonable characteristics of this technology [9]. This paper proposes a hybrid wind/fuel cell based distributed generation system and its interactions with the different system conditions of sag and swell. The main cause of disturbance to the voltage at the PCC is the frequent wind power fluctuations and the frequent variations in the load as well as changes happening on the utilities and customers side changes, which will affect the quality of power. This paper proposes a compensation strategy based on a particular FACTS device, such as UPQC. These variations have an undesirable effect on stability and power quality in distributed generation power systems. This paper proposes a novel method for improving the stable operation of a hybrid wind and fuel cell based distributed power generation system with facts controller incorporated into the medium voltage distribution system and investigate effect of using UPQC.

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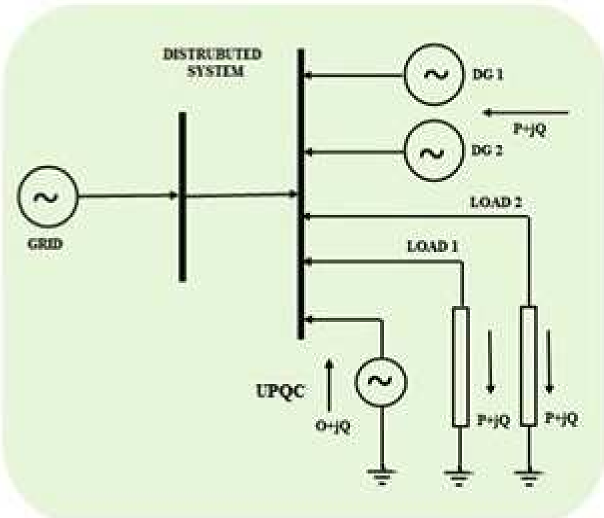


Fig. 1: DG-system employing UPQC.

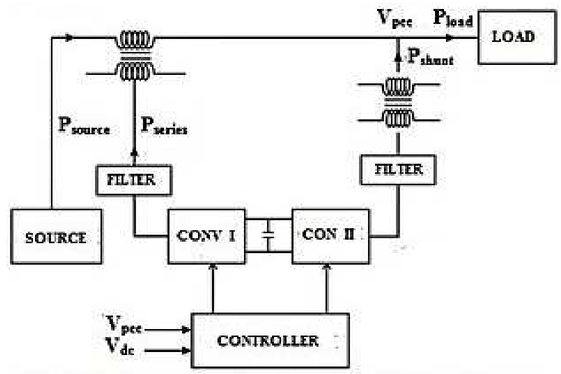


Fig. 2: Structure of Unified Power Quality Conditioner.

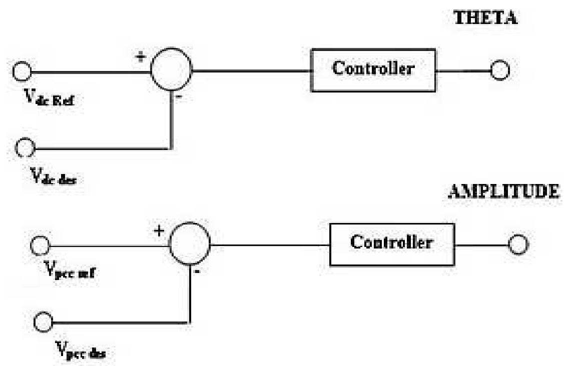


Fig. 3: Control scheme.

In this paper an attempt is made to present a stage by stage improvement of a single ample control scheme along with an active control for management of UPQC with a (INN) controller model, as a replacement for the traditional controller model. The objective of the proposed system is to retain a stable voltage profile at the load point by using UPQC through injecting a series voltage in the suitable level and phase angle at voltage sag/swell conditions. The objective of the proposed control scheme is also to remove the harmonic content in distributed generation systems, in unstable and nonlinear load condition system and also stabilize the voltage levels in the studied system.

2 Distributed Generation (DG)

DGs are being encouraged in order to reduce the burden on the national grid DG is generally employed to generate moderate generated units usually installed and incorporated at distribution feeder or consumer load levels. The limited size DG technology comprises of photo voltaic cell, wind turbine, small and micro turbine packages and fuel cell. Hybrid wind/fuel cell energy generation presents several benefits for use as a distributed energy resources. However, the integration of these sources in a distribution network has a number of issues associated, especially when a large number of DGs are integrated to the national grid. Hence maintenance of stability becomes a difficult issue. In the proposed system the problem is solved by finding some novel ways for augmenting renewable real power sources through the FACTS controllers. A block diagram of the proposed system of a DG–grid connected system with UPQC is shown in Fig. 1.

3 Modelling of UPQC

The UPQC shall perform the functions of converting the system current to balanced sinusoids through the shunt compensator and convert the load voltage V_L to be balanced sinusoids through the series compensator [10–13]. It also has to ensure that zero real power is injected by the compensators, and supply reactive power to the load. The ideal UPQC can be represented as the combination of a voltage source converter, current source converter and a common DC link. It is likely to intend combined configurations of shunt and series active filters. The function of the shunt filter is to mitigate the load current harmonics. The purpose of the series filter is to cut off the voltage harmonics between the source and the load In addition the Shunt converter regulates the voltage and compensates the flicker and the PCC voltage unbalances. UPQC used for operation of constrained power transaction by using 4 controllers to meet out constraints of power transaction. The Shunt converter is a three leg three phase Graetz bridge converter with a DC side and 3 phase AC side. The Shunt converter is connected to the point of common coupling through a shunt transformer called the excitation transformer and the configuration is as shown in Fig. 2.

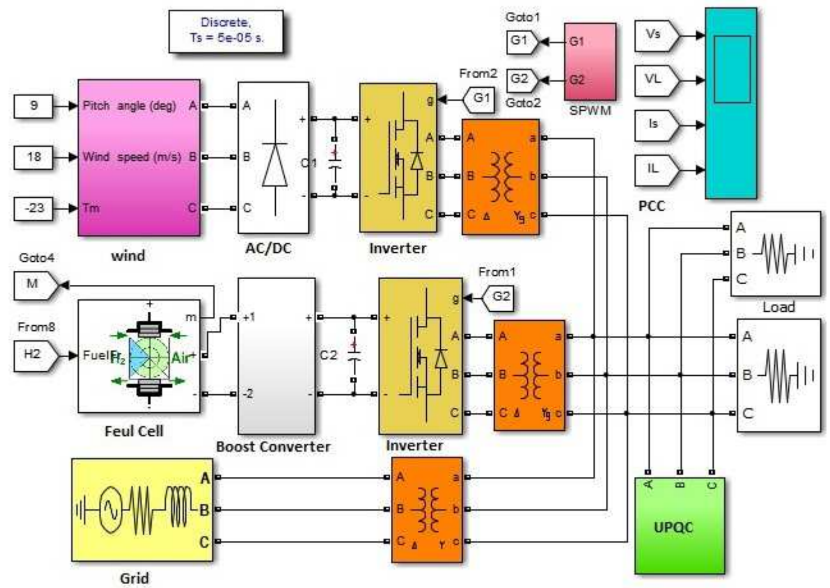


Fig. 4: Proposed simulink model.

The pulse width modulation (PWM) generator is producing synchronized switching pulses, which switch six switches of the 3 leg shunt converter. The main objective of shunt converter is achieved by proper application of switching pulses. The generation of switching pulses is generated by 3 reference signal produced by 2 controllers. The control purpose of 2 controllers influence in generation of reference signal and it lead to efficient operation of converter meeting out its requirement. A block diagram display the input signal and output signal of the two controller's position is shown in Fig. 3. The first controller is used to sort the error between the actual DC link voltage ($V_{DC\ ref}$) and the desired DC link voltage ($V_{DC\ des}$) as zero. The second controller is used to make the error between the actual point voltage of PCC ($V_{PCC\ ref}$) and the desired point of voltage PCC ($V_{PCC\ des}$) as zero. These are the two controlled parameters and the associated manipulated parameters are amplitude of modulation index (MI) and theta (Θ).

4 D–Q transformation

In the study of power systems, mathematical transformations are often used to decouple variables, to facilitate the solution of time-varying equations with coupled nature, and to refer variables to a common reference frame. A widely used [14–18] transformation is the Park (dq0) transformation; in this procedure the fundamental components of waveform will be transferred to a constant DC term under steady state conditions. The Park or dq transformation allows a general three phase electrical system, including unbalanced and distorted conditions to be studied.

Consider that V_a, V_b and V_c are the three phase voltages in sinusoidal nature at the source side. These voltage magnitudes are to be converted into equivalent DC quantities which are used in the controllers. The conversion of the sinusoidal three phase voltage denoted as V_{abc} into V_d, V_q, V_0 and into the rotating reference frame is known as Park transformation or dq0 transformation. The vector (V_a, V_b, V_c) can be converted into another vector (V_d, V_q, V_0) with the use of a transformation matrix.

The elements of the transformation matrix and the elements of the vector (V_a, V_b, V_c) are time varying but the elements of the output vector (V_d, V_q, V_0) are not time varying. However the amplitude of either V_a or V_b or V_c change will be reflected in the elements of the vector (V_d, V_q, V_0).

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \frac{2}{3} \begin{pmatrix} \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{2}{3} \begin{pmatrix} \sin\theta & \cos\theta & 1 \\ \sin\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \sin\left(\theta + \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) & 1 \end{pmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{2}$$

Thus the three phase system of voltages, which are 120 degree displaced between each other and varying in a sinusoidal pattern is converted into an alternative system of three elements by using Park transformation which are just constants. The V_d and V_q elements are orthogonal in nature. They do not have any impact on each other.

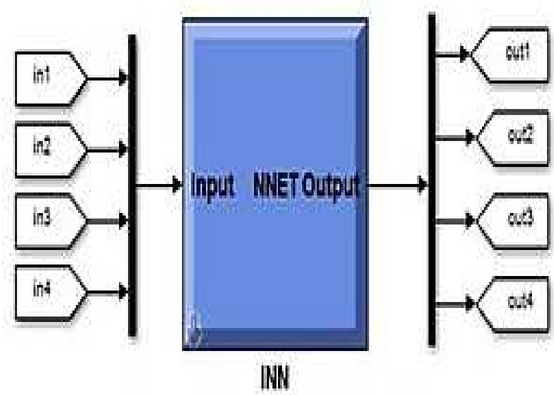


Fig. 5: Integrated neuron model.

5 Integrated Neural Networks

Here four proportional integrated controllers (PI) are designed, two PI controllers are designed for the series converter and two PI controllers for the shunt converters. These PI controllers are tuned for expected results. These four controllers are replaced by four individual ANN based controllers.

The integrated neural network, finally consists of a single ANN with inputs of eight and outputs are containing four units. Hence, if single ANN is [19–25] replaced by four ANN's it results in increasing the speed of operation and better dynamic performance of the system. The input and output data in ANN's are the error, error rate and corresponding output of proportional integral controller. This is also used in collecting the input/output data of other PI controllers. Thus the four ANN's are formed and each one is trained with the input/output data to each of our PI controllers by neural networks.

The PI controllers are replaced by ANN's in UPQC model. The performance of UPQC system by four ANN's is observed for a different wind speed variation which may cause disturbance to the power quality. When the four ANN's based scheme is satisfactory it is replaced by a single ANN. The UPQC model is now rearranged by removing four ANN's with the single INN. The inputs and outputs of the four ANN'S is routed through the INN. Hence the performance of overall UPQC systems which are controlled by INN is observed for voltage sag and voltage swells conditions which would cause disturbance to power quality.

The synaptic weights are initialized randomly at first time formation of ANN but during training period the synaptic weights undergo changes according to the learning rule. After training period is over each synaptic weight reaches its final value. During the test phase the ANN is put to mimic a function. The synaptic weight does not change on applying input but only work together to give input. The INN of feed forward back propagation type has an input layer, hidden layer and an output layer. It may also have more number of hidden layers. An INN having one hidden layer is considered in this work. The implemented INN model is as shown in Fig. 5. Due to combination of ANN'S the resultant ANN has more number of inputs and outputs. But the number of neurons in hidden layer is same. Hence all the neural networks combined to form INN have to share common hidden layer networks. For an example let us see how the ANNs are collective in this work, the following model may be considered. Considering an example, of two nonlinear equations in 'time'.

$$Y_1 = 7t^3 + 4t^2 + 5t \tag{3}$$

$$Y_2 = 4t^3 + 9t^2 + 7t \tag{4}$$

Independent ANN of the two equation are considered, which are trained with input data and output data sets respectively between 0 and 1 time range period with step of 0.01, as dictated by the equations (3) and (4). Using MATLAB/SIMULINK environment the two ANN were created and trained. The two test models are created to test the performance of the two ANN's. An ANN third model is then created with two input/outputs. The third model output is the output vectors of model one and model two. The third ANN was then trained. The performance of the integrated model is as good as the performance of the individual ANN.

6 Simulation Results and Discussion

Power system simulation with the distributed generators wind /Fuel cell distributed power generation is carried out by using MATLAB/SIMULINK model and to study the performance of the parameters of the hybrid Wind/Fuel cell DG system is obtained in sag/swell different case conditions with UPQC FACTS controller.

6.1 Voltage fluctuation compensation by PI controller

In this case study, the performances of the proposed UPQC with the INN approach under voltage sag/swell conditions were analyzed and simulations were performed. The random wind fluctuations, wind shear and tower shadow effect, may excite this mode producing large ripple on the drive train torque as well as on the generated electric power, being noticeable as voltage flickers. This produces variation in torque and result in the variation of active and reactive powers. The simulations were conducted from 0.05 s to 1.0 s sag period and from 0.15 s to 0.2 s swell period condition as shown in Fig. 6.

The simulation results for the case without UPQC FACTS device have also been recorded. The time period from $t = 0.05$ s to 0.1 s shows voltage sag state due to

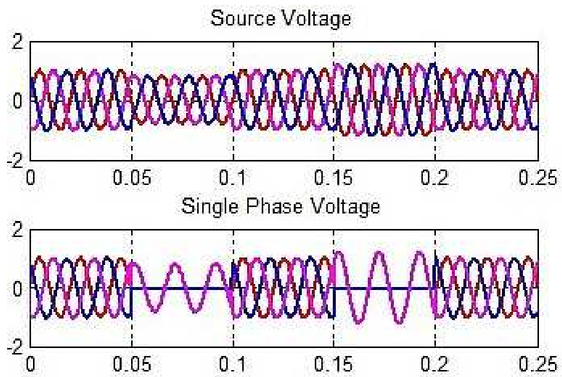


Fig. 6: Voltage sag/swell condition without UPQC.

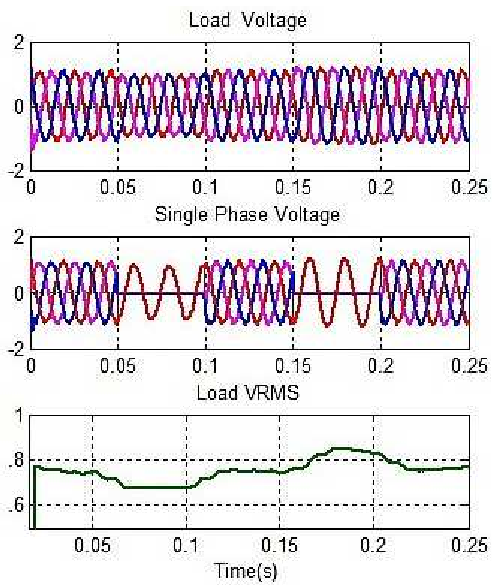
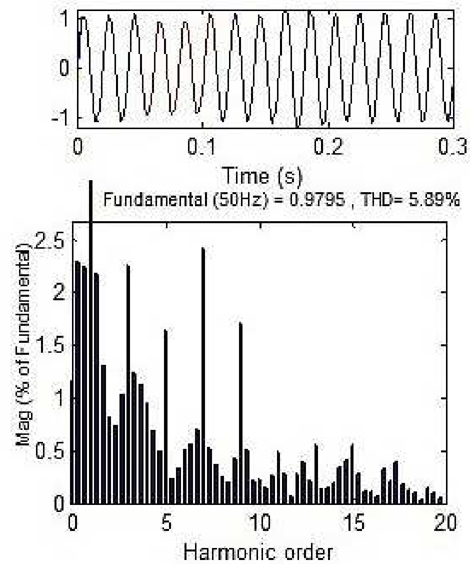


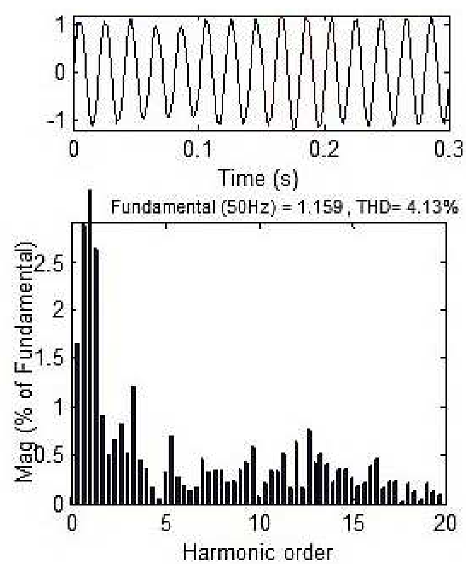
Fig. 7: Load voltage compensation of sag/swell condition with UPQC in PI controller.

sudden change in wind power generation fluctuation condition. it is also realized in voltage variation at Point of common Coupling (PCC). This fluctuation value is lower than the maximum allowed value which will affect the power quality of the distributed power generation system. And also sudden increase in wind power generation from $t = 0.15$ s to 0.2 s shows voltage swell state, Is also realized in voltage deviation at PCC. This variation value is higher than the maximum acceptable by standard value. It will affect the power quality of the distributed power generation system so we improve the system performance by introducing the FACTS controllers in DG system.

The simulation results under voltage sag /swell condition with UPQC FACTS device from $t = 0.05$ s to 0.1 s sag period and from $t = 0.05$ s to 0.1 s Swell period



(a) Harmonic spectrum of load voltage in sag condition with PI based UPQC.



(b) Harmonic spectrum of load voltage in swell condition with PI based UPQC.

Fig. 8: Harmonic spectrum of load voltage in sag/swell condition with PI based UPQC.

as shown in Fig. 7. The active power and reactive power pulsation are diminished due to active shunt and series branches of the UPQC start to operate in this condition The amplitude of the load voltage fluctuation is reduced from its original value and is compensated by the UPQC with PI controller. The FFT analysis outputs of UPQC with PI based controller action in sag/swell conditions for voltage and current are as shown in Fig. 8 and Fig. 9.

6.2 Voltage Fluctuation compensation by INN based UPQC controller

MATLAB / SIMULINK offers a convenient platform for the development of an INN based control system. The complete SIMULINK model of proposed system is as shown in Fig. 4. It shows that the position of the different sources and the loads and also UPQC FACTS controller. The results of simulations under various operating conditions is as shown in Figs. 10, 11 and 12.

7 Comparative analysis of PI and INN based UPQC controller

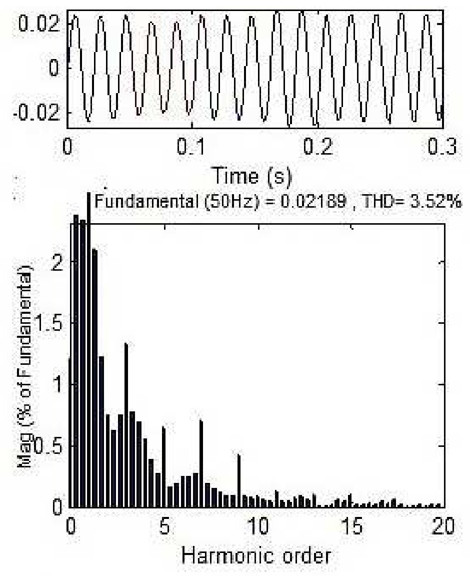
The improvements in operation with UPQC has been compared with the case that does not use an UPQC, then comparison is also carried out among the PI and INN in the case of using the UPQC. Comparative results of a UPQC with PI and INN based controllers under sag condition are as shown in Table 1. Comparative result analysis of a UPQC with PI and INN based controller under swell conditions are as shown in Table 2.

Table 1: Performance of UPQC under PI and INN controller for sag condition.

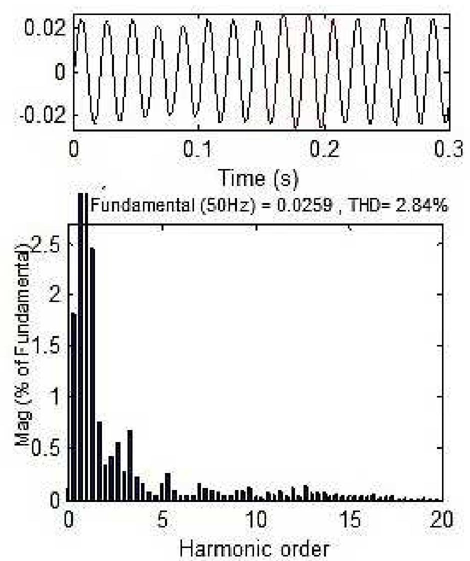
Parameter	SAG Condition	
	PI	INN
Source voltage	0.993	0.992
Load voltage	0.991	0.994
THD% of source voltage	0.93	1.90
THD% of Load voltage	5.89	1.60
THD% of source current	4.63	0.88
THD% of Load current	3.52	0.52

Table 2: Performance of UPQC under PI and INN controller for swell condition.

Parameter	SWELL Condition	
	PI	INN
Source voltage	1.167	1.166
Load voltage	0.983	0.994
THD% of source voltage	12.28	1.39
THD% of Load voltage	4.13	1.47
THD% of source current	3.66	1.63
THD% of Load current	2.84	0.49



(a) Harmonic spectrum of load current in sag condition with PI based UPQC.



(b) Harmonic spectrum of load current in swell condition with PI based UPQC.

Fig. 9: Harmonic spectrum of load current in sag/swell condition with PI based UPQC.

7.1 UPQC with different controller operation in sag condition

The universal power quality conditioner changes the unstable output powers from wind generator into stable sinusoidal load current. The source voltage under distorted condition from 0.015 s to 0.1 s undergoing sag condition. The source voltage with PI controlled UPQC

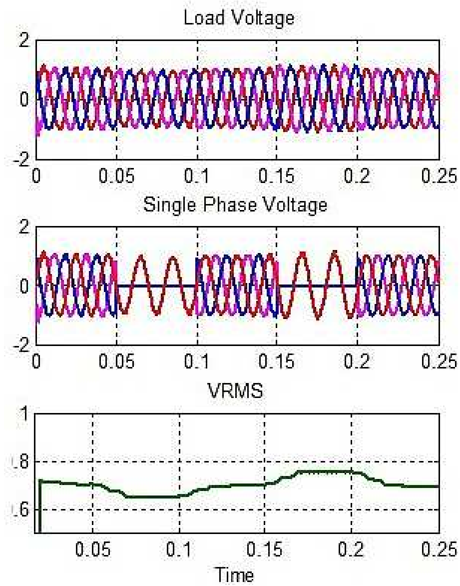


Fig. 10: Source voltage and load voltage in sag/swell condition with UPQC in INN controller.

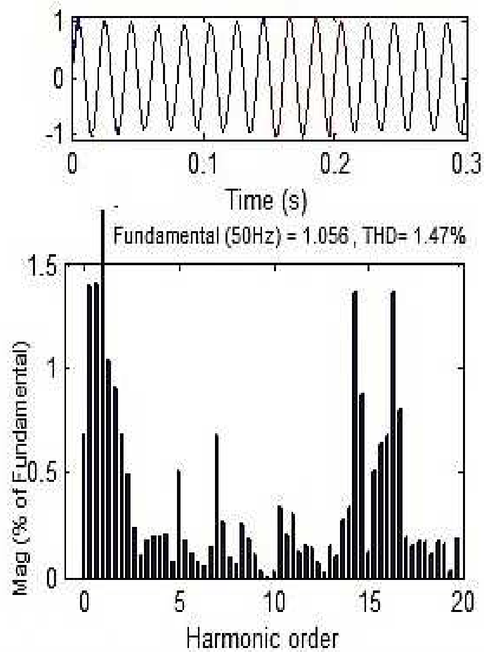
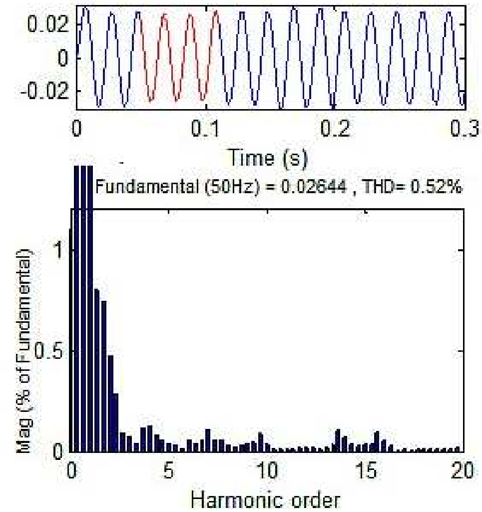
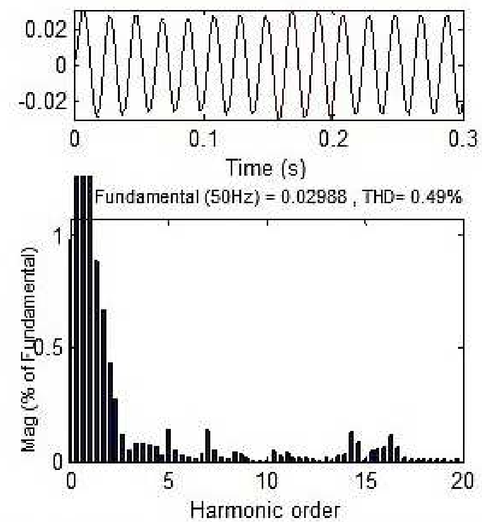


Fig. 11: Harmonic spectrum of load voltage in sag /swell condition with INN based UPQC.



(a) Harmonic spectrum of load current in sag condition with INN based UPQC.



(b) Harmonic spectrum of load current in swell condition with INN based UPQC.

Fig. 12: Harmonic spectrum of load current in sag/swell condition with INN based UPQC.

compensation has Total harmonics distortion (THD) of 9.93% in *R* phase. The load voltage with above status has THDs of 5.89% in *R* phase. The source current of PI controlled UPQC compensator connection have THDs of 4.63%. The load current with PI controller in action has a THD of 3.52%. The THD of the source voltage with INN controller is 1.90% and the THD of the load voltage is 1.60%. The UPQC performance in INN controller, the THD of the source current is 0.88% and compensation with INN controller is 0.52% The FFT analysis shows the THD values of load current for PI and INN based UPQC controller. After the inclusion of the compensator the sag voltage is supplemented as shown in the Fig. 13, it will illustrate that INN controller gives better performance in terms of reduced THDs in voltage and current.

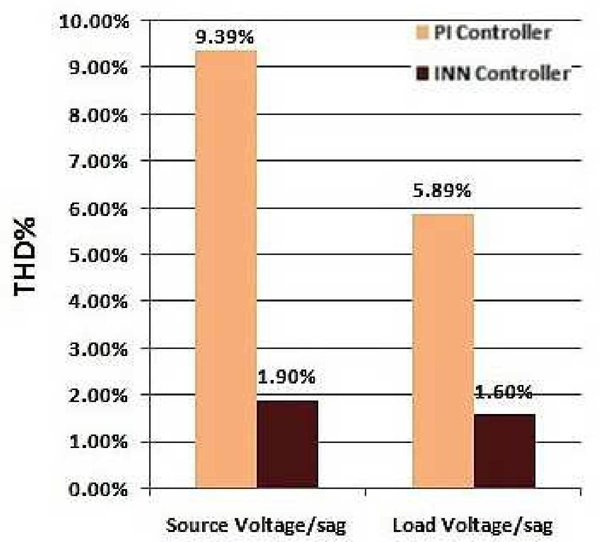


Fig. 13: Performance analysis of UPQC under PI and INN controller for sag.

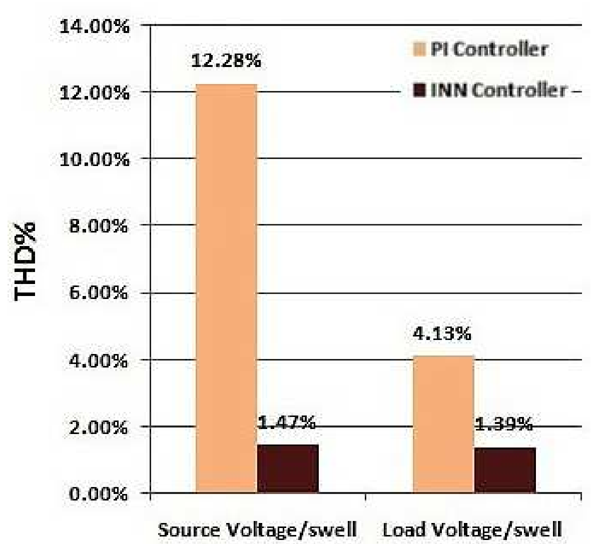


Fig. 14: Performance analysis of UPQC under PI and INN controller for swell.

7.2 UPQC with different controller operation in Swell condition

Performance analyses of PI and INN controller with UPQC FACTS device under swell conditions which are caused by means of sudden change in wind generator. Output power can be mitigated by using inclusion of FACTS controller in this system. The THD of the source voltage with INN controller is 1.39% and load voltage is

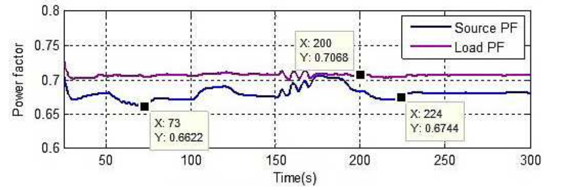


Fig. 15: UPQC with PI controller–source/load power factor condition.

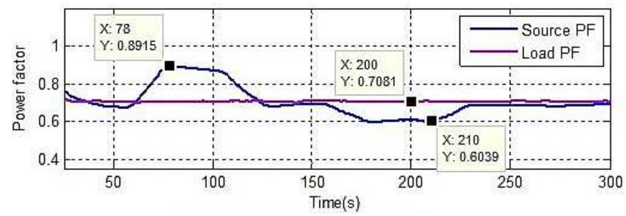


Fig. 16: UPQC with INN controller–source/load power factor condition.

1.47% and also UPQC performance in INN controller the THD of the source current is 1.63% and compensation with INN controller is 0.49%. This total performance of system of a THD value is within the limit specified in the IEEE 519–1922. The performance analysis of proposed system as shown in Fig. 14, it is observed that the performance of UPQC with INN controller gives harmonics distortion reduced in swell condition of the system and better than the traditional controllers.

8 Power factor of proposed system

The simulated results of power factor condition of source and load point with UPQC FACTS controller operation in sag / swell condition are is as shown in Figs. 15 and 16. It shows that the INN controller improves the power factor value of system under sag/swell state compared with traditional controller.

9 Conclusions

This paper proposes the hybrid wind / fuel cell power system being integrated to low voltage distribution power grid near to consumer end by using FACTS controller, UPQC for improving the performance operation of distributed generator in dispersed generation system. A novel methodology is proposed to compensate voltage sag, voltage swell and reactive power compensation for distributed generator in fluctuating output power condition. The artificial intelligence based INN controller for UPQC has been developed. The proposed system can improve the stable operation and power quality at the distributed generation systems. A comprehensive comparison is also verified in between PI and INN based UPQC controllers. The proposed INN controller provides better performance with traditional controller. The simulation results shows that the proposed controller with Unified power quality conditioner operations are valued and the efficiency of the system stability has been established for improving the stable operation of hybrid wind and fuel cell based distributed power generation.

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