Validation of photovoltaics powered UPQC using ANFIS controller in a standard microgrid test environment

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ABSTRACT

The power quality improvement becomes one of the important tasks while using microgrid as main power supply. Because the microgrid is combination of renewable energy resources. The renewable energy resources are intermittent in power supply and at the peak loading condition it has to supply the required power. So, the power quality problems may increase in that time. Out of all power quality issues the voltage drop and harmonic distortion is considered as the most serious one. In recent years unified power quality conditioner (UPQC) is emerged as most promising device which compensates both utility as well as customer side power quality disturbances in effective way. The compensating potentiality used in the UPQC is limited by the use of DC link voltage regulation and the conventional proportional integral (PI) controller. In this paper the compensating potentiality of the UPQC device is controlled by an adaptive neuro fuzzy inference system (ANFIS) control and it is powered from the available photovoltaics (PV) power generation. The effect of adding an intelligent UPQC is tested in the standard IEEE-14bus environment. MATLAB 2017b is used here for testing and plotting the simulation results.

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1. INTRODUCTION

The concept of microgrid is the connecting point of all the distribution side generator and the loads together. The power flow is monitored and controlled by central grid control system. The need for increase in microgrid is due to reduced cost of installation and time saver in implementation. The actual power system consists of generation, transmission and distribution. In microgrid it is only at the distribution all the three happens in miniatured way. The power quality improvement in smart grid environment is implemented in [1] using modified UPQC topology. A new algorithm for UPQC is proposed in [2]. A single-stage quasi UPQC is implemented in [3]. A new fuel cell power UPQC is implemented in [4]. The power quality issues due to the impact of electric vehicle is implemented in [5]. The power quality issues due to implementation of vehicle to grid system is implemented in [6]. The problem due to incoordination in charging of electric vehicle problem is handled in [7]-[8]. The charger with good efficiency using the sliding mode control is implemented in [9]. A recent trend in microgrid, architecture and control with AC and DC hybrid microgrids are presented in [10]-[12]. The architecture and review of AC and DC microgrid is discussed in [13]-[16]. The test beds of microgrid used around the world is given in [17] and its design is explained in [18], control and modelling are explained in [19]-[24]. Opportunities of microgrid is explained in [25]. The comparison of the DC and AC microgrid is presented in [26]. The microgrid standard test bed is implemented as simulation in [27]. In this paper the validation of the UPQC which is controlled with ANFIS and power by photovoltaics (PV) solar is carried out in a standard test environment. The results are presented and compared with and without UPQC.

2. PROPOSED TEST SYSTEM

In the Figure 1, the microgrid is integrated to the point of common coupling (PCC) to an electrical sub transmission system of 69 kV, 100 MVA with an X/R ratio of 10. It comprises of two voltage distribution levels: A primary 13.8 kV voltage level, represented in blue color and a secondary 0-22 kV voltage level represented in green color. The grid comprises of three sub MGs the description of three sub MGs is: AC microgrid-1 is connected at the 0-22 kV level via lines 4, 5 and 6 to the AC microgrid-2. It operates with a frequency of 60 HZ and diesel generator which provides energy to 4 loads. The second sub MG is AC microgrid-2, which operates with the PV array 2 and the battery energy storage system 2 [BESS]. The operating frequency of both AC sub MGs is 60 Hz. The DC busbar is tied to the AC microgrid-2 by way of two parallel bidirectional converters tagged 1.1 and 1.2 which functions as rectifiers or inverters to interchange active and reactive power through two transformers named TDC-1 and TDC-2 [28]. The details about the different parameters of the system is shown in Table 1.

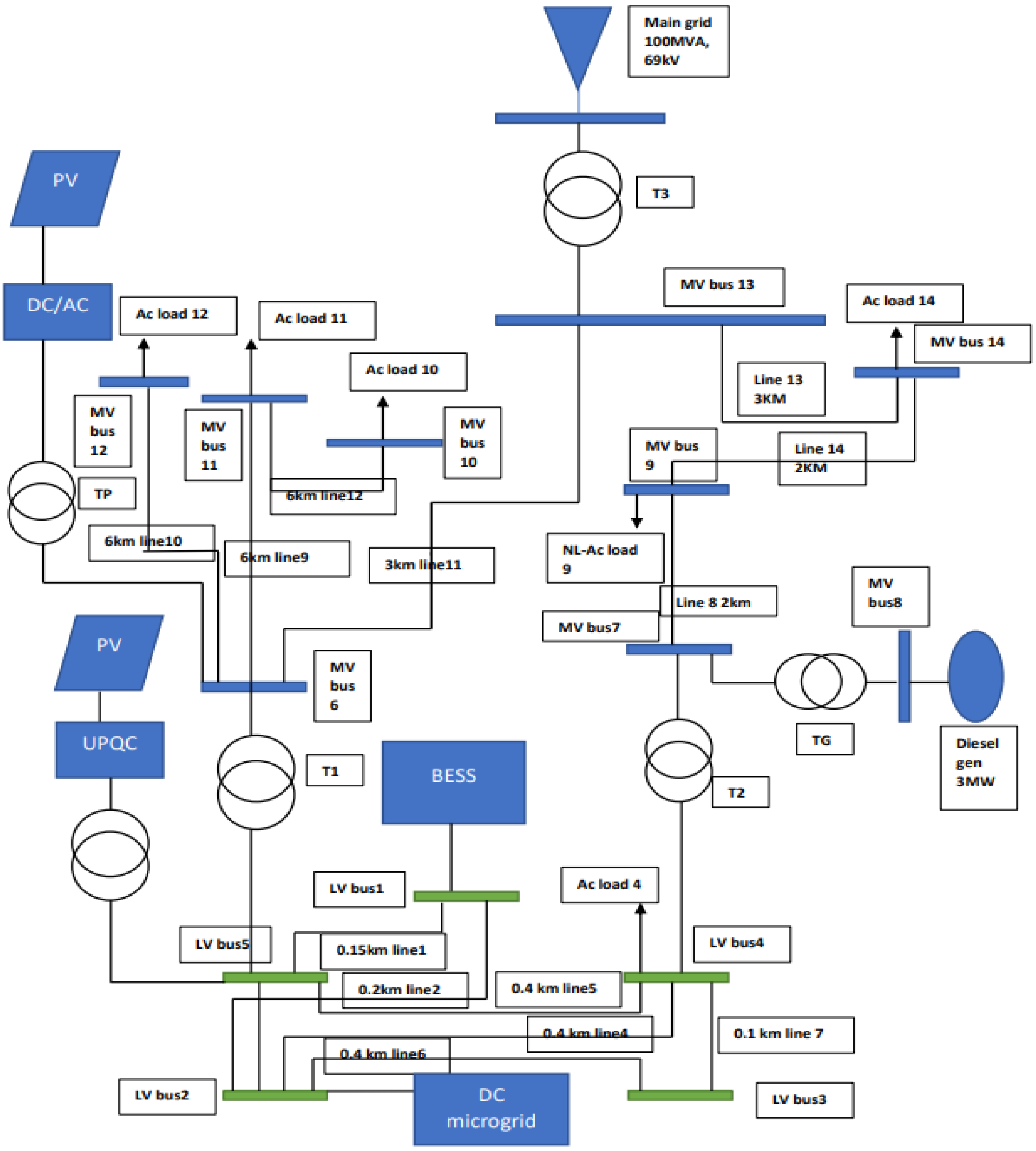

Figure 1. Proposed system

Table 1. Parameters of proposed system

Equipment	Parameters	Values
PV rating	Open circuit voltage in V	37.2 V
	Maximum power point voltage in V	30.2 V
	Wattage in W	244.62 W
Boost converter	Input voltage in V	604 V
	Output voltage in V	900 V
	Frequency in Hz	50 kHz
battery specifications	Voltage in V	750 V
	Capacity in Ah	50
	Initial SOC %	90%
EV Charger	Converter	Boost
	Inductor (L) H	30 uH
	Capacitor (C) F	2200 uF
EV battery	Battery voltage in V	48 V
	Rated capacity (Ah)	500
	Initial SOC %	50%

2.1. Block diagram of proposed system

2.1.1. Operation of proposed method

Figure 2 shows the complete block diagram of the proposed test system. The control schemes of UPQC comprises of shunt active power filter (APF) and dynamic voltage restorer (DVR) with a common DC link capacitor. APF regulator estimate the load voltages and currents, capacitor voltage and injected currents. The regulator algorithm of APF developments the measured values and initiates the needed reimbursement signals which is then equated in hysteresis controller to generate the needed gate signals. DVR controller quantifies the supply voltages to produce the required reimbursement and sag/swell recognition signals. These signals are then equated in PWM controller and the needed gate signals are produced. The PV system used as DC grid. In existing UPQC device, conventional proportional integral (PI) controller balances the actual DC link voltage for all operating conditions but it fails to balance the DC link voltage during dynamic as well as high voltage drop conditions [29]-[31].

In this paper to overcome this drawback, an adaptive neuro fuzzy inference system (ANFIS) is used which comprises of both fuzzy system and neural network learning. ANFIS has the potentiality to grasp, recall and take decision [32]. In the proposed work, ANFIS is trained to function as reference DC link voltage estimator and DC link voltage controller. The control strategy change can make the PV to be used as the islanded mode source of power. Table 1 shows the details of the transformers, loads, BESS and solar PV array.

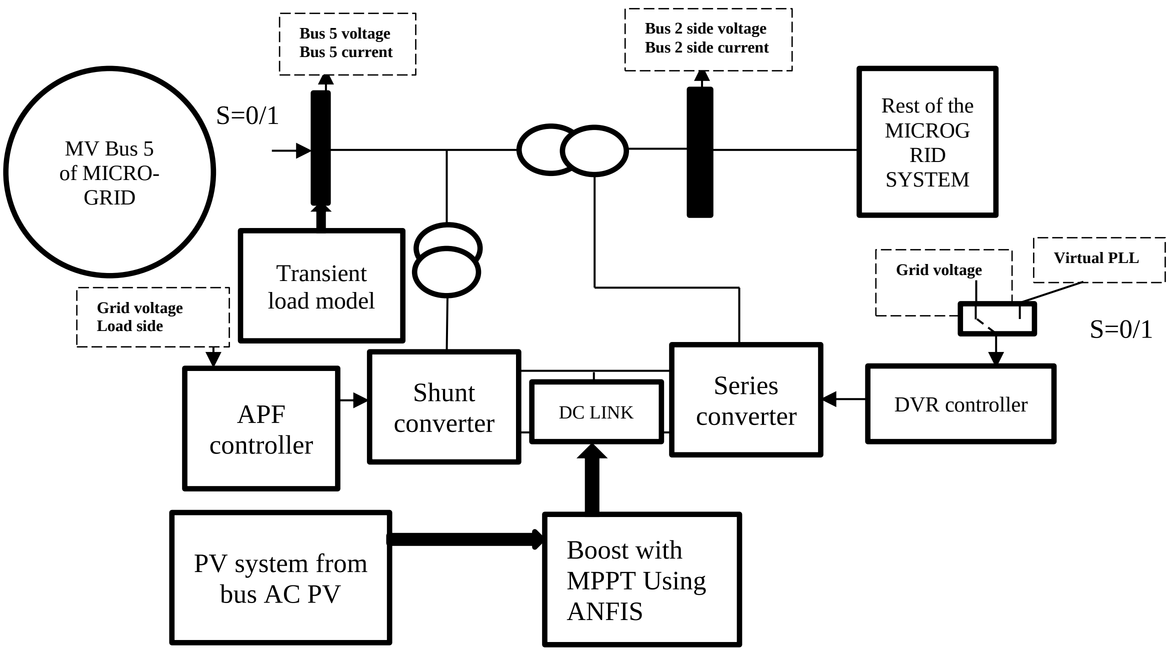

Figure 2. Block diagram of proposed test system

2.1.2. ANFIS control in UPQC

Controller is the heart of any dynamical system which takes care of any interruption in the plant and resumes the system to its initial state in a span of second. The controller aims in modelling and feedback control of dynamic system. The design of the controller using the ANFIS scheme requires a mathematical model of the control plant along with the controller, which can be further used for simulation purposes. The block diagram of the developed controller is shown in Figure 3 and its MATLAB implementation is shown in Figure 4. Inputs to the ANFIS controller, i.e., the error and the change in error, are modeled using equations as follow:

$$e(k) = V_{dc}^{*} - V_{dc}$$

$$\Delta e(k) = e(k) - e(k-1)$$

where
Vdc ref = the reference voltage,
Vdc = the actual voltage,
e(k) = the error and
Δe(k) = the change in error.

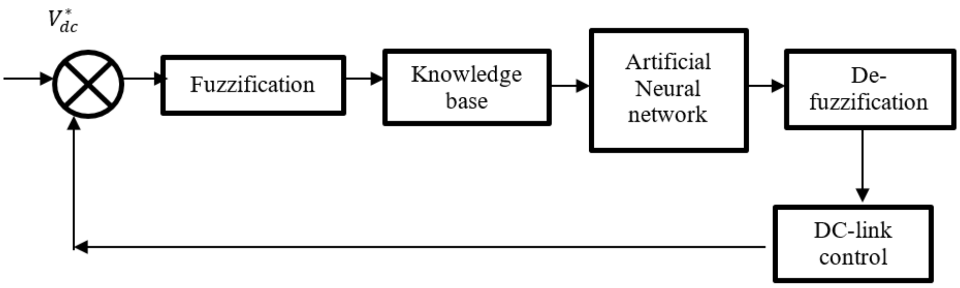

Figure 3. ANFIS implementation

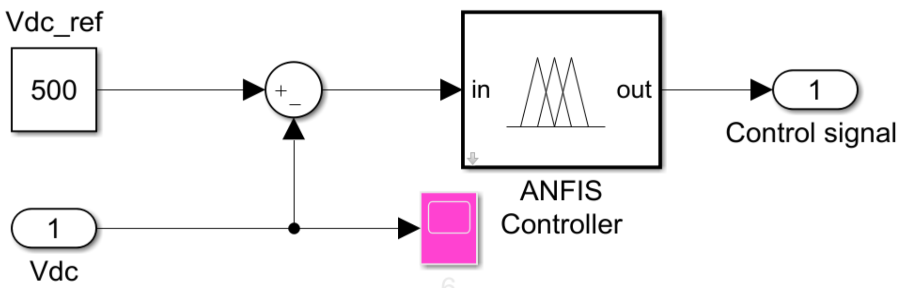

Figure 4. ANFIS MATLAB implementation

A set of 25 rules is written based on the earlier experience or previous knowledge. The input to the rule-based block is taken from the fuzzification unit which transforms crisp data into linguistic variables, which in turn is connected to the neural network block. So as to select appropriate set of rule base Backpropagation algorithm is used for NN training. To establish the control signal, training is a crucial step which involves making proper selection of the rule base. Once the appropriate rules are fixed and fired, the control signal required to obtain the optimal outputs is generated. The inputs are fuzzified using the fuzzy sets and are given as input to the ANFIS controller, which was used for Mamdani-based FLC and TS-based FLC for decision-making purposes, the same is used in this paper for decision making as well as to design the ANFIS controller. For control purpose the similar set of 25 rules are used in this paper which are not indicated here for the purpose of convenience. The inference involves a set of rules for determining the output decisions. The Figure 5 (see in appendix) shows the simulation diagram of the microgrid test system connected with UPQC which is controlled with ANFIS.

3. RESULTS AND DISCUSSION

The load pattern used in the simulation over the time 0.35 sec is given in Figure 6. In initial condition load is less and then reaches peak then drops to the lower value. Then the Figure 7 shows the voltage amplitudes and unbalancing voltage deviation (ADVS) of all the buses before connecting the UPQC. It can be seen that the A phase has 0.04619 deviation B-phase has 0.032761 pu and C phase has 0.042813 pu.

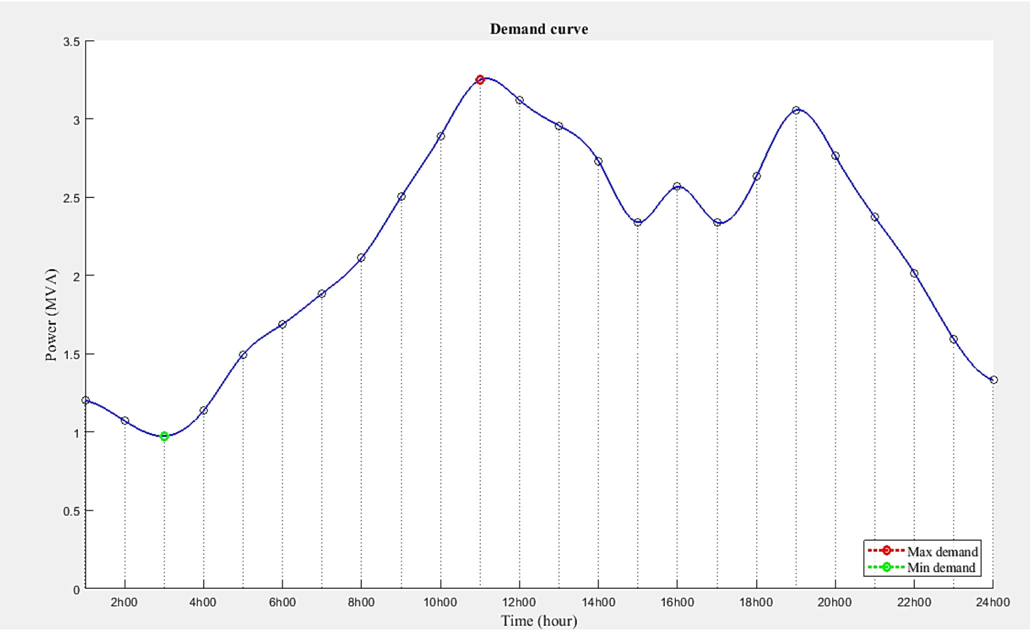

Figure 6. Load pattern of the test system

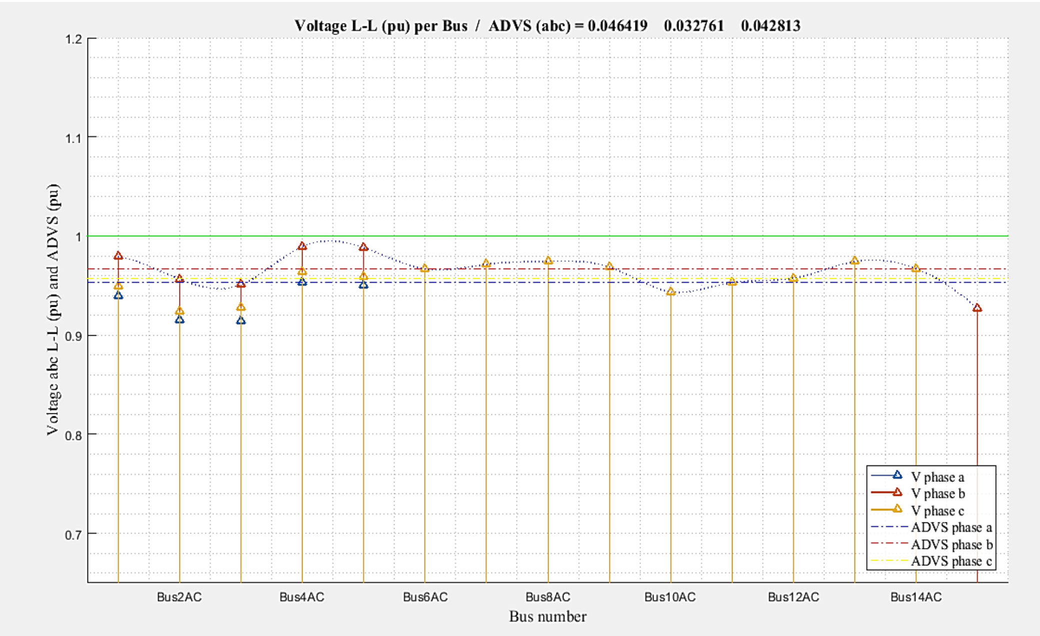

Figure 7. Voltage amplitudes and unbalancing voltage deviation (ADVS) of all the buses

Then the Figure 8 shows the power factor at each bus before connecting the UPQC. It can be seen that bus 2 and 9 are unity power factor. Where other busses have less than 0.85 power factor. Figure 9 shows the voltage amplitudes and unbalancing voltage deviation (ADVS) of all the buses after connecting UPQC-

ANFIS control. It can be seen that after connecting UPQC the A phase has 0.043969 deviation B-phase has 0.030103 pu and C phase has 0.040229 pu. So, the values of deviation of unbalancing is reduced.

The Figure 10 shows the Power factor at each bus after connecting UPQC-ANFIS control. It can be seen that the power factor got improved in bus 3 and 4 above 0.86. Other busses are not affected by the UPQC. The bus 5 power factor is reduced because the UPQC supplies the reactive power required to the other buses also. Total harmonic distortion (THD) values in each phase and buses is as shown in Figure 11 and the values are tabulated in Table 2. From the tabulated values in Table 2 it is clear that THD values are within the limits.

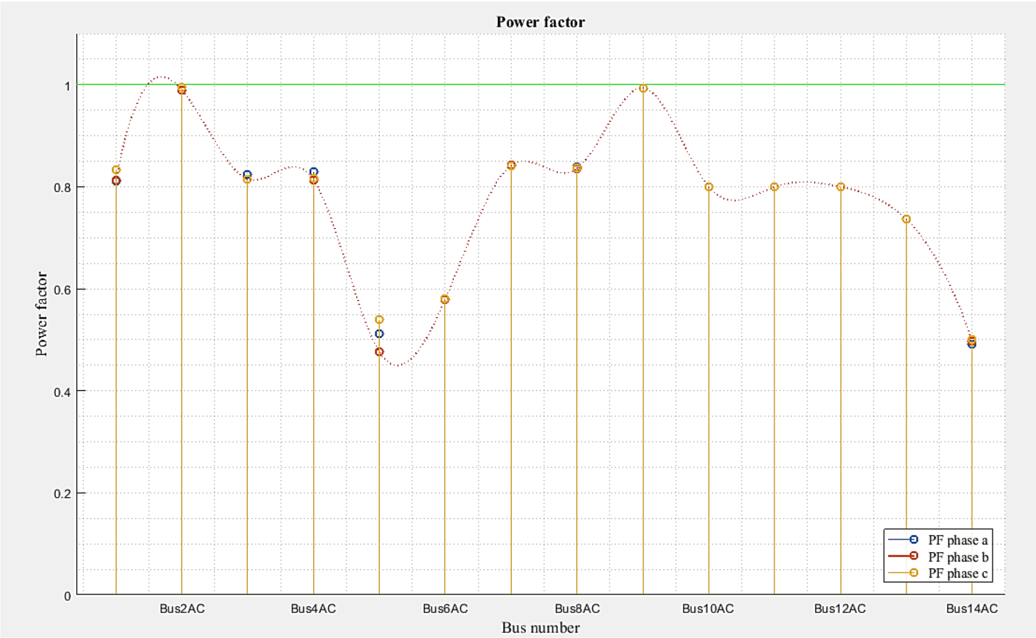

Figure 8. Power factor at each bus

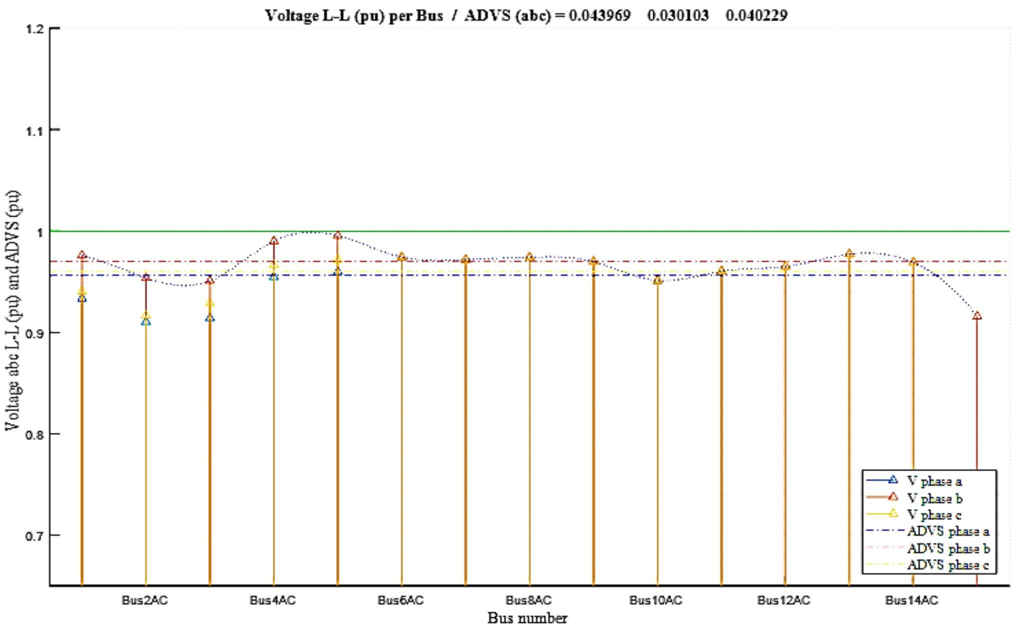

Figure 9. Voltage amplitudes and unbalancing voltage deviation (ADVS) of all the buses after connecting UPQC-ANFIS control

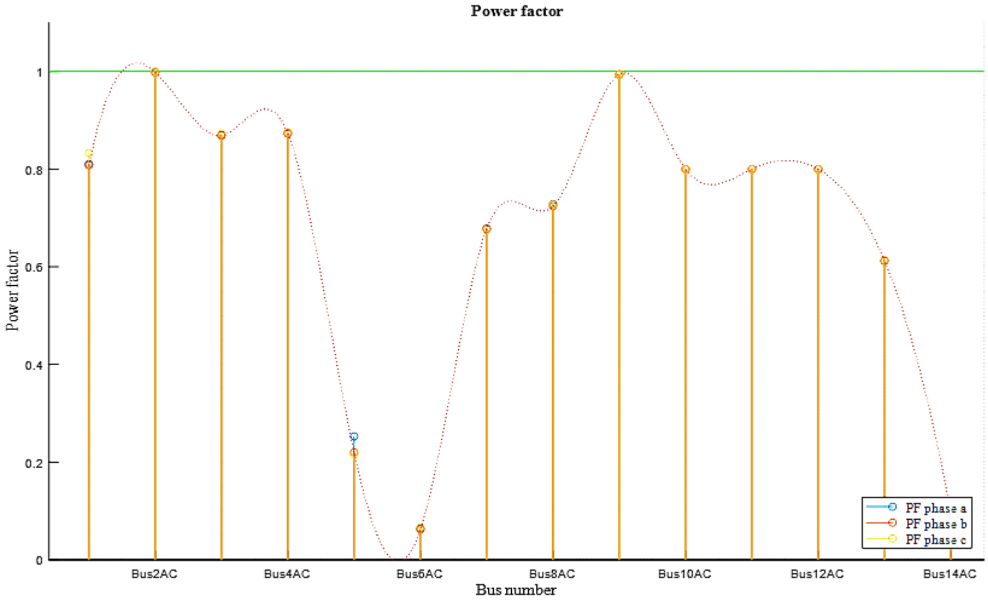

Figure 10. Power factor at each bus after connecting UPQC-ANFIS control

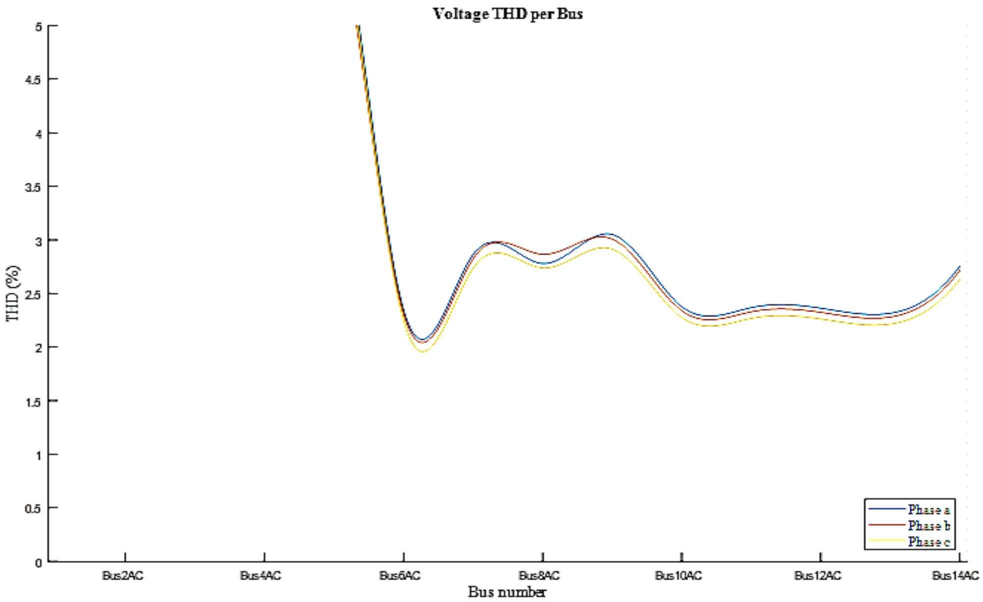

Figure 11. THD values after connecting UPQC-ANFIS control

Table 2. Total harmonic distortion (THD) values in each phase and buses

THD Values in each phase and buses			
Bus .No	Phase A	Phase B	Phase C
2	5.04	5.04	5.05
3	5.02	5.03	5.04
4	5.01	5.01	5.02
5	5.01	5.01	5.02
6	2.1	2.2	2.05
7	2.7	2.8	2.6
8	2.7	2.8	2.6
9	2.7	2.8	2.6
10	2.25	2.3	2.4
11	2.3	2.4	2.5
12	2.25	2.3	2.4
13	2.25	2.3	2.4
14	2.7	2.8	2.6

4. CONCLUSION

The standard microgrid is used here for the validation of the UPQC powered by PV and the control is done with ANFIS controller. In this paper a Simulink model of standard microgrid is developed and is analyzed for different load pattern. The result shows that the voltage sag and swell in the proposed system is compensated well by the ANFIS controller used in the UPQC. The bus number 2 is selected for UPQC placement because it has the voltage of 220 V and also power quality problems occurs at the distribution point. Here the UPQC is performing well with the ANFIS controller by improving the power factor and compensating the reactive power, sag and swell. And also, this reduces the peak current taken by the microgrid. The high spiking of PV solar generation results in deterioration of power factor in the distribution side. It is observed from the result that the power factor and THD is improved, also within limits given in IEEE-519 standard. So, a huge impact is created in the standard micro grid after the implementation of UPQC with ANFIS controller.

APPENDIX

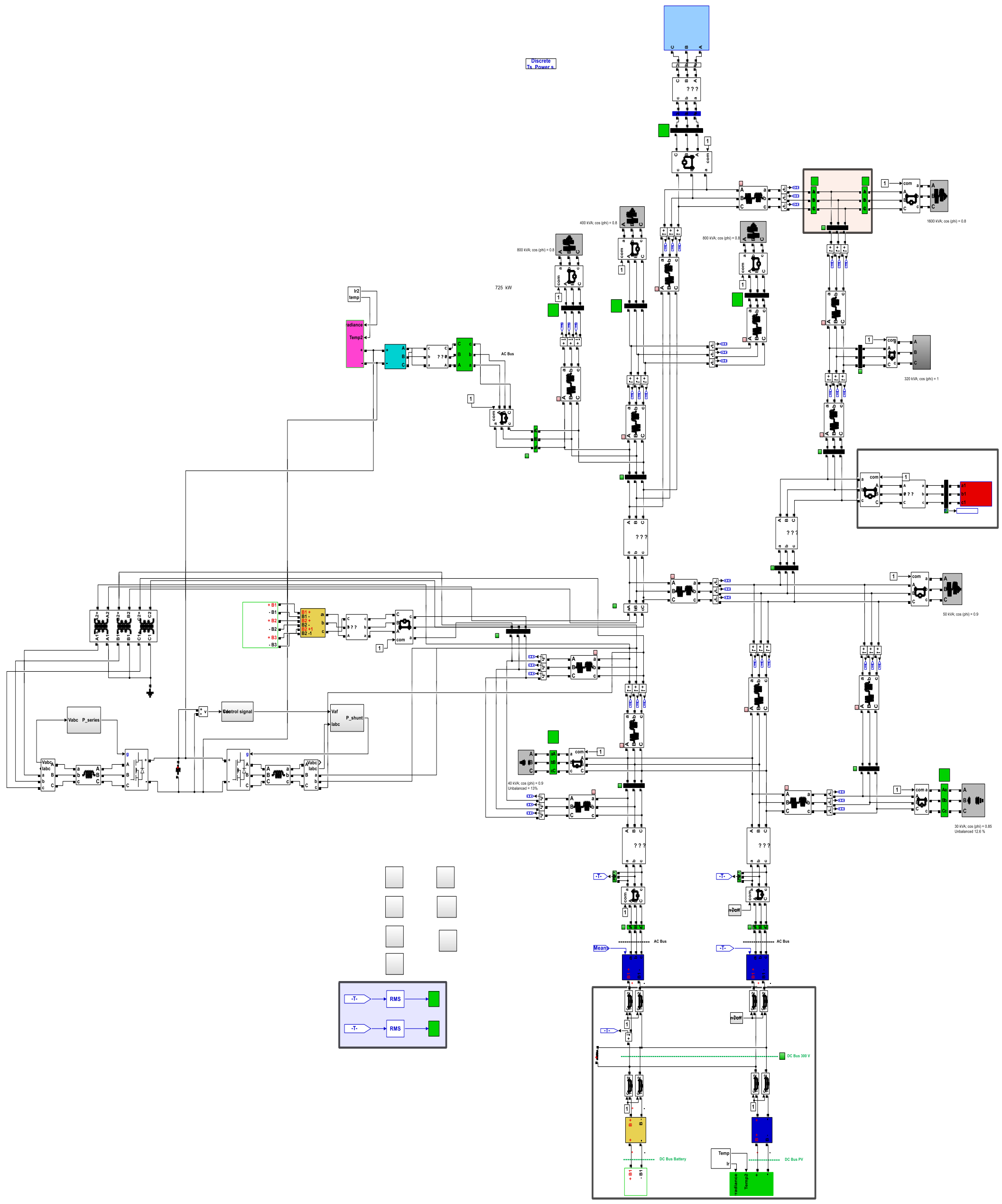

Figure 5. Microgrid test system of [31] after including UPQC

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