ANN Controller for Mitigation of Power Quality Issues Using Single Phase Unified Power Flow Controller

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***Abstract*—This research proposes a nonlinear control method for single-phase Unified Power Flow Controller (UPFC) to improve Power Quality (PQ) issues in single-phase power grid. The main objective of this work is to maintain the appropriate level of load voltage minimal distortion and the control aims include the following: (i) compensation for current harmonics and reactive power; (ii) compensation for voltage disturbances (harmonics and swell, sags and flickers of voltage); and (iii) regulate the voltage on the DC bus. For the purpose to reduce harmonics in power systems and generate reference current for AC supply, the Decoupled Double Synchronous Reference Frame (DDSRF) theory has been presented. The influence of harmonics is then lessened by injecting this harmonic into power systems. Artificial Neural Network (ANN) with Hysteresis Current Controller (HCC) is used to create hysteresis Current regulation, which lowers Total Harmonic Distortion (THD) and increases output voltage. Through several simulation outcomes, the suggested system's effectiveness is examined. Hardware results are also confirmed with simulation outcomes using Matlab/Simulink.**

Keywords—Power Quality, Unity Power factor correction, Decoupled Double Synchronous Reference Frame, Artificial Neural Network , Hysteresis Current Controller

I. INTRODUCTION

Because of the widespread use of electrical devices like variable-speed drives, computing power supplies, combustion appliances, networks of communications, switches, electrical controllers, etc., maintaining PQ in an electric power system is getting more and more difficult [1]. The amount of the sinusoidal voltage and current are affected by these elements in various load situations, which lowers the operational effectiveness of the whole electrical system and the connected components [2, 3]. Additionally, the demand for a high-efficiency power system has caused a slow change in the characteristics of electric utility network components from being primarily linear to strongly nonlinear, providing resulted in various kinds of PQ problems (such as voltage sag and swell, flickers etc.). Normally, the PQ issues resolved by the implementation of Flexible AC Transmission (FACT) devices.

The most widely used comprehensive multifunctional FACTS device is the UPFC [4]. It has the ability to precisely or concurrently adjust every factor influencing the flow of power through a gearbox line. Alternately, it may autonomously regulate the transmission line's active and reactive power flow [5]. In the electrical transmission line, both reactive and active power flow concurrently. It can also function as a harmonic isolator under certain circumstances. A typical UPFC is made up of two Voltage Source Converters (VSCs), one of that functions as a shunt and series converter, that are linked together by a dc link [6].The UPFC's shunt converter regulates the dc voltage as well as the UPFC bus voltage or its reactive power.

By infusing a desirable series voltage that is controlled through it's the phase and magnitude angle, the series converter regulates both the active and reactive power flow on the transmission line [7]. The series converter and the power system interchange reactive and active power as a result of the connection with the inserted series voltage and transmission line current. The shunt converter supplies the series converter with the active power it needs in addition to considering into account the absence of UPFC converters. For purpose of to control the voltage across dc link in both stable and transient states, active power consumption of the series converter is determined and provided as a balanced signal to the shunt converter in [8]. Additionally, the shunt converter receives the reactive electricity flow differences as a compensation signal to keep the UPFC bus voltage steady

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or to regulate the transmitting end's reactive power when the power circulation changes.

3-phase VSCs serve as the foundation of the traditional UPFC power circuit layout [9]. Unfortunately, using the traditional UPFC topology does not allow for the injection of sinusoidal series voltage waveforms with minimized THD. The use of multilevel converters and zigzag transformer connections are 2 basic solutions to this issue [10]. The zigzag arrangement takes up a lot of space, costs a great of money, and is possibly challenging to control [11]. Additionally, this setup causes power losses. The multilayer converters, however, meet THD criteria without the price of inter-phase transformers. Those appear to be an excellent choice for a UPFC arrangement. Cascade H-bridge converters, Diode-Clamped Multilevel Converters (DCMLC), [12, 13], and Flying Capacitor Multilevel Converters (FCMLC) [14] are the three main types of multilevel converters. Since it is impossible to link different dc sources with 2 converters in a back-to-back configuration (such as in UPFC), the cascade converter hasn't been determined to be appropriate for UPFC applications. This is because short-circuits are possible if two back-to-back converters is not switched synchronously.

Cascade transformer-based UPFC arrangements are suggested in [15] as a solution to this issue, however usually employ several transformers, which significantly raises the UPFC's overall expense. The DCMLC and FCMLC based UPFC structures, on the other hand, struggle with a complex power circuitry architecture and regulate scheme. Hence, to overcome aforementioned issues, this work suggests an UPFC which comprises of both series shunt converter. The proposed UPFC effectively mitigate the PQ issues in power system. At input side, the reference current generated by using DDSRF theory. The implementation of ANN with HCC controller effectively maintain the constant voltage and current supply at load side. The attained experimental results shows that, the presented system is highly efficient to enhance PQ issues.

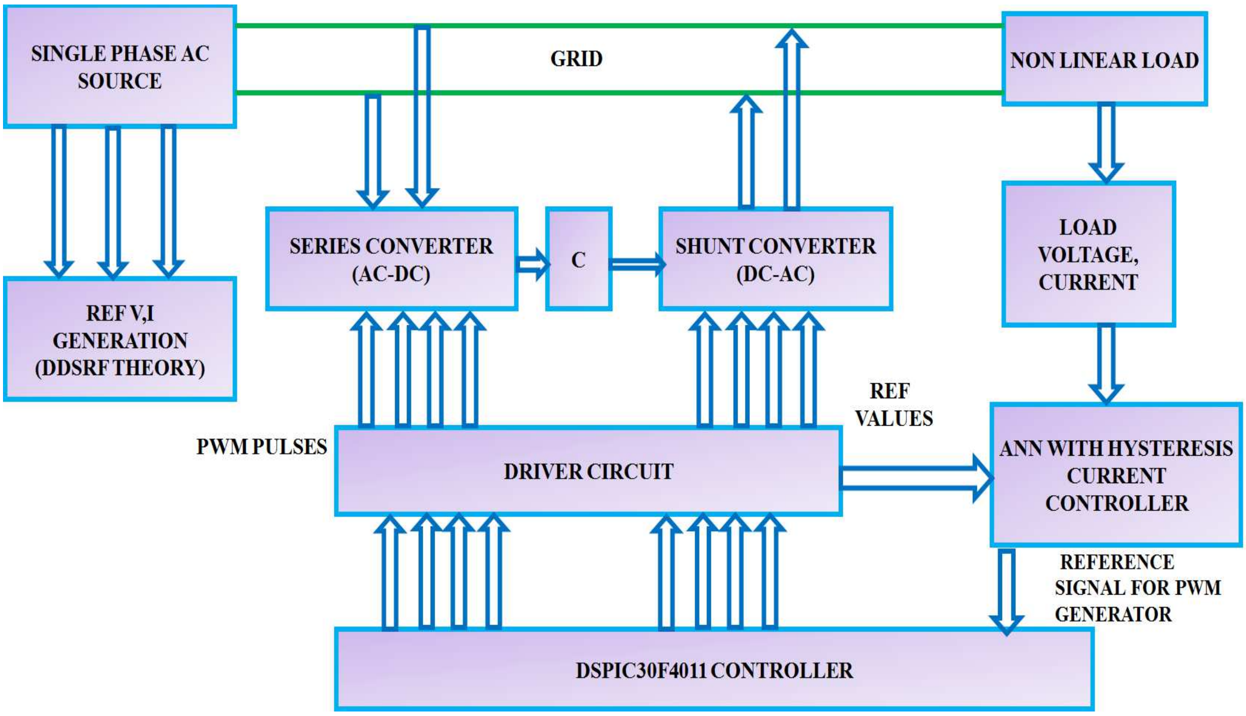

Fig.1. Proposed system model

II. PROPOSED METHODOLOGY

Fig 1 depicts the suggested single-phase UPFC system. Which is contains the components including series and shunt converter, driver circuit, DSPIC30F4011 controller and nonlinear load. UPFC is a multifunctional device, and its transmission magnitude voltage, impedance, and phase angle are the three power transmission line characteristics that are able to be changed to regulate the power flow. Reference current and voltage generated by using DDSRF theory, which lower the source current's THD. The UPFC is made up of two VSCs shunt and series converter that are linked together by a single DC connection. Shunt converter have been employed to supply reactive power to the ac system in addition to the dc power necessary for both inverters, whereas series converter is utilized to add controlled phase angle and voltage magnitude in series with the line. Every circuit is made up of a transformer and an electronic power converter. There is a shared dc capacitor between these VSCs converters. This dc capacitor has a modest energy storage capacity in overall. As a result, the active power generated by the series converter ought to correspond to the active power consumed by the shunt converter. Furthermore, the stable current and voltage is maintained at load side with the deployment of ANN with HCC controller. The proposed UPFC has the ability to enhance grid-side power quality and reduce distortions driven on by nonlinear loads.

A. Modelling of UPFC

Fig 2 depicts the suggested single-phase UPFC system. It has two back-to-back converters, two equivalent energy storage capacitors C_{dc} and is coupled to the DC bus side. PWM is used to control the IGBT-diode powered inverters. On the AC side, the 1 ϕ UPFC system is coupled in series with a nonlinear load through filtering inductor (L_s, r_s), capacitive C_s and current transformer on the one hand, and in parallel with the disrupted power supply grid on the other. The interrupted voltage source vg is connected in series with an inbuilt impedance made up of a resistor r_g and an inductor L_g to represent the disrupted power grid.

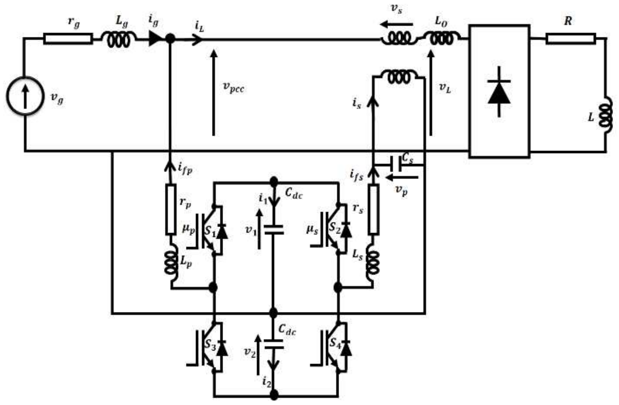

Fig .2. 1 ϕ UPFC model

The 1 ϕ UPFC system of switching function (μ_p, μ_s) can be described as

$$\mu_p = \begin{cases} +1 \; if \; S_1 \; is \; ON \; and \; S_3 \; is \; OFF \\ -1 \; if \; S_1 \; is \; OFF \; and \; S_3 \; is \; ON \end{cases};$$

$$\mu_s = \begin{cases} +1 \; if \; S_2 \; is \; ON \; and \; S_4 \; is \; OFF \\ -1 \; if \; S_2 \; is \; OFF \; and \; S_4 \; is \; ON \end{cases};$$

The periodic signal of load current $i_L(t)$ can be written as (1)

$$i_L(t) = \sum_{h=1}^{\infty} I_h sin(h\omega_g t + \varphi_h) \quad (1)$$

Where I_h h order current harmonic and φ_h phase harmonic in phase order.

Single Phase UPFC Modelling

The following is the 1ϕ UPFC system's simultaneous structure:

$$\frac{di_g}{dt} = \left(\frac{1}{L_g}\right)\left(-r_g i_g + v_g - v_s - v_L\right) \quad (2)$$

$$\frac{di_{fp}}{dt} = \left(\frac{1}{L_p}\right)\left(-r_p i_{fp} + \frac{\mu_p v_o}{2} + \frac{v_d}{2} - v_s - v_L\right) \quad (3)$$

$$\frac{dv_s}{dt} = \left(\frac{1}{C_s}\right)\left(m_s i_{fs} + m_s^2 + i_L\right) \quad (4)$$

$$\frac{di_{fs}}{dt} = \left(\frac{1}{L_s}\right)\left(-r_s i_{fs} + \frac{\mu_s v_o}{2} + \frac{v_d}{2} - \frac{v_s}{m_s}\right) \quad (5)$$

$$\frac{dv_o}{dt} = \left(\frac{1}{C_{dc}}\right)\left(-\mu_p i_{fp} - \mu_s i_{fs}\right) \quad (6)$$

$$\frac{dv_d}{dt} = \left(\frac{1}{C_{dc}}\right)\left(-i_{fp} - i_{fs}\right) \quad (7)$$

Where m_s is the present transformer's conversion ratio, $v_o = v_1 + v_2$ and $v_o = v_1 - v_2$.

The representation of the model $(2a - f)$ proves useful in developing a precise UPFC network simulation. But because it uses binary controlling inputs, specifically μ_p and μ_s the control architecture cannot be constructed around it. Instantaneously signals are usually substituted by typical shapes in averaging models to solve this kind of problem. Over cutting intervals, the signals are averaged. The single-phase UPFC system's average model is written as (8), (9), (10), (11), (12), and (13):

$$x_1 = \left(\frac{1}{L_g}\right)\left(-r_g x_1 + v_g - x_3 - v_L\right) \quad (8)$$

$$x_2 = \left(\frac{1}{L_p}\right)\left(-r_p x_2 + \frac{\mu_p x_5}{2} + \frac{x_6}{2} - x_3 - v_L\right) \quad (9)$$

$$x_3 = \left(\frac{1}{C_s}\right)\left(m_s x_4 + m_s^2 i_L\right) \quad (10)$$

$$x_4 = \left(\frac{1}{L_s}\right)\left(-r_s x_4 + \frac{\mu_s x_5}{2} + \frac{x_6}{2} - \frac{x_3}{m_s}\right) \quad (11)$$

$$x_5 = \left(\frac{1}{C_{dc}}\right)\left(-u_p x_2 - u_s x_4\right) \quad (12)$$

$$x_6 = \left(\frac{1}{C_{dc}}\right)\left(-x_2 - x_4\right) \quad (13)$$

Here, $x_1, x_2, x_3, x_4, x_5, x_6$ μ_p, μ_s are the average values of $i_g, i_{fp}, v_s, i_{fs}\mu_p, \mu_s$.

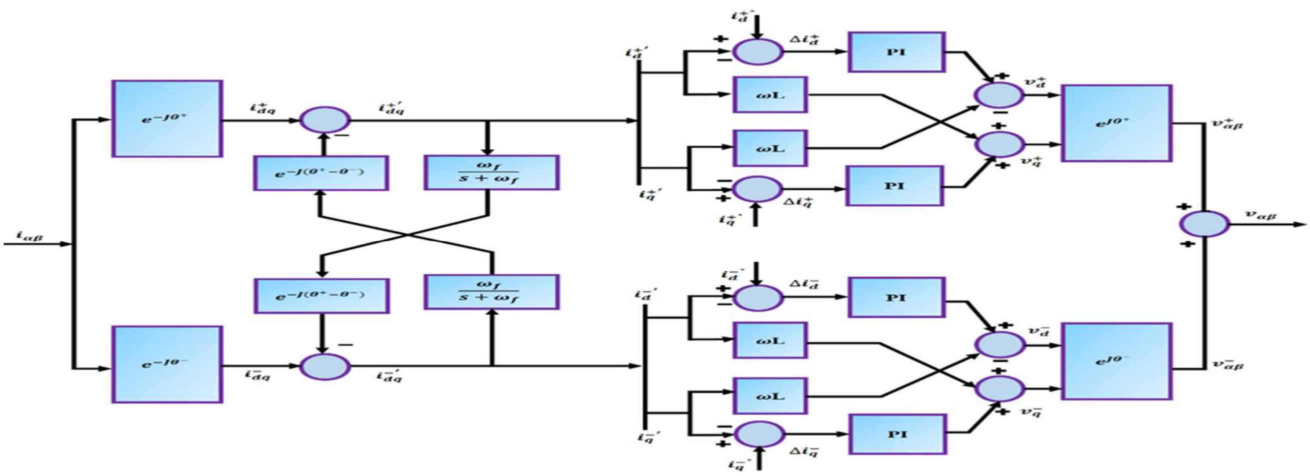

Fig .3. Architecture of proposed DDSRF

B. Modelling of DDSRF theory

During imbalanced circumstances, the combination of a dc value and an overlapped perturbations causes the dq current in the DSRF. To gain maximum potential for injecting the required reactive and active power while a grid fault, this fluctuation needs to be prevented. For minimizing this undesired effect, the DDSRF described in this research is based on a calculation of the oscillations. It is simple to conclude that the result is a the cross-coupling impact across both sequences since the amplitude of the fluctuation in the observed positive-sequence current matching the dc value of the dq negative-sequence current element and vice versa.

The decoupling connection and the DC value are going to calculate and remove oscillation from the measured current in the suggested DDSRF example. Fig 3 depicts the suggested DDSRF current controller architecture.

The oscillation's amplitude in the reverse cycle is equal to the dc value of the initial sequence. To derive the predicted oscillating waveform, however, Park's transformation is applied over the difference in angular position between the two frames. The proposed DDSRF successfully eliminated the current distortions at input side.

C. Modelling of ANN controller

In a typical ANN, each layer of the system has a few hidden neurons. As a result, an ANN's activity and an actual neural network's reaction are certainly identical. This research makes use of the feed-forward ANN, also referred to as the FF-ANN. In FF-ANN, the input automatically moves forward. According to mathematics, a specific neuron's action is defined as:

$$y = Act\ (b + \sum_{i=1}^{M} x_i w_i) \tag{14}$$

Here the input component attributes $x = \{x_1, x_2, \dots x_m\}$, and the triggering parameters are expressed by $Act(.)$,w_i, b and M, correction and bias factor, $x_i$is every input weight, and the number of input elements appropriately.The many neurons could be combined into a single layer to create an FF-ANN layer. The following can serve as a symbol for the entire approach used to predict the results of the single-output multi-input FF-ANN:

$$y_1 = Act\left(\sum_{j=1}^{J} 2_{w_{j1}} h_j + 2_{b1}\right), and \quad h_j = Act\left(\sum_{m=1}^{M} 1_{w_{mj}} x_m + 1_{b_j}\right), \forall j = \{1,\dots,J\}, \tag{15}$$

If $y_1$is the result of the ANN, ($1_{w_{mj}}$,$2_{w_{j1}}$) stands for the respective weights of the hidden and output layers, J for the number of hidden layers, M for the number of input neurons and (1_{b_j} , 2_{b1}) for the biases of the associated layers.

The diagrammatic representation of the recommended ANN-based DC link stabilization is shown in Figure 4. While the reference dc voltage ($V_{dc}\ ref$), actual dc voltage ($V_{dc}\ act$), and inductor current i_l have been selected as the input attributes of the established ANN-based manage method, the optimal switching state S_{Opt} is taken for consideration as that of the governing technique's output in the present article.

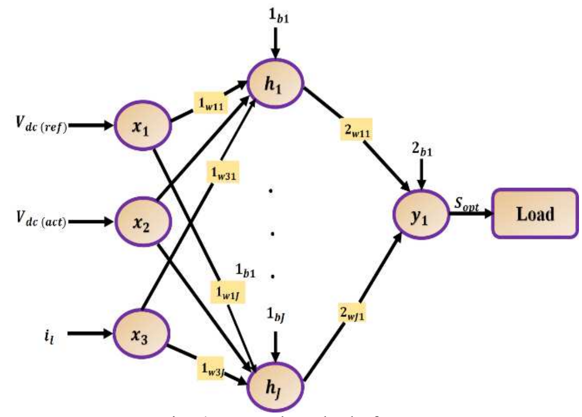

Fig .4. Control method of ANN

With the help of the hyper variables adjusting method, the 14-neuron architecture is chosen. The Bayesian Regularized Technique (BRT) is used to train the ANN and modify its biases and weights. Since BRT is more dependable than traditional propagation strategies, it serves to reduce or totally replace the need for time-consuming cross-validation activities.

Fig .5. Estimation of ANN accuracy

In the present research, 60% of the randomized input data is used for training the ANN, with the remaining 40% used for validation and verification. The developed ANN's accuracy is measured using the overall confusion matrix depicted in Figure 5. While certain members of the diagonal matrix indicate the wrong classification for the data, the diagonal matrix components show the right classification of the data class.

D. Modelling of HCC

One of the simplest methods of regulation to use is hysteresis current control. It is uncomplicated to develop and exhibits reliable current management performance versus modifications to load and source parameters. A voltage source inverter is controlled by HCC which compares the current being observed to the reference current on an immediate basis. To generate switching pulses for the voltage source inverter, the current error is next directly tested within the hysteresis band, a preset band. This technique ramps the amount of current flowing via an inductor up and down to match a reference current signal by controlling the switches in an inverter asynchronously. Fig.6 illustrates diagram for proposed HCC.

Fig .6. HCC model

The current is denoted by the symbol i_{ref} in equation (16), while the variation over i_o and i_{ref} is represented by the symbol error (e). The hysteresis band current controller controls the switching behavior of a PWM generator.

$$e = i_o - i_{ref} \tag{16}$$

The obtained reference current is given by

$$i_{ref} = kv_g \tag{17}$$

$$\text{Where, } k = \frac{2P_L}{V_m^2} \tag{18}$$

The switching frequency is can expressed as,

$$V_{dc} = L_f \frac{di_o}{dt} + V_g \tag{19}$$

From above equation (8),

$$i_o = i_{ref} + e \tag{20}$$

$$f_s = \frac{V_{dc}^2 - V_g^2}{4V_{dc} L_f HB} \tag{21}$$

Therefore, the stable voltage and current delivered to the load without any interruptions.

III. RESULTS AND DICUSSION

The suggested represents the ANN controller method to deliver the constant supply voltage to the single ϕ inverter.The presented HCC achieves better reliability with less current distortions. The graphs of comparison and the waveform for the suggested technique are shown below. The obtained experimental outcomes are shows that the proposed system effectively enhance the PQ issues. The suggested ANN controller approach achieves a reduced THD value compared to traditional methods.

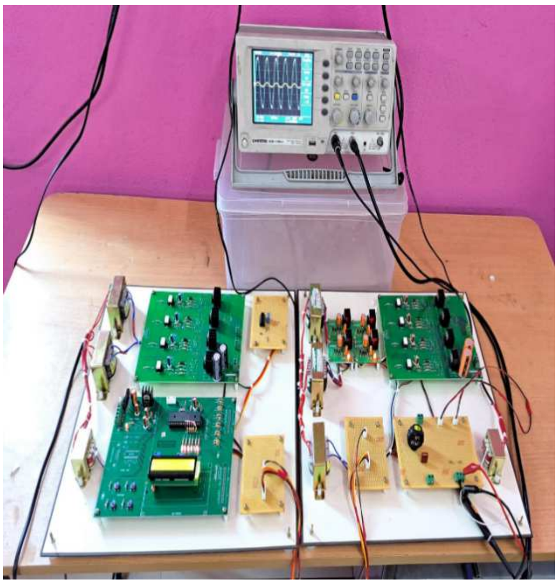

Fig .7. Hardware Set-up

The PQ mitigation using single phase UPFC with ANN controller is implemented in hardware. The experimental proto type is denoted in Fig.7. The relevant outcomes are explained below.

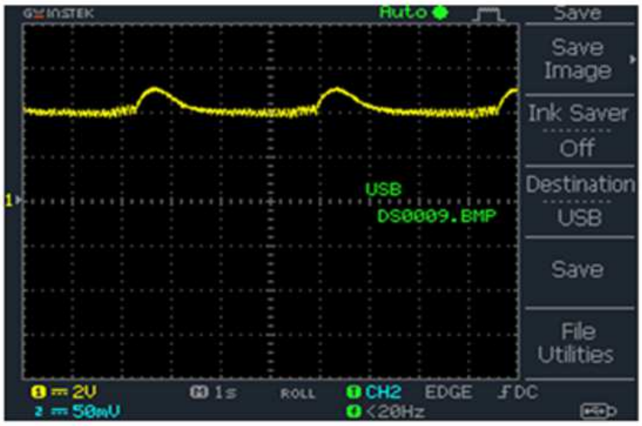

Fig. 8. Waveform of the input DC voltage source

The obtained input DC voltage source is shown in Fig.8. After the particular time, its maintain the constant with minor distortions.

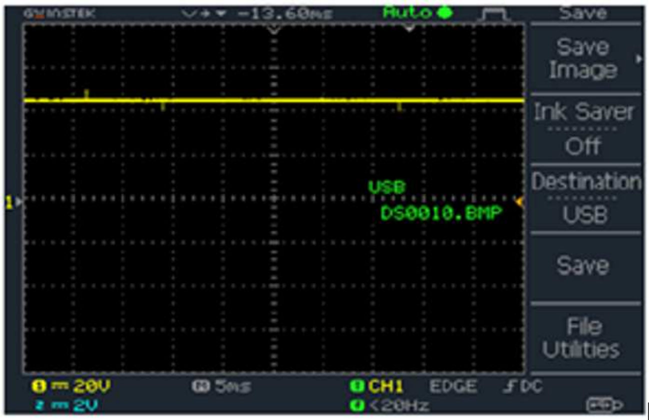

Fig. 9. DC link voltage waveform

The attained DC link voltage waveform is shown in Fig.9. The voltage across DC link is maintained steady value with help of proposed controller.

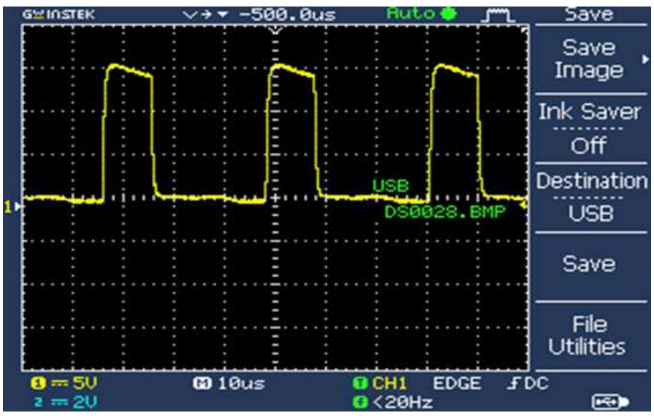

Fig. 10. Pulse waveform representation

Fig 10 denotes the DSPIC30F4011 controller pulse waveform. From the waveform representation, is it clear that the square pulse waveform is obtained.

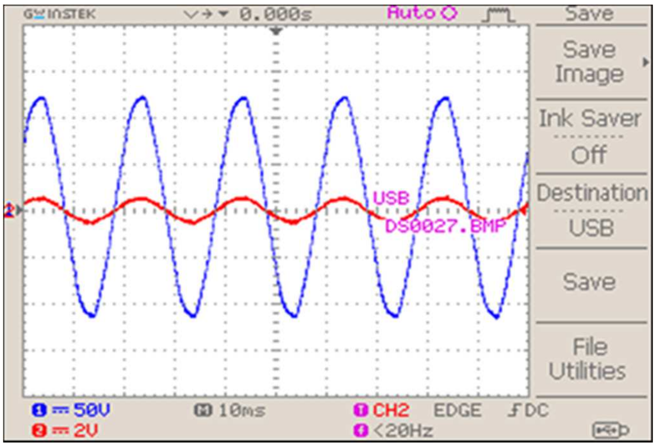

Fig. 11. Grid synchronization

The waveform that denotes the single phase grid synchronization is denoted in Fig 11.

IV. Conclusion

Now a days, problems with power quality are receiving a lot of attention these days because of the financial effects they have on both utilities and customers. The most frequent and serious power quality issues are voltage sags and current harmonics. This study examines a 1 ϕ UPFC for compensating voltage and current fluctuations in a power distribution network. The PQ problems in the power system are successfully mitigated by the proposed UPFC. The reference current is produced at the input side utilizing DDSRF theory. When ANN is used with an HCC controller, the load side supply of constant voltage and current is efficiently maintained. The obtained experimental findings demonstrate the great efficacy of the proposed solution to improve PQ concerns.

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