International Journal for Innovative
Engineering and Management Research
A Peer Revieved Open Access International Journal
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Volume 06, Issue 07, Pages: 121 – 130.

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FUZZY LOGIC CONTROLLER BASED GRID VOLTAGE SYNCHRONIZATION FOR DISTRIBUTED GENERATION SYSTEMS

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Abstract-In this project behavior of advanced grid synchronization systems and structures are presented. The transmission system operators (TSOs) are especially concerned about the low-voltage-ride-through requirements. Conventional phase-locked loop (PLL) schemes have contributed to enhance their response under faulty and distorted scenarios and, hence, to fulfill these requirements. Instead the angular frequency is detected and used for synchronization purposes. The design of UH-PLL is based on a complete description of a three-phase signal which involves both positive and negative sequences in stationary coordinates of the fundamental and harmonic components. Fuzzy-based expert system is proposed for selecting and ranking the most appropriated periods to an integration of distributed generations with a feeder. Madami type fuzzy logic controller was developed for sizing of distributed generation, whereas Sugeno type fuzzy logic controller was developed for the DG location. Input parameters for Madami fuzzy logic controller are substation reserve capacity, feeder power loss to load ratio, voltage unbalance, and apparent power imbalances. DG output, survivability index, and node distance from substation are chosen as input to Sugeno type fuzzy logic controller

Key words- Transmission System operators, Phase locked Loop, UH-PLL, Fuzzy Logic.

I.INTRODUCTION

Grid connected inverter plays a vital role in maintaining voltage at the point of common coupling (PCC) constant. For the reliable operation of utility grid based on DG system, the power plant operators should satisfy the grid code requirements such as fault ride through, grid stability, grid synchronization and power control etc. The major issue associated with DG system is their synchronization with utility voltage vector. The information about the phase angle of utility voltage is tracked accurately to control the flow of active and reactive power and to turn on and off power devices.

The basic phase locked loop (PLL) concept was originally published by Appleton in 1923 and Bellescize in 1932, which was mainly used for synchronous reception of radio signals. After that, PLL techniques were widely used in various industrial fields such as communication systems, motor control systems, induction heating power supplies and contactless power supplies [10].Recently, PLL techniques have been used for synchronization between grid-interfaced converters and the utility network. An ideal PLL can provide the fast and accurate synchronization information with a high degree of immunity and insensitivity to disturbances, harmonics, unbalances, sags/swells, notches and other types of distortions in the input signal. This paper aims at presenting a comprehensive survey on various PLL synchronization techniques to facilitate the proper selection for specific applications.Due to the increasing number of DPGSs connected to the utility network, new and stricter standards in respect to power quality, safe running, and islanding protection are issued. As a consequence, the control of distributed generation systems should be improved to meet the requirements for grid interconnection. This paper gives an overview of the structures for the DPGS based on fuel cell, photovoltaic, and wind turbines. In addition, control structures of the grid-side converter are presented, and the possibility of compensation for low-order harmonics is also discussed. Moreover, control strategies when running on grid faults are treated. Four different synchronization methods for a voltage source converter connected to a three-phase grid are investigated. The methods are adapted for use in a digital controller. The performance of the synchronization methods is studied by response characteristics of phase-shift steps, frequency steps and low-frequency grid voltage harmonics. The low-pass filtering method can be used only if the frequency of the grid is constant and phase jumps do not occur. If phase jumps occur, the novel space vector filtering method is recommended. The extended space vector filtering method is adapted to handle frequency variations and is also preferred if fast frequency variations occur. This method even has a higher performance than the extended Kalman filter method, in spite of the large number of calculations that must be performed..The performance of unified power quality conditioner is mainly depends on how quickly and accurately compensation signals are derived. The control strategies used here are based on PI Controller and fuzzy logic controller [9]. The PI control based techniques are simple and reasonably effective. Further, the control of UPQC based on the conventional PI control is prone to severe dynamic interaction between active and reactivepower flows [10]. The conventional PI controller may be replaced by a Fuzzy Logic Controller (FLC) for better response [11]. The beauty of fuzzy logic controller over PI controller is that it does not need an accurate mathematical model and can handle nonlinearity, work with imprecise input and may be more robust than the conventional PI controller. Recently fuzzy logic controller has generated a great deal of Interest in various applications and has been introduced in the power systems and power electronics field [12].

II.GRID SYNCHRONIZATION TECHNIQUES FOR DISTRIBUTED GENERATED SYSTEM

Wind turbines transform wind energy into electricity. The wind is a highly variable source, which cannot be stored, thus, it must be handled according to this characteristic. A general scheme of a wind turbine is shown in Fig. 1, where its main components are presented.The principle of operation of a wind turbine is characterized by two conversion steps. First the rotor extract the kinetic energy of the wind, changing it into mechanical torque in the shaft; and in the second step the generation system converts this torque into electricity. In the most common system, the generator system gives an AC output voltage that is dependent on the wind speed. As wind speed is variable, the voltage generated has to be transferred to DC and back again to AC with the aid of inverters. However, fixed speed wind turbines are directly connected to grid.

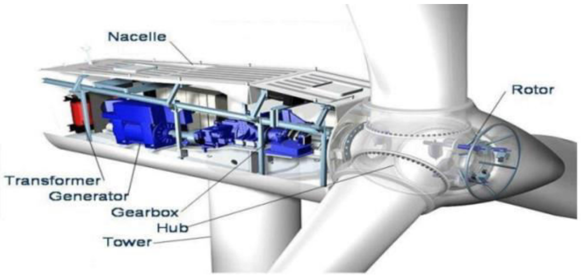


Fig. 1 Schematic diagram of a Wind Turbine

Wind power is fast becoming one of the leading renewable energy sources worldwide. Most of the wind farms uses fixed speed wind turbine, its performance relies on the characteristics of mechanical sub circuits, every time a gust of wind strikes the turbine, a fast and strong variation of electrical output power can be observed, as the response time of mechanical sub-circuits is in the range of 10 milliseconds. These load variations necessitates a stiff power grid and sturdy mechanical design to absorb high mechanical stresses. This approach leads to expensive mechanical construction, so that in order to overcome the above issues, now-a-days DFIG based variable speed wind turbine comes into picture which is benefitted with the following pros:

- Cost effective
- Simple means of pitch control
- Reduced mechanical stresses
- Dynamic compensation of torque pulsations
- Improved Quality of Power
- Reduced acoustic noise

The schematic diagram of interconnection of Grid with DFIG based wind power system is shown in Fig.1. The stator of DFIG is used to supply power directly to the grid, while the rotor supplies power to the grid via power electronic converter. As the back to back converter is connected only to the rotor, the converter costs only 25% of the total system power which improves entire system efficiency to a greater extent. While integrating electric grid with wind power system, owing to the stochastic nature of the wind, the quality of power from the generator output gets affected. If a huge proportion of the grid load is supplied by wind turbines, the output deviations owing to wind speed alternations incorporate voltage variations, harmonics and flicker. The origin of voltage variations such as voltage sag and swell is due to wind velocity, generator torque and switching of wind turbine generator. Harmonics is one of the severe problems in grid connected wind power system. As the consequences faced by voltage sag and harmonics are dominant and leads to degradation of PQ at the consumer's terminal, this paper concentrates on alleviating these two PQ problems. The foremost impacts of the PQ problems are In order to keep PQ within bounds, there is a need PQ Enhancement. For this custom power devices plays a vital role for the purpose of supplying required level of PQ thus make the grid connected wind power system free from PQ problems. Induction and synchronous generators are electrical machines which convert mechanic energy into electric energy then dispatched to the network or loads. Induction generators produce electrical power when their shaft is rotated faster than the synchronous frequency driven by a certain prime mover (turbine, engine). The flux direction in the rotor is changed as well as the direction of the active currents, allowing the machine to provide power to the load or network to which it is connected. The power factor of the induction generator is load dependent and with an electronic controller its speed can be allowed to vary with the speed of the wind. The cost and performance of such a system is generally more attractive than the alternative systems using a synchronous generator. The induction generator needs reactive power to build up the magnetic field, taking it from the mains. Therefore, the operation of the asynchronous machine is normally not possible without the corresponding three-phase mains. . In that case, reactive sources such as capacity r banks would be required, making the reactive power for the generator and the load accessible at the respective locations. Hence, induction generators cannot be easily used as a backup generation unit, for instance during islanded operation. A generator connected to a very large (infinite bus) electrical system will have little or no effect on its frequency and voltage, as well as, its rotor speed and terminal voltage will be governed by the grid. Normally, a change in the field excitation will cause a change in the operating power factor, whilst a change in mechanical power input will change the corresponding electrical power output

III.PROPOSED CONCEPT

The power share of renewable energy-based generation systems is supposed to reach 20% by 2030, where wind and photovoltaic (PV) systems are assumed to be the most outstanding examples of integration of such systems in the electrical network. The increased penetration of these technologies in the electrical network has reinforced the already existing concern among the transmission system operators (TSOs) about their influence in the grid stability; as a consequence, the grid connection standards are becoming more and more restrictive for distribution generation systems in all countries.

In the actual grid code requirements (GCRs), special constraints for the operation of such plants under grid voltage fault conditions have gained a great importance. These requirements determine the fault boundaries among those through which a grid-connected generation system shall remain connected to the network, giving rise to specific voltage profiles that specify the depth and clearance time of the voltage sags that they must withstand. Such requirements are known as low voltage ride through (LVRT) and are described by a voltage versus time characteristic Although the LVRT requirements in the different standards are very different, as shown in the first issue that generation systems must afford when voltage sag occurs is the limitation of their transient response, in order to avoid its protective disconnection from the network. This is the case, for instance, of fixed speed wind turbines based on squirrel cage induction generators, where the voltage drop in the stator windings can conduct the generator to an over speed tripping, as shown in Likewise, variable speed wind power systems may lose controllability in the injection of active/reactive power due to the disconnection of the rotor side converter under such conditions Likewise, PV systems would also be affected by the same lack of current controllability.Solutions based on the development of auxiliary systems, such as STATCOMs and dynamic voltage regulators (DVRs), have played a decisive role in enhancing the fault ride through (FRT) capability of distributed generation systems, as demonstrated in [Likewise, advanced control functionalities for the power converters have also been proposed In any case, a fast detection of the fault contributes to improving the effects of these solutions; therefore, the synchronization algorithms are crucial.In this paper, three improved and advanced grid synchronization systems are studied and evaluated: the decoupled double synchronous reference frame PLL (DDSRF PLL) [34], the dual second order generalized integrator PLL (DSOGI PLL),]and the three-phase enhanced PLL (3phEPLL) Their performance, computational cost, and reliability of the amplitude and phase detection of the positive sequence of the voltage, under unbalanced and distorted situations, have been evaluated according to experimental grid fault patterns extracted from and, which have been reproduced in a real scaled electrical network.

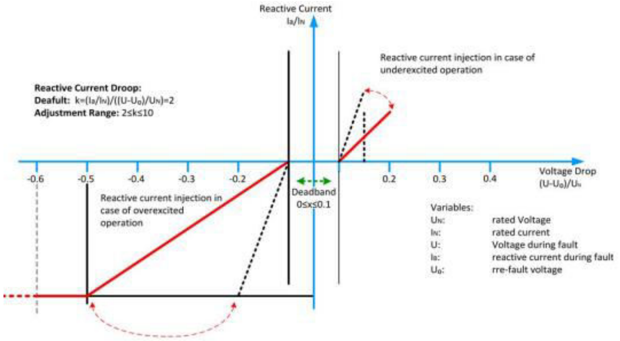


Fig. 2 E-on voltage support requirement in the event of grid fault

Considering these demands, this paper will consider that the estimation of the voltage conditions will be carried out within 20–25 ms, as this target permits it to fulfill the most restrictive requirements, in terms of dynamical response, available in the grid codes. This condition will be extended to frequency estimation; although this parameter is more related to secondary control algorithms than LVRT, the same time window between 20 and 25 ms will be considered in this work for the detection of the disturbance.The discretization of this system has been performed using trapezoidal integrators, as they offer a better detection of the phase, which is important when dealing with sinusoidal signals. The symbolic values of each matrix of (7) are detailed, shown at the bottom of the page. In these matrices, Ts is the sampling time of the discrete system, ω'[n] is the estimated frequency magnitude, which comes from the estimation made at the SRF-PLL block at each computation step, and k is the SOGI gain. The discrete state space of (6) is obtained from the continuous representation by means of the mathematical procedure

IV.ANALYSIS OF UNBALANCED HARMONIC (UH) BASE PLL

A model describing the grid voltage signal is presented. This signal is originally described inthree-phase coordinates v = $[v1, v2\ v3]$. The grid voltage signal is transformed to (fixed frame)αβ-coordinates using Clarke's transformation. Moreover, both positive and negativesequences are considered to deal with the unbalanced case.

$$V_{\alpha\beta}=V^{p}_{\alpha\beta}+V^{n}_{\alpha\beta}=e^{J\theta}V^{p}{}_{dq}+e^{-J\theta}V^{n}{}_{dq} \qquad (1)$$

$$e^{J\theta}=\begin{bmatrix} cos\theta_0 & sin\theta_0 \\ -sin\theta_0 & cos\theta_0 \end{bmatrix}, \qquad J=\begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \tag{2}$$

Where $v_{\alpha\beta}^{P}$ and $v_{\alpha\beta}^{n}$ and represent the positive and negative symmetric components of $V_{\alpha\beta}$ respectively. Based on this, the following model that completely describes the unbalanced sinusoidal signal generator $V_{\alpha\beta}$ is obtained as

$$\dot{V}_{\alpha\beta}=\omega_O J V_{\alpha\beta} \tag{3}$$

$$\phi_{\alpha\beta} = \omega_O J V_{\alpha\beta} \tag{4}$$

Where ω_O represents the fundamental frequency of the grid voltage and the following auxiliary variable has been defined, which is necessary to complete the model.

$$\phi_{\alpha\beta} = V_{\alpha\beta}^{P}\text{-}V_{\alpha\beta}^{n}$$

Notice that (3) and (4) represents the model of an oscillator generating an unbalanced sinusoidal signal, therefore, it is referred as the unbalanced harmonic oscillator (UHO). Based on definitions of $V_{\alpha\beta}$ in (1) and $\phi_{\alpha\beta}$ in (5) possible to establish the following relationship

$$\begin{bmatrix} V_{\alpha\beta} \\ \varphi_{\alpha\beta} \end{bmatrix} = \begin{bmatrix} I_2 & I_2 \\ I_2 & -I_2 \end{bmatrix} \begin{bmatrix} V_{\alpha\beta}^{p} \\ V_{\alpha\beta}^{n} \end{bmatrix} \tag{5}$$

Where I2 is the Identity matrix.

Where $\omega 0$ represents the fundamental frequency of the grid voltage and the following auxiliary variable has been defined, which is necessary to complete the model. The grid voltage signal is transformed to (fixed frame)αβ-coordinates using Clarke's transformation. Moreover, both positive and negativesequences are considered to deal with the unbalanced case.Having the estimates $V\ \hat{}\ \alpha\beta$ and $\hat{\varphi}\alpha\beta$ coming out of estimator and based onrelationship with, the positive and negative sequences of the grid voltage can now be reconstructed as follows Which is referred as the positive and negative sequences generator (PNSG). Summarizing, the proposed U-PLL consists of the U-AQSG, U-FFE , and the PNSG .A block diagram of the proposed U-PLL algorithm is depicted in Fig..3. Notice that in the U-FFE a feed forward term has been included that prevents transients during the startup operation. In this diagram all thick lines represent vector variables, while normal lines represent scalar variables [13]. Notice also that the U-AQSG is composed by a basic block referred as the unbalanced harmonic oscillator (UHO-1), whose output is compared to the measured voltage signal and the error is fed back to it.

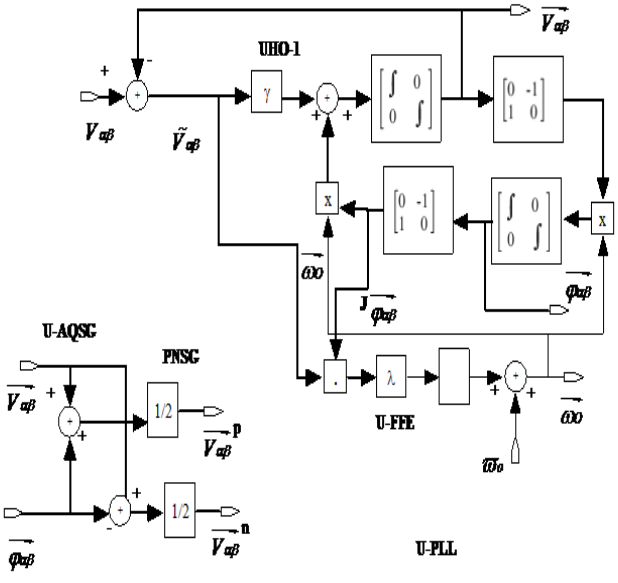


Fig 3. Block diagram of the proposed U-PLL algorithm considering a sinusoidal unbalanced reference signal [13].

The previous scheme U-PLL is extended to consider harmonic distortion present in the grid voltage. For this purpose it is proposed to introduce a harmonic compensation mechanism (UHCM) as shown in Fig. 3. The scheme is referred as UH-PLL as it considers the operation under unbalanced and harmonic distortion. Previous algorithms in [13] and [20] did not include any explicit mechanism for harmonic cancelation. And thus a slight ripple was present in the responses. This effect could be alleviated by limiting the bandwidth of the overall scheme; however, the speed of response is reduced. Hence a tradeoff between the speed of response and the harmonic compensation properties was established. In the UH-PLL scheme this tradeoff is relaxed by the introduction of the UHCM, which allows fast and clean responses.

Unbalanced Harmonic Compensation Mechanism – UHCM:

The idea behind the UHCM consists of designing an estimator to reconstruct the harmonic distortion part of the grid voltage, which is later subtracted from the original signal as shown in the scheme of Fig. 2. Notice that the difference with respect to the diagram of Fig. 3 is simply the introduction of the feedback block UHCM. Hence the UHCM can be seen as plug-in block that can be easily added to the basic scheme U-PLL. This scheme represents an alternative to the harmonic compensation scheme reported

$$\dot{\hat{V}}_{\alpha\beta,k} = k\widehat{\omega_0}J\ \hat{\varphi}_{\alpha\beta,k} + \gamma_k\tilde{V}_{\alpha\beta} \qquad (6)$$

$$\dot{\hat{\varphi}}_{\alpha\beta,k} = k\widehat{\omega_0}J\ \hat{V}_{\alpha\beta,k} \qquad (7)$$

Where Y_K is a positive design parameter used to introduce the required damping.Notice that the estimator similar to the U-AQSG, except a new equation of $V\tilde{}\ \alpha\beta \cong V\alpha\beta - V\hat{}\ \alpha\beta$, which includes the harmonic contents according to (8). Hence, this part of the scheme will be referred as UH-AQSG.

$$\hat{V}_{\alpha\beta} = \hat{V}_{\alpha\beta,1} + \hat{V}_{\alpha\beta,h} \qquad (8)$$

Where $\dot{V}_{\alpha\beta}$ represents the estimate of the fundamental component $\hat{V}_{\alpha\beta,h}$ represents the estimate of the harmonic distortion components of the grid voltage. From (6)-(7), it is clear that of the fundamental component $\hat{V}_{\alpha\beta,h}$ can be decomposed as follows

The harmonic distortion component $V\hat{}\ \alpha\beta{,}h$ computed in block UHCM is performed as follows [13]. First, each harmonic component is reconstructed according to (6)-(7) for k ∈{3, 5, ...}. Second, all harmonic components are accumulated in a single signal as follows.

$$V\hat{}\alpha\beta{,}h = \Sigma\, V\hat{}K \in \{3{,}5\ldots\}\ \alpha\beta{,}k \qquad (9)$$

Reconstruction of signal $\omega 0\dot{\hat{}}$ involved and in the UHCM is performed by the following adaptive law.

$$\omega 0\hat{} = \lambda V\tilde{}\ \alpha\beta T\ J\hat{\varphi}\alpha\beta{,}\ 1 \qquad (10)$$

Whereas before, λ > 0 represents the adaptation gain, and J was defined in (2). Notice that (4.21)coincides with the U-FFE described in (10) except for the new definition of $V\tilde{}\ \alpha\beta$.It includes the harmonic contents according to (8).Therefore this part of the scheme will be referred as UHFFE.As before, a scheme is proposed to generate the positive and negative sequences of the fundamental component of the grid voltage (F-PNSG).

B. Fuzzy Logic Controller

FLC is one of the most successful operations of fuzzy set theory. Its chief aspects are the exploitation of linguistic variables rather than numerical variables. FL control technique relies on human potential to figure out the systems behavior and is constructed on quality control rules. FL affords a simple way to arrive at a definite conclusion based upon blurred, ambiguous, imprecise, noisy, or missing input data. The basic structure of an FLC is represented in Fig.5.

- A Fuzzification interface alters input data into suitable linguistic values.
- A Knowledge Base which comprises of a data base along with the essential linguistic definitions and control rule set.
- A Decision Making Logic which collects the fuzzy control action from the information of the control rules and the linguistic variable descriptions.
- A Defuzzification interface which surrenders a non fuzzy control action from an inferred fuzzy control action.

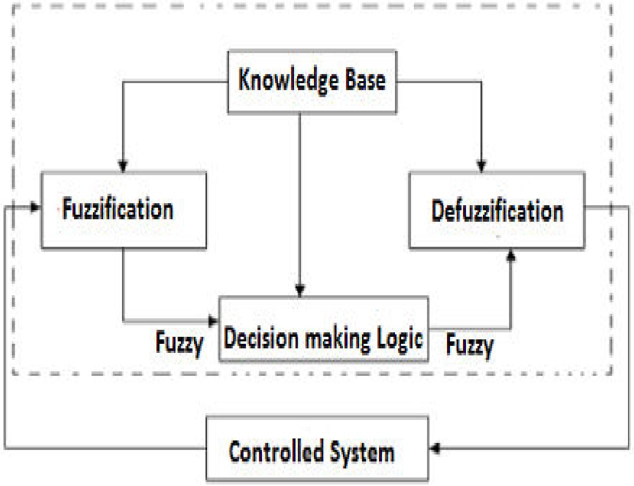


Fig 4 Basic structure of Fuzzy Logic controller

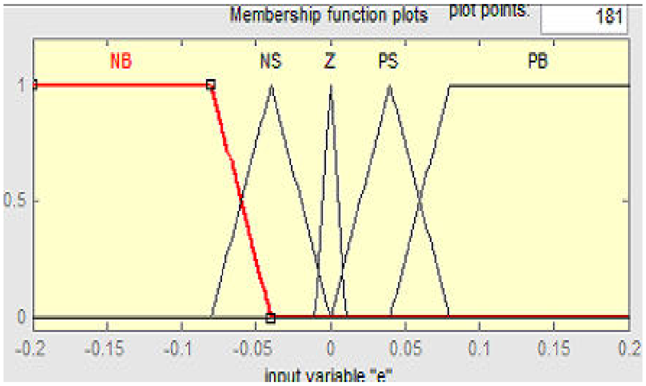


Fig.5. Error as input.

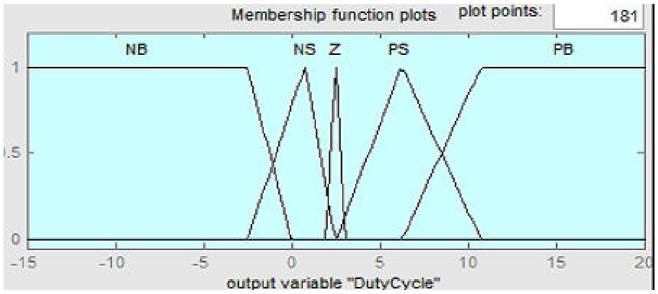
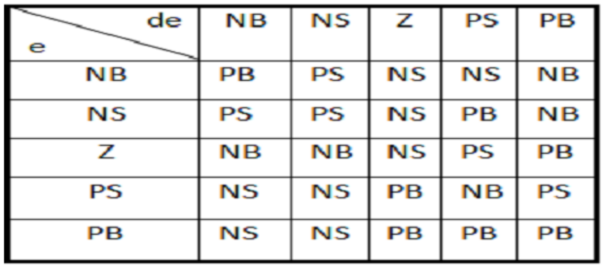


Fig.6Output variables to defuzzification process

In this paper, an advanced control strategy, FLC is implemented along with UPQC for voltage correction through Series APF and for current regulation through Shunt APF. Error and Change in Error are the inputs and Duty cycle is the output to the Fuzzy Logic Controller as shown in Fig.6-Fig.8.



de e	NB	NS	Z	PS	PB
NB	PB	PS	NS	NS	NB
NS	PS	PS	NS	PB	NB
Z	NB	NB	NS	PS	PB
PS	NS	NS	PB	NB	PS
PB	NS	NS	PB	PB	PB

Table.1. Fuzzy Rule Representation.

C. ANFIS Controller

This ANFIS controller is widely used for controlling the non-linear system. As this is the best controller as compared to conventional PID controller, and other controller. This controller is used in Temperature water bath controller. Also this controller is used in planes

V. MATLAB/SIMULATION RESULTS

Case 1: Uncompensated System

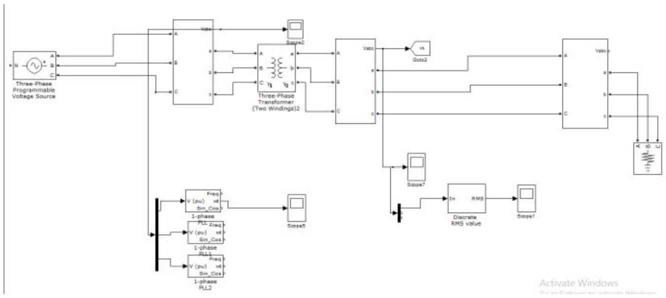


Fig.7 MATLAB/SIMULINK circuit of uncompensated system

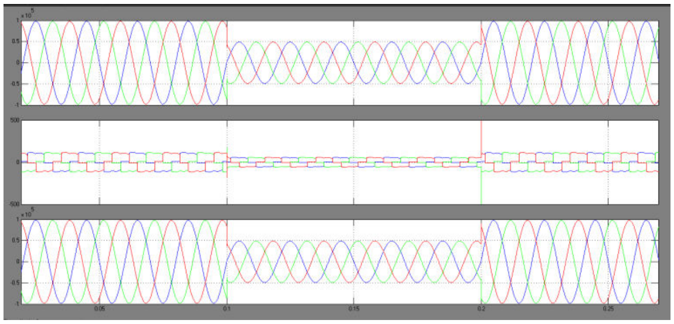
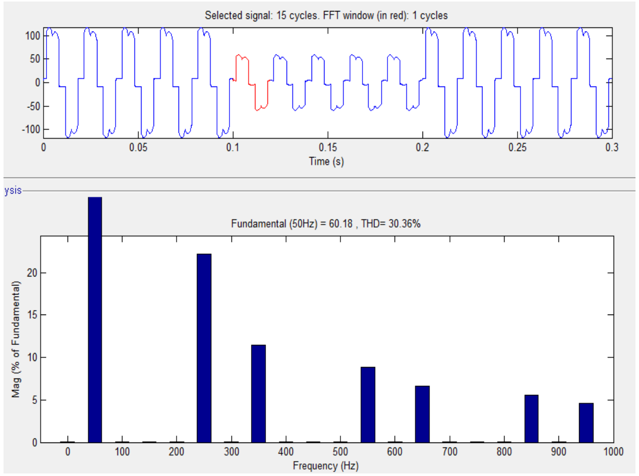


Fig.8. Source voltage, Load current, load voltage



VI.CONCLUSION

This paper studied the behavior of three advanced grid synchronization systems. Their structures have been presented, and their discrete algorithms have been detailed. Moreover, their performances have been tested in an experimental setup, where these algorithms have been digitally implemented in a commercial DSP, allowing proof of their satisfactory response under balanced and distorted grid conditions. The DDSRF PLL and the DSOGI PLL allow estimating the ISCs of a three-phase system working in the $\alpha\beta$ reference frame, while the 3phEPLL uses the "*abc*" reference frame, thus working with three variables. As has been shown, this feature simplifies the structure of the DSOGI PLL and the DDSRFPLL, The Fuzzy Logic Controlled UPQC completely mitigates voltage sag. For mitigation of voltage swell and to improve power quality ANFIS controller is used.

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