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IMPROVEMENT OF POWER QUALITY IMPROVEMENTS FOR INTEGRATION OF HYBRID AC/DC NANO GRIDS FOR INDUCTION MOTOR DRIVES

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ABSTRACT

This paper presents a power factor correction (PFC)-based hybrid ac/dc infrastructure for residential homes (Hybrid Nanogrid) -fed brushless dc Induction motor drive. a hybrid ac/dc home infrastructure which involves DC distribution network connected to the current AC infrastructure through an efficient ac/dc controlled converter. DC network in the home allows for efficient integration of renewable sources and electric vehicles supplying all the native DC loads (DC appliances), while the AC loads (AC appliances) will continue to be connected to an existing AC infrastructure. The speed of the Induction motor is controlled by an approach of variable dc-link voltage, which allows a low-frequency switching of the voltage source inverter for the electronic commutation of the Induction motor, thus offering reduced switching losses. The proposed Induction motor drive is designed to operate over a wide range of speed control with an improved power quality at ac mains. a control scheme for the ac/dc converter is proposed based on a modified synchronous reference frame for Active Power Filter control (APF) to mitigate harmonics, providing a power factor correction and compensating for unbalances resulting from nonlinear loads. The objective of the controller is to force the AC grid currents at the point of common coupling (PCC) to be balanced three-phase currents with minor harmonics while maintaining a controllability of power flow regardless of the characteristics of the local AC load. Then a comparative analysis based on simulation results of bridgeless and bridge boost rectifier is presented. The performance of the proposed drive is validated with test results obtained on a developed prototype of the drive.

1 INTRODUCTION

THE power quality of electric power processing and delivery is gaining more attention. Bad quality of the electric power wears out the system equipment rapidly, increasing the cost of maintenance resulting in system failure or an inconvenient shutdown while leading to strong negative effect to environment [1], [2]. Nowadays, the unprecedented expansion usage of the native DC electrical equipment such as compact fluorescent lamps (CFLs), LED lighting, electric vehicles (EVs), consumer electronics (CEs) and computers put extra burden on the existing AC infrastructure. These DC loads require individual rectifiers to be connected to the ac distribution network to achieve two major jobs. One is to convert the energy from ac to dc to be appropriate to supply the dc load while the second is to work as power factor corrector. DC Nano grids have a centralized rectifier to supply all dc loads offer a sensible solution for residential home network [3], [4] which replace the rectifiers. DC distribution system for electrical energy transmission offers several advantages such as higher reliability, smaller footprint, lower costs, higher efficiency, as a result of not only a smaller number of conversion stages, but also the absence of skin effect and reactive power [5],[6]. Furthermore, most electronic loads, appliances, and variable frequency drives operate with DC voltage. For these reasons, the transition to a DC distribution low voltage network will be the efficient solution for future home. Therefore, the feasibility of DC systems has been verified for residential systems [7], commercial systems [5], shipboard power systems [8], and industrial systems [9].However, the best solution for contemporary home is to combine a dc network along with the legacy ac network [3]. As a consequence, this paper proposes a hybrid ac/dc Nanogrid for a residential home network in which the ac and dc infrastructures coexist to complement each other as depicted in Fig. 1. The hybrid Nanogrid comprises of a Photovoltaic (PV) source and dc loads connected to the dc side, legacy ac loads are connected to the current ac infrastructure. A bidirectional ac/dc converter to control the power flow between both sides.Normally, legacy ac loads comply with the electrical regulation standards in distribution networks such as harmonic levels, but for congested areas, further improvement can be achieved. The main concern for the utility companies is the huge utilization of nonlinear loads in today’s homes which degrade the power quality [10]. There are many regulation standards which define the interconnection requirement of distributed generation (DG) units, especially in low voltage distribution systems [11]-[13]. Also, lots of regulation standards specify the interconnection regulation for the electric loads such as home appliances [13]-[16]. Since, Nanogrid such as ac, dc, or hybrid home will be connected to the low voltage distribution network.So that, the design aspects of the Nanogrid and the interconnection requirement should follow the power quality standard. The injected current harmonics and the total harmonic distortion (THD) is one of the power quality issues that need to be tackled, especially with increasing usage of nonlinear loads in today’s homes. One of the well-known standards in power quality issues is the IEEE 1547 which define the harmonics and THD levels.In order to mitigate harmonic components and compensate for reactive current, negative harmonics and reactive current must be injected into the power network. Many approaches were developed and utilized to mitigate harmonics and provide power factor correction [17]-[19]. One of these approaches is the Active Power Filter (APF), which provides capability to compensate simultaneously for harmonics and reactive power drawbacks. Moreover, APF can compensate for unbalanced loads and regulate the voltage at the point of common coupling (PCC) with the grid. APF can be connected in shunt or series, and its performance is mainly dependent on the accuracy of the used method to extract undesired current. In three phase balanced systems, the Synchronous Reference Frame (SRF) method is used. In three phase four wire unbalanced systems, the instantaneous power theory usually used. The disadvantage of this method that it requires more computation due to measuring the voltage and current for the three phases, which is reflected on the cost of implementation.In this paper, a hybrid ac/dc Nanogrid is proposed for a residential home network. Unlike the previous research, a control scheme based on modified (SRF) is used to control the bi-directional ac/dc converter linking the ac and dc sides of the Nanogrid. This developed controller allows the bidirectional ac/dc converter to act as APF by forcing the AC grid currents at the PCC to be balanced three-phase currents with minor harmonics. Furthermore, it maintains power flow controllability between both ac and dc sides of the hybrid Nanogrid. Using the modified SRF for the proposed APF technique reduces the computational burden as it uses only current measurements to support a three phase unbalanced system.

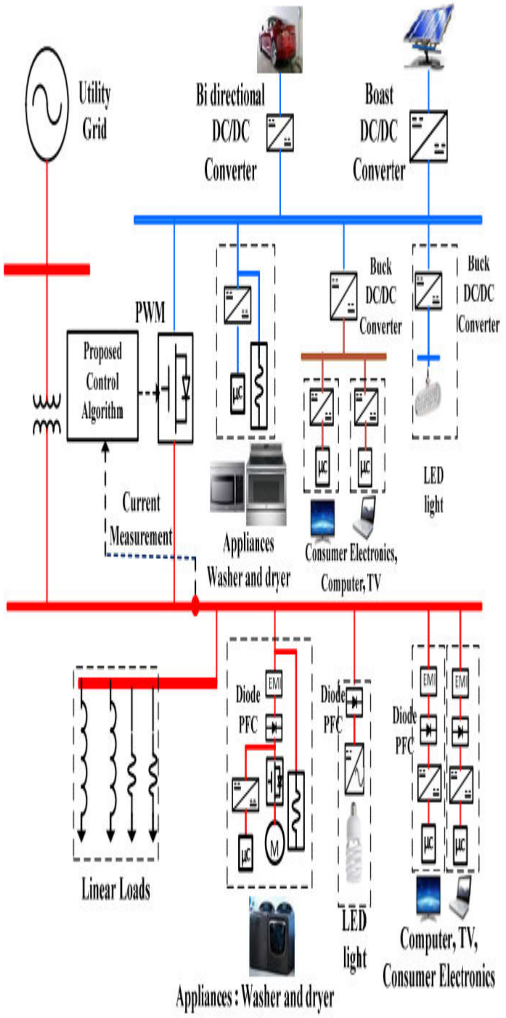

Fig. 1. The main configuration for the hybrid AC–DC Nanogrid

II. AC/DC CONVERTER CONTROL AND ACTIVE FILTERING TECHNIQUES

In this section, a brief overview of the various techniques adopted for inverter control and active power filtering will be presented to clarify the contribution of the proposed technique.

A. AC/DC Converter Control Techniques

Generating a reference current which represents harmonics and reactive current contents is the first stage in the APF control. Calculating the reference current is either based on the time or frequency domain. Time domain compensations are based on the instantaneous derivation of the compensating signals from the distorted ones. Most time domain compensation techniques are based on synchronous reference frame and instantaneous power theory. The frequency domain compensation is based on Fourier analysis of the distorted signal to extract the harmonics, which leads to high computation burden and slow response.

Instantaneous Power Theory

The instantaneous power theory method remains one of the most popular APF control schemes. It transfers the three phase voltages and currents from the abc coordinates to the Įù0 Coordinates via Clarks transformation. As a result, the active and the reactive instantaneous powers can be calculated. Generally, each of the active and the reactive powers are composed of both continuous and alternating terms. The continuous term corresponds to the fundamentals of the current and the voltage. The alternating term represents the power related to the sum of the harmonic components of the current and the voltage. A low-pass filter or a high-pass filter is required to separate the continuous and alternating terms of the active and the reactive instantaneous powers.

The instantaneous power theory can be applied to three phase four-wire balanced and unbalanced systems. It can also be applied to system with voltage harmonics. However, there are some disadvantages of the instantaneous power theory technique; they involve complex hardware implementation due to the requirement of measuring voltages and line currents, and extra calculations to transform voltage and current to Įù0 coordinates. Fig. 2 shows the block diagram for instantaneous power theory.

Synchronous Reference Frame

The SRF compensation method uses the Parks transformation to represent the distorted signal in d-q plane a given in (1):

$$\begin{bmatrix} i_0 \\ i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

In which, the fundamental component will be represented by a DC value in the d-q plane. Moreover, the harmonic component will be represented by an AC component with a frequency of 120 Hz and/or other multiples of 60 Hz. The component of the current in the d-axis will represent the active power, while the component of the current in the q-axis will represent the reactive power. Hence, bi-directional control of the flow of active and reactive power can be done separately. Moreover, the harmonic compensation current can be extracted from the d-axis current using a high pass filter. One is the limitation of this method that, when applying Parks transform, an AC component appears in the d-q plane with a frequency of 120 Hz in 60 Hz networks due to unbalancing. This AC component is equal to the AC component produced by the third harmonic which leads to injection of 3rd harmonic to the grid [22].

B. Active Power Filter configuration

An APF may take one of several possible configurations to meet different load compensation requirements. An APF can be classified according to the supply system and load type into: single-phase APF, three-phase four-wire APF, and three-phase three-wire APF. A single-phase or three-phase APF can be connected in series, shunt or unified power quality conditioner, operating with either a voltage source or a current source converter. In case of a three-phase four-wire system with unbalanced load, APFs can be designed as a four-wire filter to compensate neutral current and balance the load, or three independent single-phase filters with isolation transformers for independent phase control. There are two configurations for three-phase four-wire active filters: the first configuration is known as the four-arm converter type in which the fourth converter-arm is used to compensate the neutral current. The second configuration is known as capacitor mid-point type in which the entire neutral current flows through DC bus capacitors. A three phase three arm voltage converter is utilized as link converter between ac and dc sides. The same link converter will be used to control the power flow and perform the APF function. The proposed APF uses the link converter which work in current control mode to inject the reactive and harmonic current required by the nonlinear load system.

III SYSTEM AND CONTROLLER DESCRIPTION

A. System and proposed control description The system under study is a hybrid AC/DC Nanogrid to represent future home integrated to power system as depicted in Fig. It consists of an AC zone, a DC Zone, and bidirectional AC/DC converter. The AC zone represents the legacy AC infrastructure with an AC load connected to it. This AC low voltage network is connected to the utility low voltage network at the PCC. The DC zone, with a 0.38 kV DC voltage as the main DC bus is used to integrate the alternative DC sources and load to the system. The 5 kW PV connected to the main DC bus through DC/DC boast converter. The DC powered appliances are connected to the main bus through multiple stages of DC/DC buck converters based on their voltage level. A 10 kW hysteresis current-controlled bi-directional DC/AC converter connects both zones together to maintain bidirectional power flow and act as an APF to the AC loads connected directly to the utility grid. Therefore, it is used to create a DC zone network in the low voltage home infrastructure while working as an APF to improve the power quality of the system at PCC.

The proposed control technique will be consist of two part. One is the bidirectional control for the ac/dc converter which maintain the power balanced into proposed hybrid Nanogrid. The other one responsible for the APF functionality.

Power Flow Control

In order to maintain the power balance through the Nanogrid, the amount of power controlled by the linking converter need to be calculated. By calculating the difference power between the PV power and the local DC load power (2).

$$Pcon = Ppv - Pldc \tag{2}$$

Based on the instantaneous power theory the active power given in equation (3)

$$Pcon = Vd\ Id + Vq\ Iq \tag{3}$$

Since the synchronous reference frame d-axis is aligned with the three phase voltage angle, Vq will be equal zero. Then the Id reference is calculated from equation (4).

$$Id = Pcon/Vd \tag{4}$$

APF Control

The filtering functionality serves two purposes: compensating the unbalance due to existence of different appliances supplied with single and three phase loads, mitigates harmonics due to nonlinear loads, and corrects the power factor at the PCC. In the proposed system, the reference current signal is obtained from the measured load current through the use of a modified synchronous reference frame based method. The modified synchronous reference frame method is capable of dealing with a balanced and unbalanced system with a three or four wire connection. Fig. 4 shows the block diagram for the reference current generator. It is shown that ild is being calculated from the three phase currents using Parks transformation. The calculated id contains a DC component that represents the fundamental active component current, while the AC component represents the harmonic components. To obtain the DC component, id passes through a low pass filter with a cut-off frequency of 75 Hz. The output of the low pass filter will represent the magnitude of the fundamental active current component existing in the load. A dc voltage regulator is used to calculate the active current component required to regulate the DC bus voltage. The reference current from the DC voltage regulator in addition to reference current calculated from a power balance controller are added to the calculated ild. A three phase sinusoidal current reference is calculated by using inverse Park's transform where iq and i0 will be set to zero since we need to obtain the active fundamental component only.Consequently, the calculated sinusoidal component is subtracted from the load current. The obtained component is a reference current that represents all harmonics and reactive components existing in the load current plus a fundamental component necessary for power balancing.

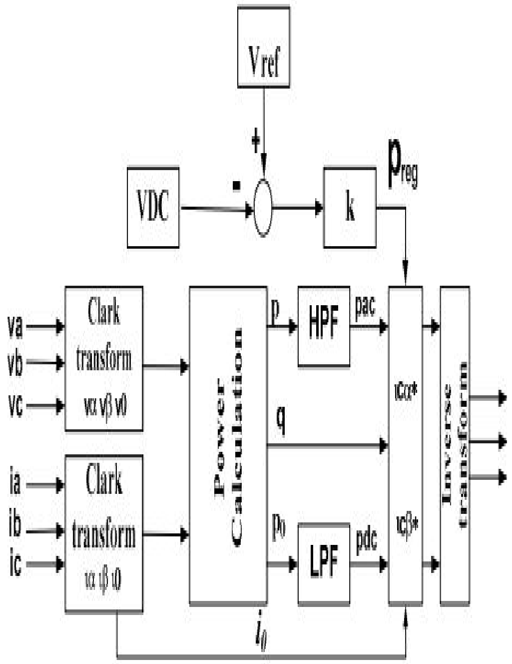

Fig. 2. Block diagram of instantenous power theory APF control.

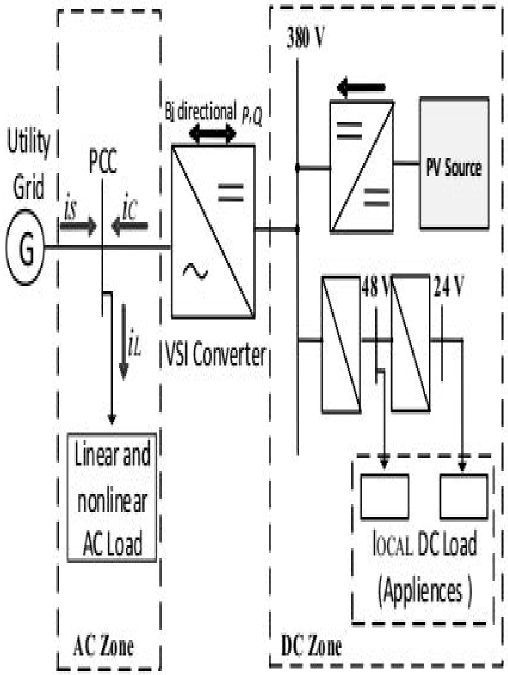

Fig. 3 Block diagram for the hybrid Nanogrid under study

Fig. 4 shows the block diagram for the power balance calculation.

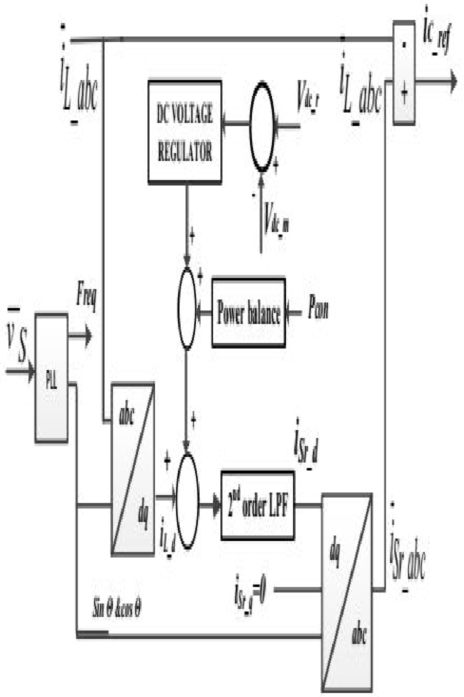

Fig. 4. A block diagram of the reference current generator.

By this method, we can manage to overcome the problem of an unbalanced AC current component where the calculated three phase sinusoidal reference is being subtracted from the load current to obtain the final current injected to the AC side. To calculate the Parks transform, sin (ș) and cos (ș) should be known. A phase locked loop (PLL) is used to obtain the supply voltage phase angle in order to calculate sin (ș) and cos (ș). In some cases, a frequency drift of the fundamental component can happen. The adopted PLL has the capability to accurately track the frequency and compensate for this drift. The developed controller detects power quality problems resulting from the load and automatically generates the needed compensating currents. Hence, it prevents power quality issues from propagating to the network of the grid as the harmonics or distorted current that are not seen beyond the PCC.

IV. INDUCTION MOTOR

An asynchronous motor type of an induction motor is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding. An induction motor can therefore be made without electrical connections to the rotor as are found in universal, DC and synchronous motors. An asynchronous motor's rotor can be either wound type or squirrel-cage type.Three-phase squirrel-cage asynchronous motors are widely used in industrial drives because they are rugged, reliable and economical. Single-phase induction motors are used extensively for smaller loads, such as household appliances like fans. Although traditionally used in fixed-speed service, induction motors are increasingly being used with variable-frequency drives (VFDs) in variable-speed service. VFDs offer especially important energy savings opportunities for existing and prospective induction motors in variable-torque centrifugal fan, pump and compressor load applications. Squirrel cage induction motors are very widely used in both fixed-speed and variable-frequency drive (VFD) applications. Variable voltage and variable frequency drives are also used in variable-speed service.In both induction and synchronous motors, the AC power supplied to the motor's stator creates a magnetic field that rotates in time with the AC oscillations. Whereas a synchronous motor's rotor turns at the same rate as the stator field, an induction motor's rotor rotates at a slower speed than the stator field. The induction motor stator's magnetic field is therefore changing or rotating relative to the rotor. This induces an opposing current in the induction motor's rotor, in effect the motor's secondary winding, when the latter is short-circuited or closed through external impedance. The rotating magnetic flux induces currents in the windings of the rotor; in a manner similar to currents induced in a transformer's secondary winding(s). The currents in the rotor windings in turn create magnetic fields in the rotor that react against the stator field. Due to Lenz's Law, the direction of the magnetic field created will be such as to oppose the change in current through the rotor windings. The cause of induced current in the rotor windings is the rotating stator magnetic field, so to oppose the change in rotor-winding currents the rotor will start to rotate in the direction of the rotating stator magnetic field. The difference, or "slip," between actual and synchronous speed varies from about 0.5 to 5.0% for standard Design B torque curve induction motors. The induction machine's essential character is that it is created solely by induction instead of being separately excited as in synchronous or DC machines or being self-magnetized as in permanent magnet motors.For rotor currents to be induced the speed of the physical rotor must be lower than that of the stator's rotating magnetic field (n_s); otherwise the magnetic field would not be moving relative to the rotor conductors and no currents would be induced. As the speed of the rotor drops below synchronous speed, the rotation rate of the magnetic field in the rotor increases, inducing more current in the windings and creating more torque. The ratio between the rotation rate of the magnetic field induced in the rotor and the rotation rate of the stator's rotating field is called slip. Under load, the speed drops and the slip increases enough to create sufficient torque to turn the load.

Synchronous Speed:

The rotational speed of the rotating magnetic field is called as synchronous speed.

$$Ns = \frac{120 \times f}{P} \quad (RPM) \tag{47}$$

Where,

f = frequency of the supply

P = number of poles

Slip:

Rotor tries to catch up the synchronous speed of the stator field, and hence it rotates. But in practice, rotor never succeeds in catching up. If rotor catches up the stator speed, there won’t be any relative speed between the stator flux and the rotor, hence no induced rotor current and no torque production to maintain the rotation. However, this won't stop the motor, the rotor will slow down due to lost of torque, and the torque will again be exerted due to relative speed. That is why the rotor rotates at speed which is always less the synchronous speed.

The difference between the synchronous speed (Ns) and actual speed (N) of the rotor is called as slip.

$$\% \text{ slip} \quad s = \frac{Ns - N}{Ns} \times 100 \tag{48}$$

V. MATLAB/ SIMULATION RESULTS

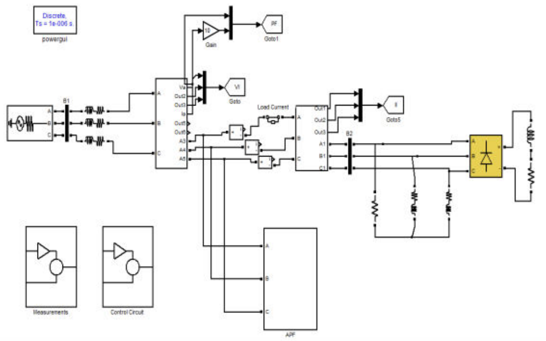

Figure5 Simulink diagram of proposed concept

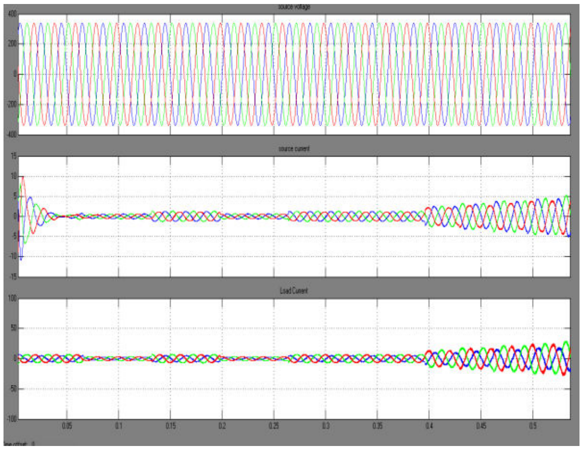

Fig. 6 simulation result: (a) Main DC bus Voltage (V). b) three phase AC supply current c) three phase AC load current

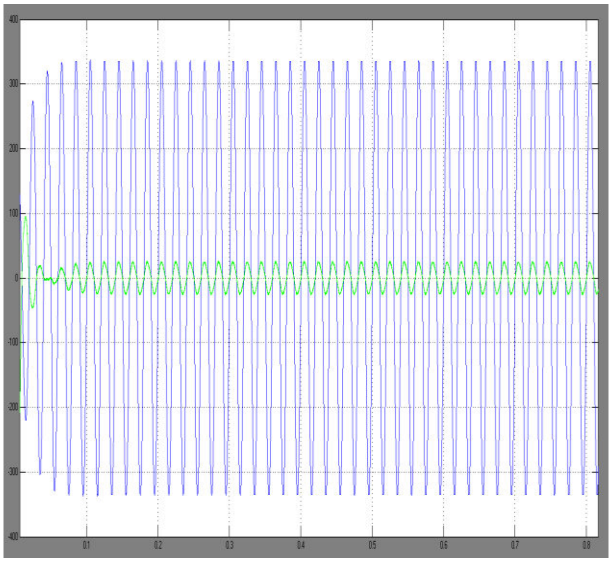

Figure 7 source power factor

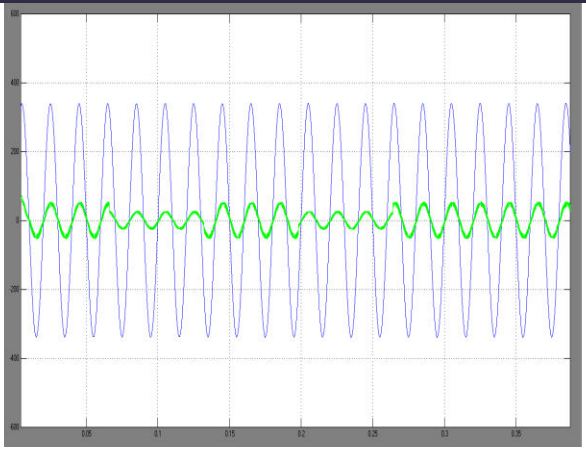

Figure 8 Load power factor

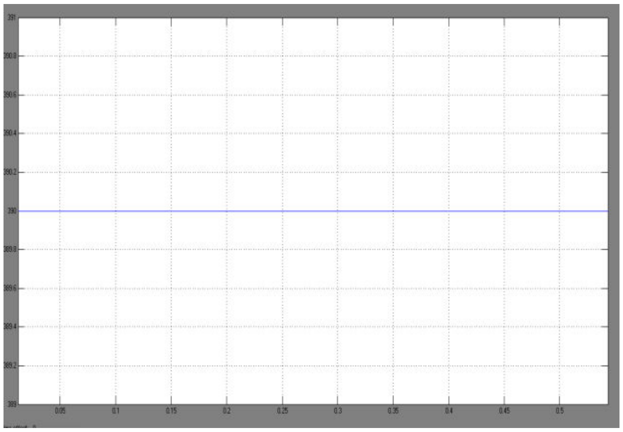

Figure 9 Voltage of the Pv system

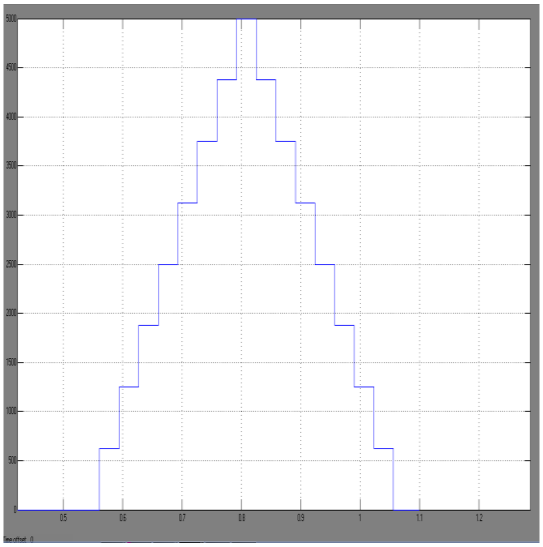

Fig 10 PV system output power

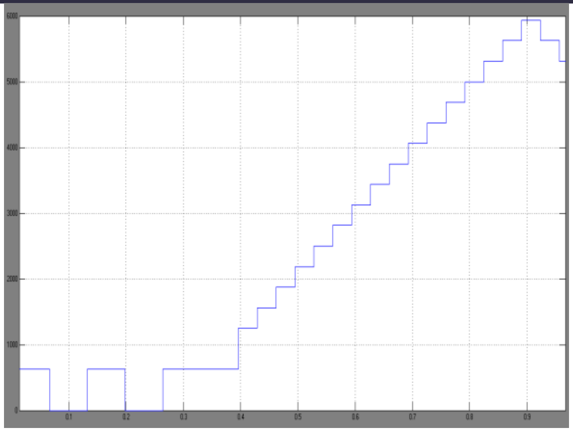

Fig 11 DC load power (Watt)

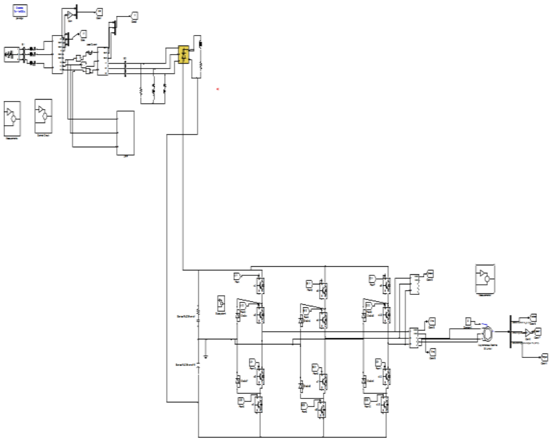

Fig 12 Simulink diagram of proposed concept with Induction motor drive

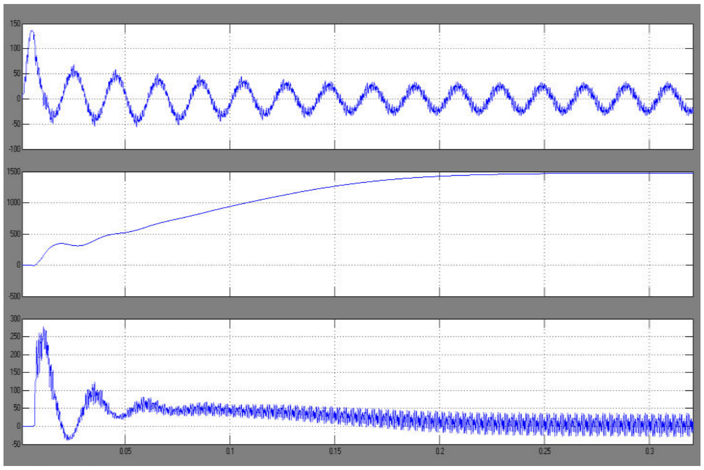

Figure 13 characteristics of stator current Stator current, speed, torque Induction motor

VI CONCLUSION

In this paper, a new proposal was put forward to develop the conventional distribution networks into hybrid AC/DC micro grids with Induction motor drive through the utilization of the capacity of the DC micro grid. The simple design of the proposed control systems helps with the fast response and ease of implementation. In the proposed plan, the possibility of simultaneous realization of the goals of power quality and reactive compensation was provided in both the grid-connected and isolated modes of the hybrid micro grid. In summary, realization of the power quality objectives includes maintaining the quality of the voltage delivered to consumers, as well as the currents drawn from the AC grid. As a new feature of the proposed to offer a solution for the near future smart home. It consists of an AC and DC network and interlinking AC/DC converter connecting them. The linking converter was controlled by an intelligent controller based on modified SRF. This control technique enables the linking converter to act as APF in order to force the AC supply current at the PCC to be a balanced three phase current regardless the loading condition and the deterioration level of the local AC load current. Moreover, the controller provides harmonic mitigation and power factor correction at the PCC.. Finally, having investigated the results of simulating several scenarios with poor power quality and the need for reactive power compensation, the efficiency of the proposed hybrid AC/DC micro grids with Induction motor drive plan was studied.

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