MATLAB/SIMULINK based Three-Phase Converter for Unbalanced AC

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ABSTRACT

The energy demand across the globe has increased in many folds due to technological advancement, rapid growth in industries and increase in household energy demand. This led the engineers and planners to think and find the means to harvest the alternative energy sources other than the fossil fuel. Microgrids are low-voltage distribution networks comprising various renewable power sources, storage units, and local loads. Microgrids can be utilized to provide different services for the main grid such as grid supporting during peak period. In microgrids single phase loads or sources can be used by the end-users and can make the grid currents unbalanced with poor power factor. The control strategy is able to mitigate negative effects of grid connected microgrid such as unbalanced operation and reactive power compensation, working under highly unbalanced conditions. Simulation results have been carried out by using MATLAB/SIMULINK to verify the effectiveness of the proposed control strategy.

Keywords: Microgrid, Unbalanced ac, three phase converter

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INTRODUCTION

Distributed generation (DG) has attracted attention in recent years, due to the progress in new generation technologies and advanced power electronics. The Micro-grid has been an example by integrating various generation sources with the existing power distribution network through power electronics converters. The Micro-grid converters are required to operate in a decentralized unit and the power-frequency droop control and reactive power-voltage droop control have been adopted for this purpose. A droop control technique for imbalance compensation within the three-phase AC distributed generation system is proposed for Micro-grid converters [1]. The DG systems based on renewable energy sources are of interest due to their low environmental impact and technical advantages such as improvements in voltage levels and reduced power losses when a distributed generation system is installed in radial lines. Two control algorithms were proposed to improve the grid connected and intentional-islanding operations methods, in which the distributed generation system must detect the situation and switch from power or current to voltage as a control variable to provide constant voltage to the local loads. The power flow between the grid and the DG is controlled by applying a power/voltage method that regulates the amplitude and the displacement of the grid voltage synthesized by the distributed generation, while a phase-locked loop algorithm is used to synchronize the grid and DG [2]. A novel control strategy for achieving the maximum results from these grid interfacing inverters when installed in 3-phase 4-wire distribution systems using MATLAB/SIMULINK simulation. The inverter is controlled to perform multi-task by incorporating shunt active power filter functionality. The grid interfacing inverter is mainly utilized to perform the functions like to inject maximum available power of renewable energy sources to the ac grid, to provide load active power, to compensate load reactive power and current harmonics, to compensate current unbalance and neutral current in case of 3-phase 4-wire system. All of these functions may be successfully performed either individually or simultaneously [3].

Microgrids can be utilized to provide different services for the main grid such as grid supporting during peak period. In microgrids single phase loads or sources can be used by the end-users and can make the grid currents unbalanced with poor power factor. This paper presents a control strategy for three-phase four-leg power converter, based on synchronous reference frame to improve the quality of power exchanged between microgrid and the main grid. The proposed control strategy is able to mitigate negative effects of grid connected microgrid such as unbalanced opera-

tion and reactive power compensation which allows the microgrid to become grid friendly, even it is working under highly unbalanced and poor power factor conditions [4]. The use of a sign-error based adaptive control for a three phase single stage grid-tied SPV (Solar Photovoltaic) system is another study. The SPV grid tied system, consists of a SPV array, a voltage source converter, a ripple filter and three phase loads connected to a 3- phase AC grid. The SPV array coupled with the voltage source converter does the tasks of providing active power to grid and acts as a distributed static compensator [5].

An improved direct power control with space vector modulation for a 3-phase 3-level neutral point clamped converter supplied by unbalanced and/or distorted grid voltage is proposed. To achieve the control objectives, compensated active and reactive powers are calculated and added to the referencing one. In order to calculate the compensated powers, the extraction of positive, negative, and harmonic sequences of voltage and current is needed and a multiple-complex coefficient filter-based method is used for rapid and accurate extraction. The proposed controller also ensures voltage balance in DC-link capacitors using redundant vectors in the space vector modulation block without the need for additional components [6]. A functional simulation model for the voltage source inverter using the switching function concept is studied and the actual implementation of the model is proposed with the help of MATLAB SIMULINK. This concept is extended to the voltage-doubler-type pulse width-modulated ac–dc rectifier and the PWM Ac–dc–ac converter. With this model, the simplification of the static power circuits can be achieved so that the convergence and long run-time problems can be solved using [7].

A single-stage, bidirectional, current-source converter topology, under a balanced grid voltage condition, the dc-link inductor current can be regulated over a wide range from zero to rated value while the ac-side current has low harmonic distortion. However, unbalanced grid voltages result in second-harmonic pulsation in the current and power on the dc side of the converter. In addition, the ac-side currents will be unbalanced due to the presence of a negative-sequence component. This would result in undesired tripping of the converter if one of the phase currents exceeded its rated value. A control scheme to inject balanced three-phase currents into the ac grid under an unbalanced grid voltage condition is proposed in [8]. A power conversion system for Universal and Flexible Power Management in Future Electricity Network is proposed in [9]. Its structure is based on a back-to-back three-phase AC-DC 7-level converter; each AC side is connected to a different PCC, representing the main grid and/or various distributed generation systems. Effective and accurate power flow control is demonstrated through simulation in MATLAB- Simulink environment on a model based on a two-port structure and using a Predictive Control technique.

A stationary-frame-based generalized control diagram for PWM AC-DC front-end converter is presented in [10]. During the unbalanced fault of grid voltage, commonly two control objectives should be fulfilled. The first one is the balanced grid-connected current, and the second one is the stable DC bus voltage. In order to reach the generalized control diagram, proportional-resonant controller is used to control the positive and negative sequence of the grid-connected current simultaneously. Meanwhile, the generation of current references for different operation modes is derived.

Unbalanced Operation

Increasing of supply is one way of meeting the gap between the demand and supply of electric power. Environment friendly resources to generate electrical power due to increasing concern over greenhouse gas emission. The integration of renewable energy based small and medium scale power generating units called DG, into the power distribution system has given a solution to this power crisis and environmental issue. DGs have gained significant importance due to reduced transmission and distribution losses, reliability due to backup generation, relief to the utility against uncertain growth of power demand and reduced cost of grid expansion.

The distributed generation covers a wide range of schemes for local power generation from solar energy, wind energy, fuel cells and micro-turbine engines. The bi-directional power flow between the grid and the distributed generation results in grid capacity enhancement, virtually uninterrupted power supply and optimum energy cost due to the possibility of use/buy/sell options. The impact of DG on the operation of distribution network depends on the grid interfacing technology.

In many important applications for power electronics such as power generation, motor drives, power quality, etc., the three-phase DC-AC converters are important part as the backbone interface between DC and AC electrical systems. The power electronics are widely used and becoming essential in the energy conversion technology, the failures or shutting down of these backbone DC-AC converters may result in serious problems and cost. It is becoming a need in many applications that the power converters should be reliable to withstand some faults or disturbances in order to ensure certain availability of the energy supply. When the voltages become distorted and unbalanced under faults or disturbances, the unbalanced AC voltages have been proven to be a great challenge for the control of DC-AC converters in order to keep them normally operating and connected to the AC sources. Many control methods which can regulate both the positive and negative sequence currents have been introduced to handle these problems.

However, the resulting performances by these control methods are not satisfactory: either distorted load currents or power oscillations will be introduced, and thereby not only the grid/generator but also the power converter will be further stressed. A three-phase power system is called balanced or symmetrical if the three-phase voltages and currents have the same amplitude and are phase shifted by 120° with respect to each other. If either or both of these conditions are not met, the system is called unbalanced or asymmetrical.

Causes of Unbalance
The system operator tries to provide a balanced system voltage at the PCC between the distribution grid and the customer's internal network. Under normal conditions, these voltages are determined by- the terminal voltages of the generators, or impedance of electricity system or currents drawn by the loads throughout the transmission and distribution grid. The system voltages at a generation site are generally symmetrical due to the construction and operation of synchronous generators used in large centralized power plants. Therefore, the central generation does not in general contribute to unbalance. Even with induction generators, as used for instance in some types of wind turbines, a balanced three-phase set of voltages is obtained.

Presently DG, installed at the customer's site, has become more popular and taken up a significant share of the electricity production. Many of these relatively small units, such as photovoltaic installations, are connected to the grid at LV by means of single-phase power electronic inverter units. The connection point has relatively high impedance, leading to a potentially larger unbalance of the voltage than is the case for connections at higher voltage level. The impedance of electricity system components is not exactly the same for each phase. The geometrical configuration of overhead lines, asymmetric with respect to the ground for instance, causes a difference in the electrical parameters of the line. Generally, these differences are very small and their effect can be neglected when sufficient precautions, such as the transposition of lines, are taken. In most practical cases, the asymmetry of the loads is the main cause of unbalance**.**

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MATLAB/SIMULINK SIMULATION

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- DC to three-phase AC converters is used uninterruptible power supplies, small power generating units in renewable energy sources. In these converters, there is often a need to generate a neutral line, on which the voltage is balanced with respect to the two terminals of the DC power source. Providing such a neutral line is called DC-link balancing. If two equal DC sources are present, connected in series, then of course this problem does not arise. However, often only one DC source is present, for example, if the DC voltage is obtained by rectifying a variable frequency AC voltage, produced by a generator. The neutral line is usually needed on the AC side of the converter to provide a current path for the zero-sequence current components, which could be large if the load is unbalanced or nonlinear.
- An L filter or LCL filter is usually placed between the inverter and the grid to attenuate the switching frequency harmonics produced by the grid-connected inverter. L filter has better attenuation capacity of high-order harmonics and better dynamic characteristic. The attenuation of the filter is designed for 60 dB/decade for frequencies above resonant frequency. It also provides better decoupling between the filter and the grid impedance and lower current ripple across the grid inductor. The L filter has good current ripple attenuation even with small inductance values. However, it can bring also resonances and unstable states into the system. Therefore, the filter must be designed precisely according to the parameters of the specific converter.
- The pulse-width modulation (PWM) technique involves generation of a digital waveform, for which the duty cycle is modulated such that the average voltage of the waveform corresponds to a pure sine wave. The simplest way of producing the PWM signal is through comparison of a low-power reference sine wave with a triangle wave. In order to create a signal which is closer to a true sine wave, a 3 level PWM signal can be generated with high, low, and zero voltage levels. For the resulting 3-level PWM signal to correspond to a sine wave, the signal comparison stage must also be 3-level. A triangle wave is used as it is in the 2-level PWM comparison, but it half the amplitude and summed with a square wave to compare one half of the sine reference signal at a time.

The block diagram of proposed system is given in Figure 1, consists of the DC supply bus, DC/AC three phase converters, LC filter circuit, three phase transformer, fault simulated, reference component (dq/abc), three PWM generator, error connection, local load and AC grid. When the distribution transformer is used by the generation system to interface to the utility network, the voltage fault occurs at grid. If a severe grid fault like one of the phase is shorted to ground, the voltage magnitude is dependent on two impedance values. It leads to the unbalanced AC source; Characteristic of the unbalanced ac source is to appearance of the negative-sequence component in the grid voltages which leads to the oscillations in the grid voltage.

DC source block is used to generate the dc supply of 600V, then the dc source is converted into ac source with the help of DC/AC converter, this converter is designed with four-wire control system. Thus the zero sequence current control strategy is implemented in converter to get the improved output. [Figure 2,3,4] Thus the pulse of output sig-

nal is send to the LC filter circuit, thus it is designed to remove the unwanted harmonic in converter output and produces continues output. The output of filter is given to the transformer and local grid. The current sequence from the grid is controlled using reference component (dq/abc), error correction blocks to reduce the errors in the feedback signal; hence pulse generator will generate the pulses to the converter control.
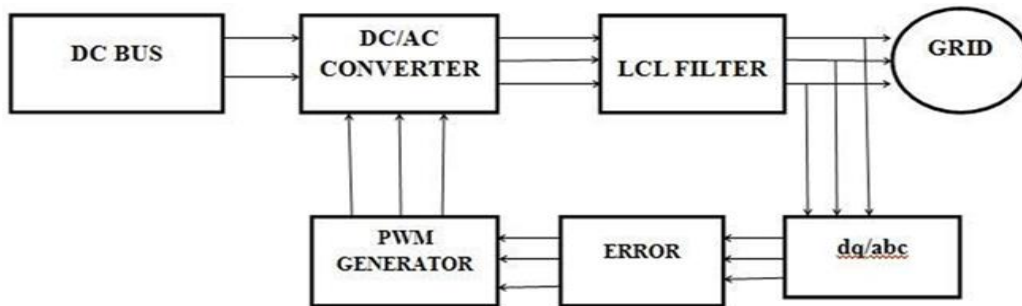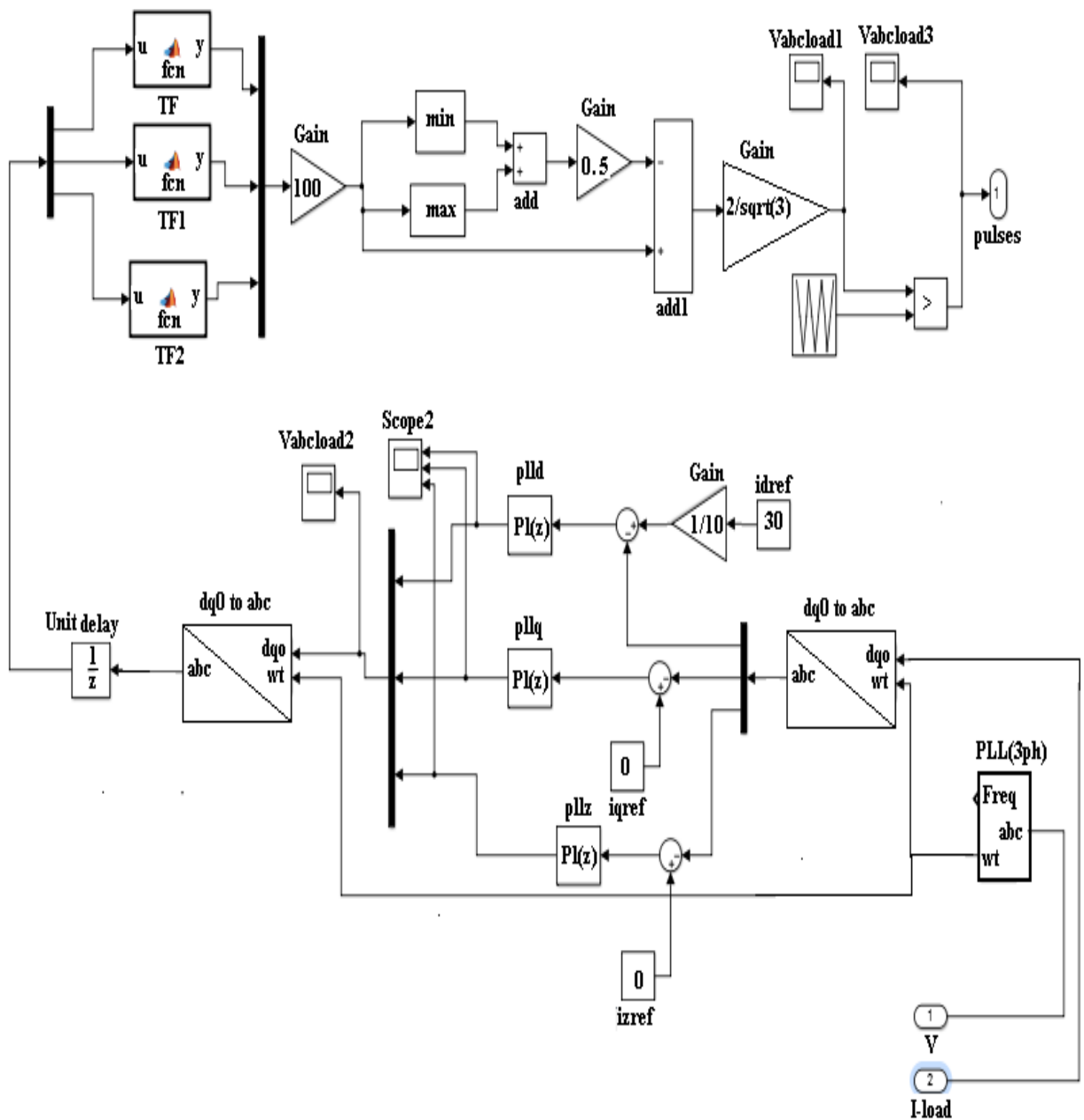

Fig. 1 Block Diagram of the proposed system

Fig. 2 Subsystem of inverter
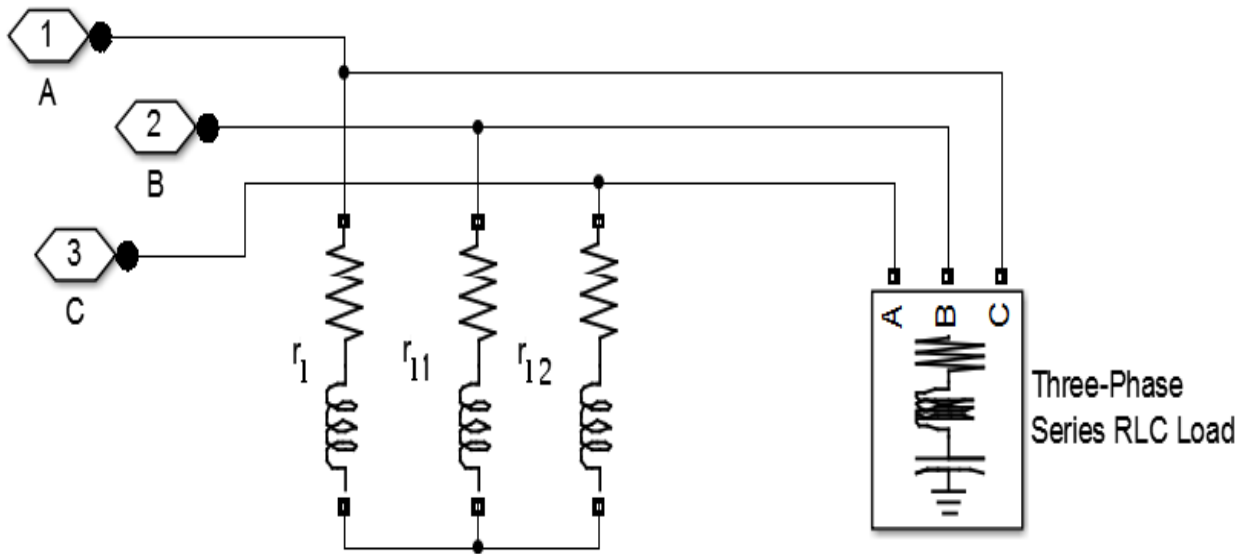
Fig. 3 Modelling of the proposed system
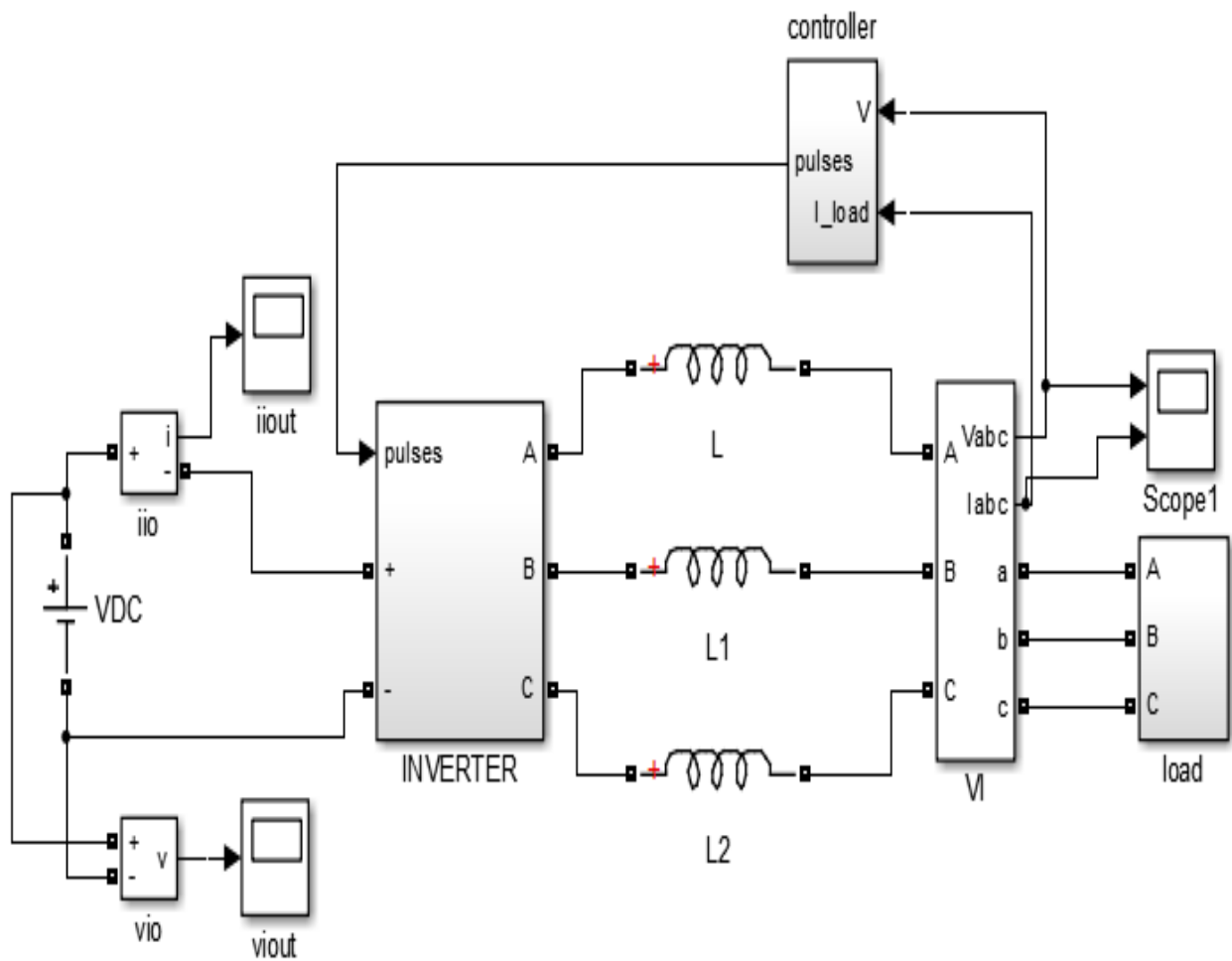
Fig. 4 Subsystem of Controller

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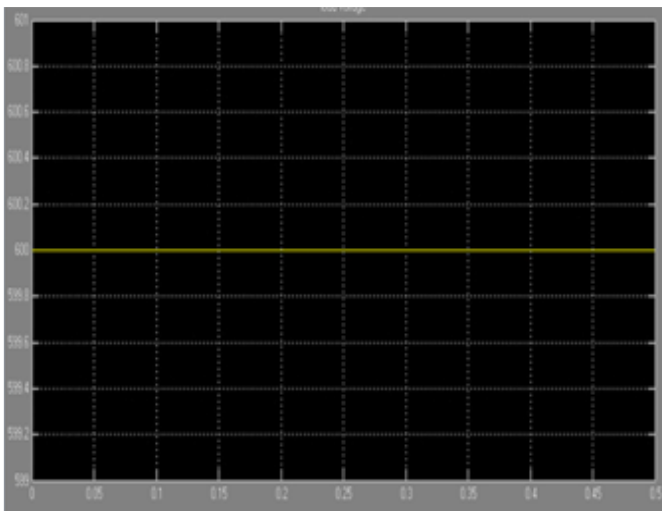
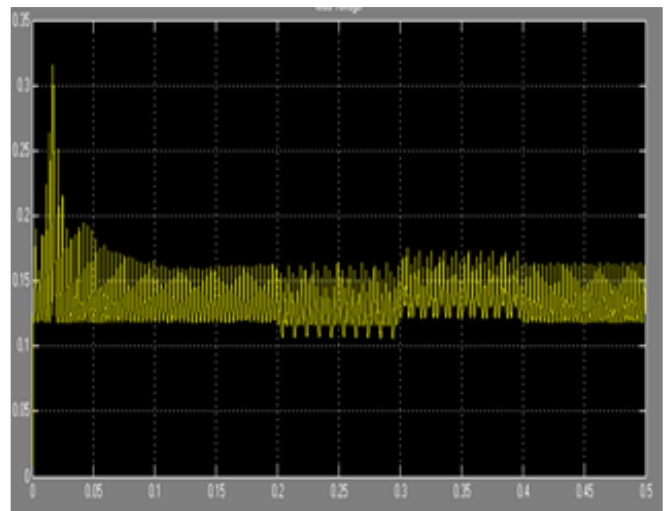**Fig. 5 Input voltage**

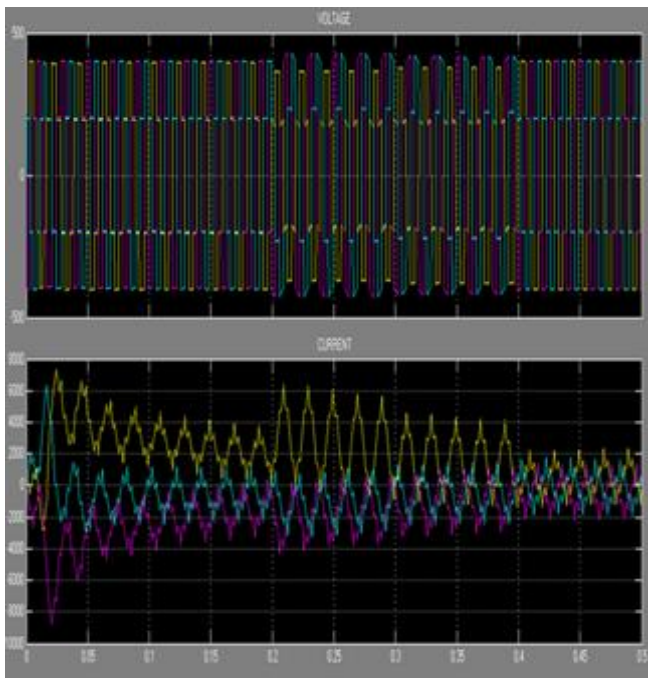**Fig. 6 Input current**

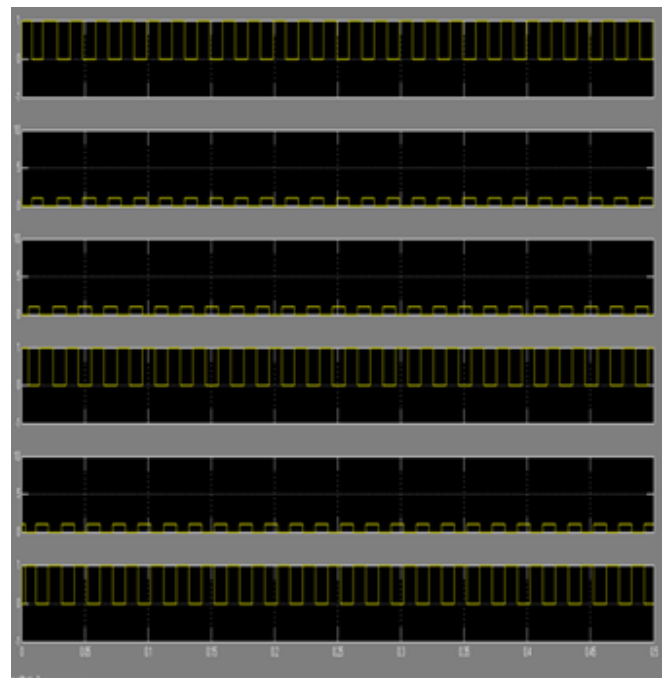**Fig. 7 Inverter output voltage and current**
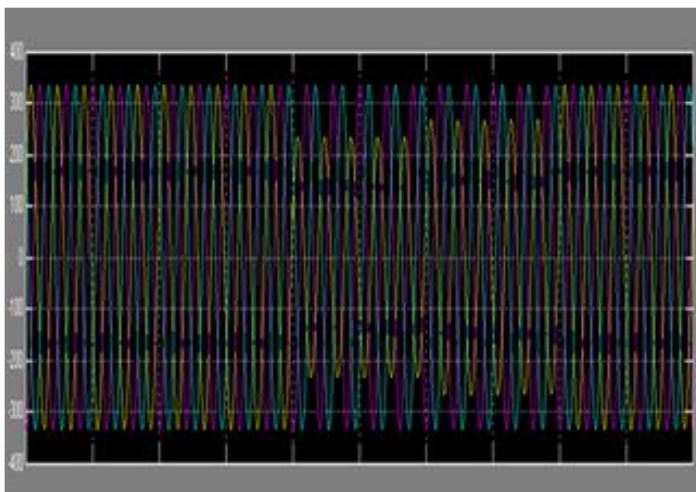

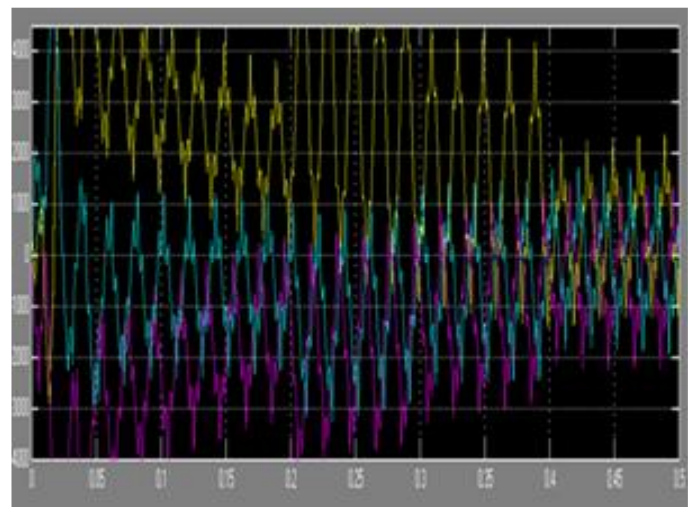**Fig. 8 Gate pulse**

Fig. 9 Load Voltage

Fig. 10 Load current

CONCLUSION

In a typical three-phase three-wire converter structure, there are four current control freedoms, and it may be not enough to achieve satisfactory performances under unbalanced AC source, because either significantly oscillated power or over-loaded current will be presented. In the three-phase converter structure with zero sequence current paths, there are six current control freedoms. The extra two control freedoms coming from the zero sequence current can be utilized to extend the controllability of the converter and improve the control performance under unbalanced AC source. By the proposed control strategies, it is possible to totally cancel the oscillation in both the active and the reactive power, or reduced the oscillation amplitude in the reactive power [Fig 5-10]. Meanwhile, the current amplitude of the faulty phase is significantly relieved without further increasing the current amplitude in the normal phases. The advantage and features of the proposed controls can be still maintained under various conditions when delivering the reactive power. The analysis and proposed control methods are well agreed by experimental validations.

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