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# Power Quality Improvement in Grid Connected DFIG using Multi-Level Inverter

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ABSTRACT

Doubly fed induction generator (DFIG) based wind turbines have arisen as the leading technologies in wind power market as they offer a variable-speed, economically viable and efficient alternative to the fossil fuel. The present paper comprises of a wind energy conversion system which is simulated using two level pulse width modulation (PWM) converter as well as three level (PWM) converter and their performance under normal and fault conditions are compared. It is observed that multi-level inverters generate purer sinusoidal voltage with reduced total harmonic distortion thus bringing an improvement in the quality of generated power.



## Introduction

In the recent years, there has been a strong penetration of renewable energy resources into the power generation system. Wind energy generation has played and will continue to play a very imperative role in this area for the coming years.

Increasing penetration of wind energy conversion system (WECS) in the conventional power system has put tremendous challenge to the power system operators as well as planners to ensure reliable and secure grid operation.

It poses a principal problem given today's system balancing practices because such generators cannot contribute to maintaining the system balance. Most of the major wind turbine manufactures are developing new larger wind turbines in the range of 3 to 5 MW range. These large wind turbines are all based on variable-speed operation with pitch control using a direct-driven synchronous generator (without gearbox) or a doubly-fed induction generator (DFIG).

The variable- speed wind energy conversion systems equipped with doubly- fed induction generators (DFIG) constitute almost 50% of the total installed wind turbines globally in on-shore applications as they have noticeable advantages such as, low cost, slip power rating of the power converters, wide speed range, decoupled power control, and low power losses [1].

Due to bi-directional power flow capability of the converters, the system can be operated in sub-synchronous or super- synchronous modes.

The stator of DFIG is directly connected to the power grid while the rotor is connected to the grid through a back-to-back converter as shown in fig.1, which only takes about 20–30% of the DFIG rated capacity for the reason that the converter only supplies the exciting current of the DFIG.

Thus as shown in fig.1, the back-to-back converter consists of three parts: rotor-side converter (RSC), grid side converter (GSC) and DC Link capacitor. [2]

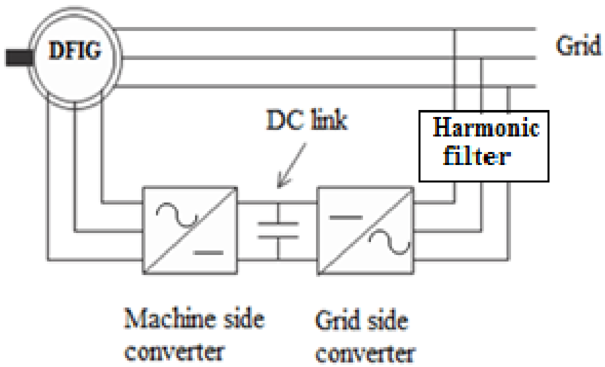


**Fig 1. Doubly Fed Induction Generator based Wind Energy Converter**

Multilevel voltage source converter topologies allow the handling of high power with standard components (semiconductors& drives) and smaller filters, enabling operation to higher voltage levels. This is achieved by arranging a higher number of switches than in the classical two level converters, configuring more complicated converter technologies. In general, the increased number of switching devices provides extra degree of freedom, which is also used to improve the performance and quality of the output power and voltage.

A multilevel inverter can eliminate the need for the step up transformer and reduce the harmonics produced by the inverter. Although the multilevel inverter structure was initially introduced as a means of reducing the output waveform harmonic content, it was found that the dc bus voltage could be increased beyond the voltage rating of an individual power device by the use of a voltage clamping network consisting of diodes. By using voltage clamping techniques, the system KV rating can be extended beyond the limits of an individual device. The intriguing feature of the multilevel inverter structures is their ability to scale up the kilovolt ampere (kVA) rating and also to improve the harmonic performance greatly without

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having to resort to PWM techniques. The key features of a multilevel structure follow:

a) The output voltage and power increase with number of levels. Adding a voltage level involves adding a main switching device to each phase.

b) The harmonic content decreases as the number of levels increases and filtering requirements are reduced.

c) With additional voltage levels, the voltage waveform has more free switching angles, which can be preselected for harmonic elimination.

d) In the absence of any PWM techniques, the switching losses can be avoided. Increasing output voltage and power does not require an increase in rating of individual device.

e) Static and dynamic voltage sharing among the switching devices is built into the structure through either clamping diodes or capacitors.

f) The switching devices do not encounter any voltage sharing problem. For this reason, multilevel inverters can easily be applied for high power applications such as large machine drives and utility supplies.

g) The fundamental output voltage of the inverter is set by the dc bus voltage Vdc, which can be controlled through a variable dc link.

h) Three-level converters have been incorporated in wind energy conversion systems as they offer the lower voltage stress on switching de- vices, lower total harmonic distortion (THD), and reduced active and reactive power variations [3]. various studies in the literature have introduced a three-level NPC converter with active clamping switches, namely, active NPC (ANPC) converter, to overcome the drawback of unbalanced loss distribution in traditional NPC converters [4–7]. When several voltage levels are used, the dv/dt of the output voltage is smaller thus the stress in cables and machine is smaller [8].

When the wind speed changes, the rotor speed will change, and hence the rotor injection frequency should also be adjusted. A key requirement of a DFIG is to have its three-phase rotor circuit injected with a voltage at a controllable frequency and controllable magnitude. This three-phase ac voltage can be synthesized using various switching techniques, including six-step switching [8], pulse width modulation (PWM) [9], and space vector PWM [10]. In the present system PWM techniques have been implemented.

**The Proposed DFIG Control Model**

A DFIG-based wind turbine of 1.5 MW is coupled to a 25 kV bus via 575V/25 kV transformer. 25 Kv bus is integrated with 120 kV grid via 5 km feeder and 25kV/120kV transformer. In the simulation model 120kV controlled voltage is considered as infinite grid as infinite grid is characterized by constant voltage and constant frequency. In the Fig. 2 the doubly-fed induction generator (DFIG) which is essentially a wound rotor induction generator is integrated with grid.

There is a direct coupling of stator with grid IGBT based PWM converters in the rotor circuit establish the connection between rotor and grid. Both the PWM converters are coupled by dc-link capacitor of 10pF as shown in fig 2. In the proposed system following two types of PWM converters are used and their performance and total harmonic distortion in output voltage have been compared"

**Using Two Level PWM Converter**

**Case I : Under Normal Condition using Two Level PWM Converters**

The system is analyzed under normal condition. The FFT analysis as shown in fig. 3 and performance curves (fig. 4) has been found by simulation.

The simulation results show that during normal operation the p.u. voltage at 25 kV grid is maintained at 1 pu. The Vdc is maintained at around 1150V. The reactive power is regulated at 0 value and DFIG supplied active power to the grid.

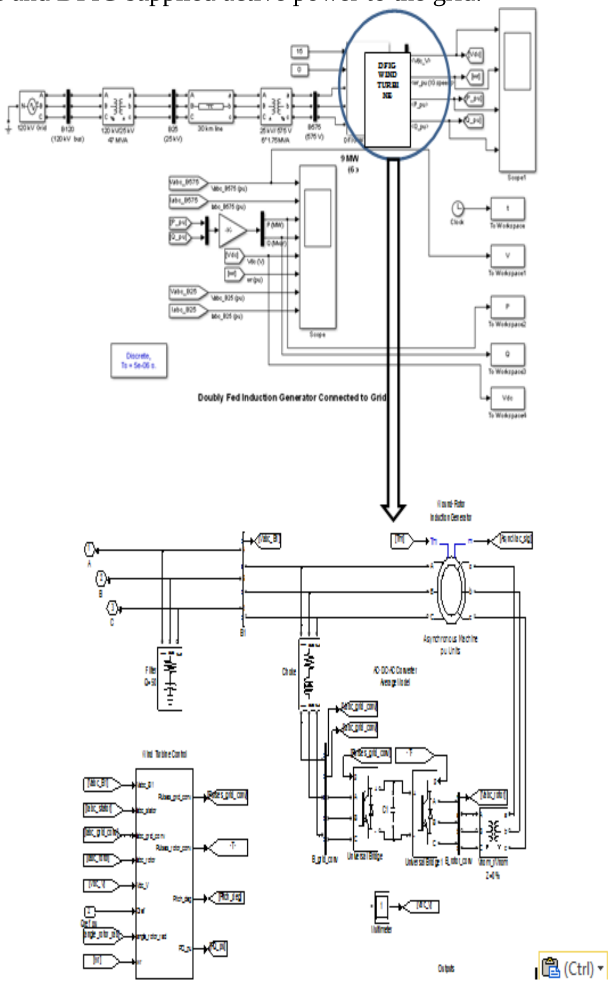


**Fig 2. Simulation Model DFIG connected to the grid**

(A) Two Level PWM converters

(B) Three Level PWM converters

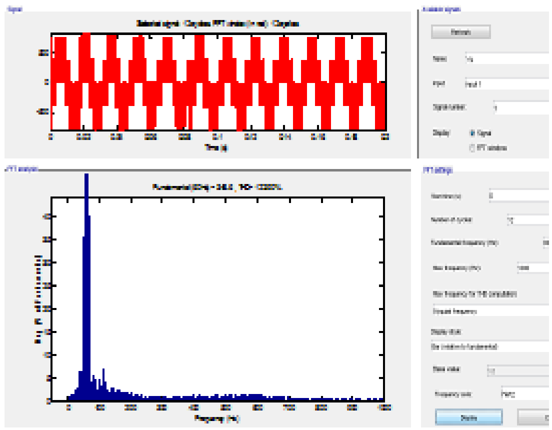

**Fig 3. FFT Analysis under normal condition using 2 level PWN inverter**

**Case II : Under three phase Line-line-line-ground(LLLG) fault using Two Level PWM Converter**

The fault is described by fault resistance Ron of 0.001 ohm, ground resistance Rg of 0.001 ohm & Snubber resistance Rp of 1M ohm. A LLLG fault at 25 kV grid occurs at 1/60 sec and are cleared at 5/60 sec The FFT analysis & performance cureves are shown in fig. 5 & fig. 6 respectively.

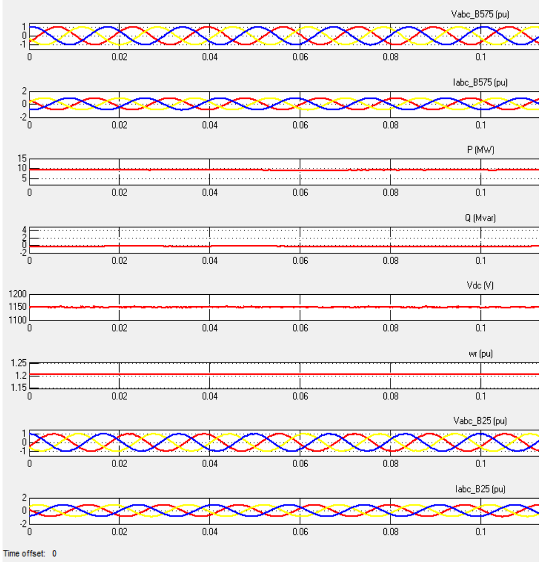


**Fig 4. Performance under normal condition using two level inverter**

The simulation results show that during LLLG fault the p.u. voltage at 25 kV grid is dropped from 1 pu. There are large fluctuations in Vdc during fault. The reactive power is varied away from zero value.

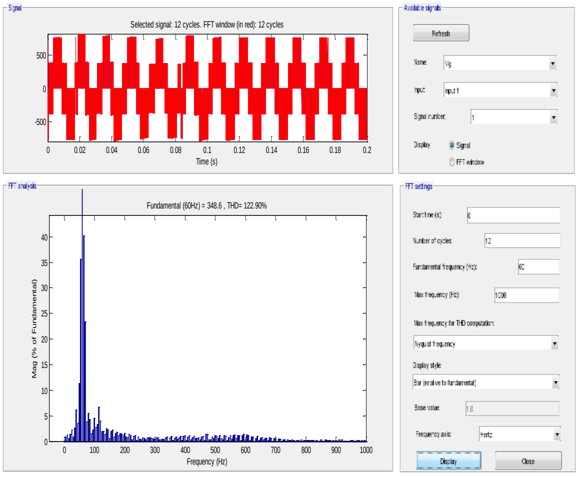


**Fig 5. FFT Analysis under LLLG fault at 25 kV bus using 2 level PWN inverter**

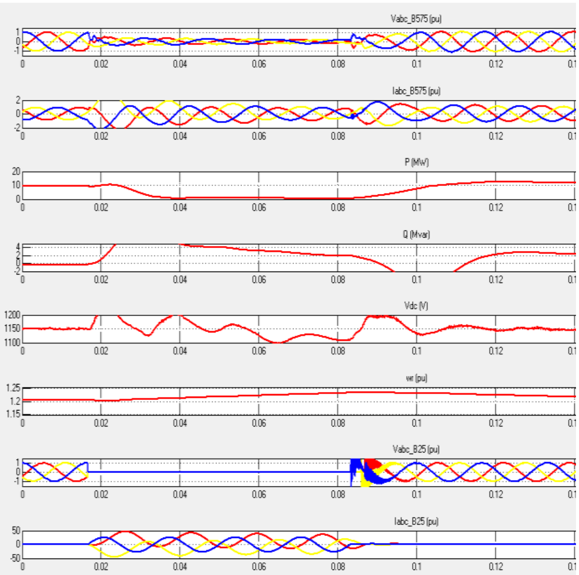


**Fig 6. Performance under LLLG fault at 25 kV bus using 2 level PWN inverter**

**Case III: Under LLG fault using Two Level PWM Converter**

The fault is described by fault resistance Ron of 0.001 ohm, ground resistance Rg of 0.001 ohm & Snubber resistance Rp of 1M ohm. A LLG fault at 25 kV grid occurs at 1/60 sec and are cleared at 5/60 sec.

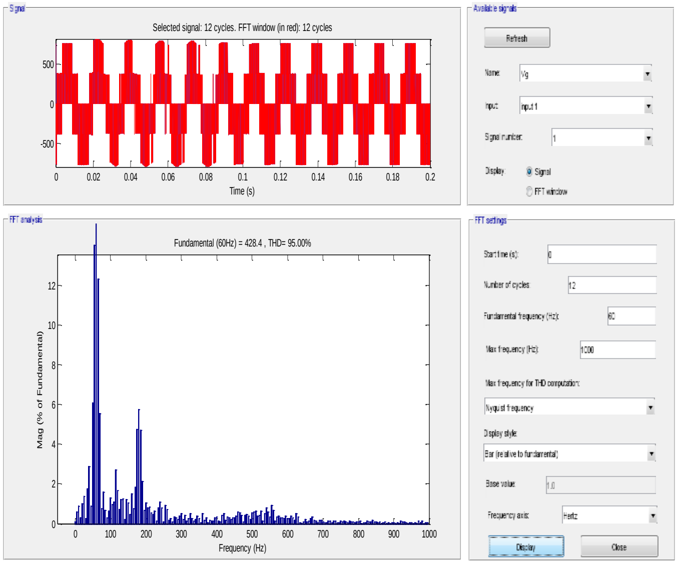


**Fig 7. FFT Analysis at LLG fault condition using 2 level PWM inverter**

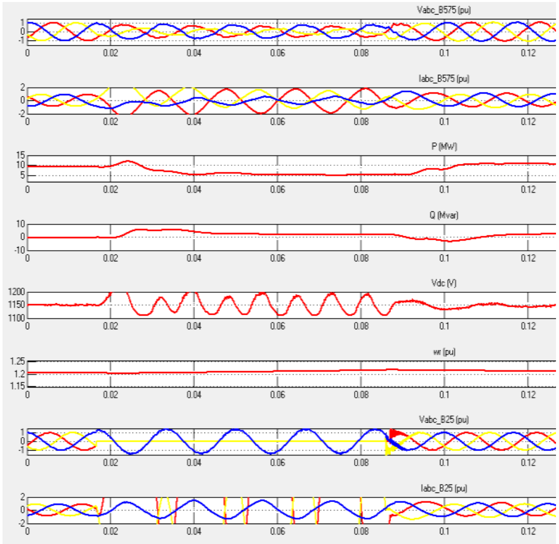


**Fig 8. Performance under LLG fault at 25 kV bus using 2 level PWN inverter**

**Case IV: Under Line-ground (LG) fault using Two Level PWM Converter**

The system is subjected to LG fault at 25 kV grid which occurs at 1/60 sec and are cleared at 5/60 sec.

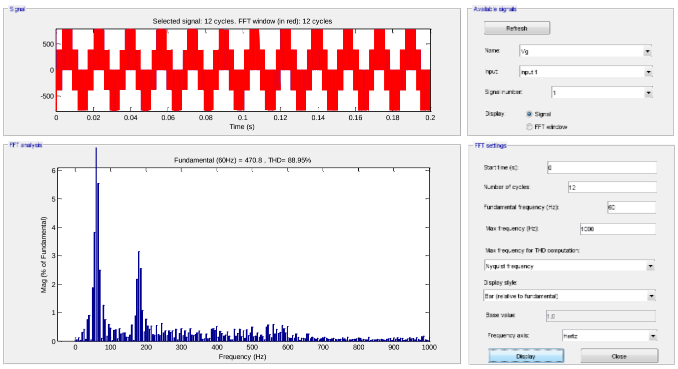


**Fig 9. FFT analysis during LG fault**

The simulation results show that during LG fault the p.u. voltage at 25 kV grid is dropped from 1 pu. There are fluctuations in Vdc during fault. The reactive power is deviates from zero value during fault.

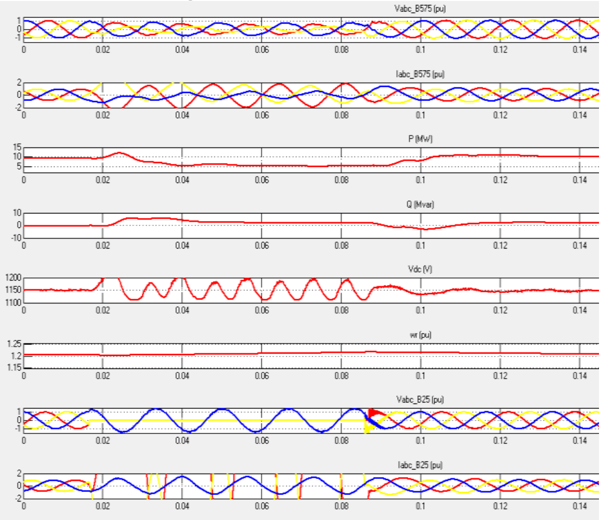


**Fig 10. Performance analysis with LG fault at 25 kV grid Using Three Level PWM Converter**

**Case I : Under Normal Condition using Three Level PWM Converter**

The system has been analyzed under normal condition. The FFT analysis and performance curves have been found by simulation. The simulation results show that during normal operation the p.u. voltage at 25 kV grid is maintained at 1 pu. The $V_{dc}$ is maintained at around 1150V. The reactive power is regulated at 0 value and DFIG supplied active power to the grid.

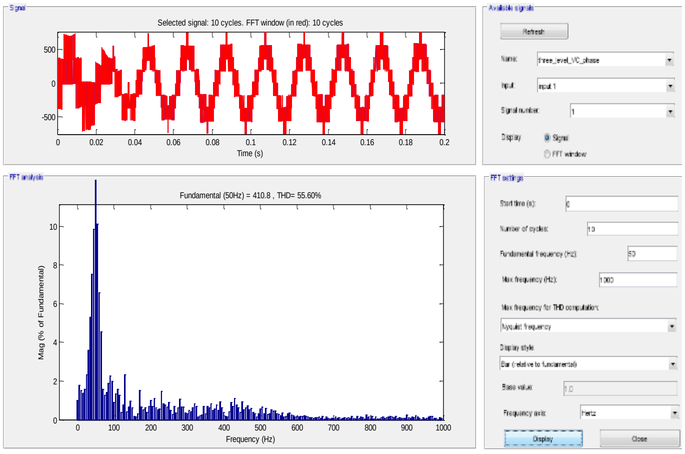


**Fig 11. FFT analysis with three Level PWM converter under normal operation**

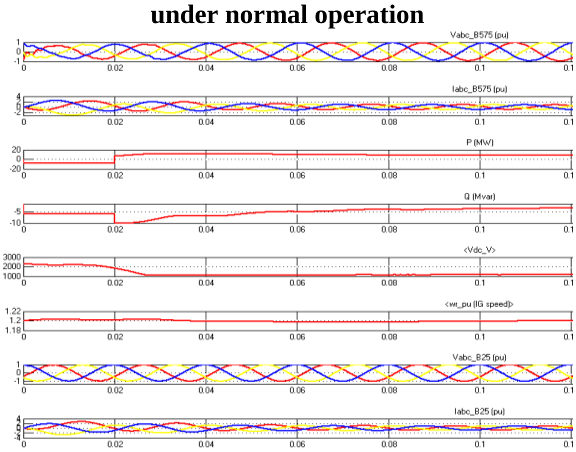


**Fig 12. Performance with three Level PWM converter under normal operation**

**Case II: Under LLLG fault using Three Level PWM Converter**

The fault is described by fault resistance Ron of 0.001 ohm, ground resistance Rg of 0.001 ohm & Snubber resistance Rp of 1M ohm. A LLLG fault at 25 kV grid occurs at 1/60 sec and are cleared at 5/60 sec

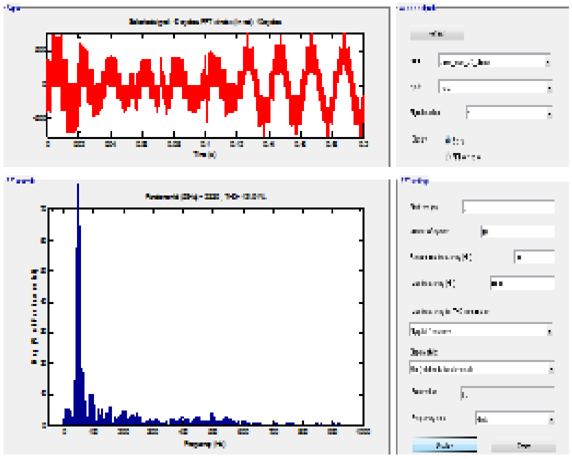

**Fig 13. FFT analysis with Three Level PWM converter under LLLG fault**

The simulation results show that during LLLG fault the p.u. voltage at 25 kV grid is dropped from 1 pu. There are large fluctuations in Vdc during fault. The reactive power is negative which means its is being drawn from the supply.

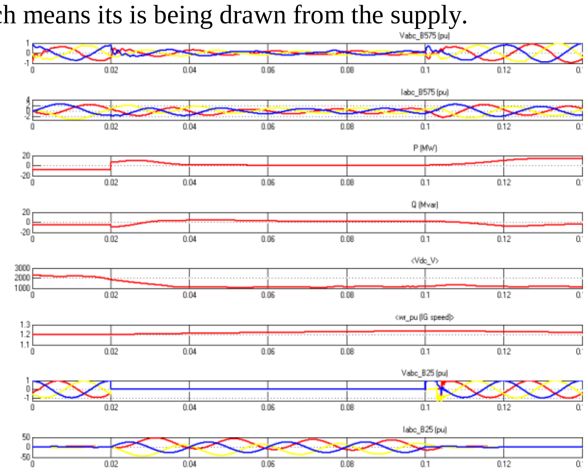


**Fig 14. Performance with Three Level PWM converter under LLLG fault**

**Case III: Under LLG fault using three Level PWM Converter**

An unsymmetrical LLG fault occurred at 25 kV grid occurs at 1/60 sec and are cleared at 5/60 sec.

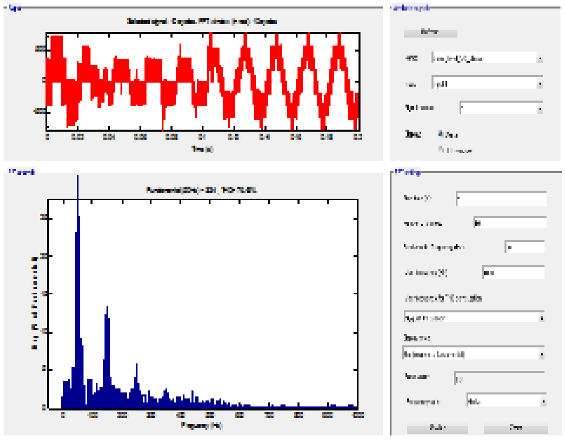

**Fig 15. FFT analysis with Three Level PWM converter under LLG fault**

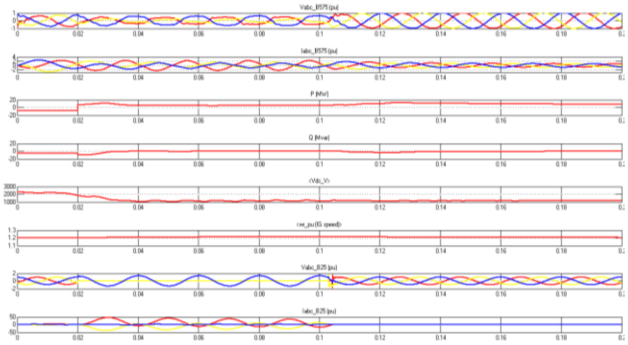

**Fig 16. Performance with Three Level PWM converter under LLG fault**

It can be inferred from the results that during LLG fault the p.u. voltage at 25 kV grid is dropped from 1 pu. There are large fluctuations in Vdc during fault. The reactive power is varied away from zero value.

**Case IV : Under LG fault using 3 Level PWM Converter**

The system is simulated under the condition of LG fault at 25 kV grid which occurs at 1/60 sec and is cleared at 5/60 sec. The simulation results show that during LG fault the p.u. voltage at 25 kV grid is dropped from 1 pu. There are significant fluctuations in Vdc during fault. The reactive power is deviates from zero value during fault.

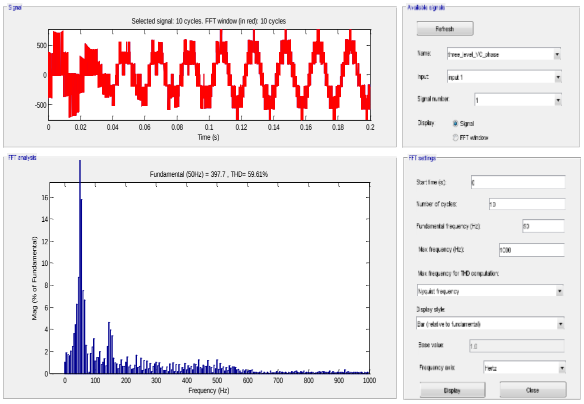


**Fig 17. FFT analysis with Three Level PWM converter under LLG fault**

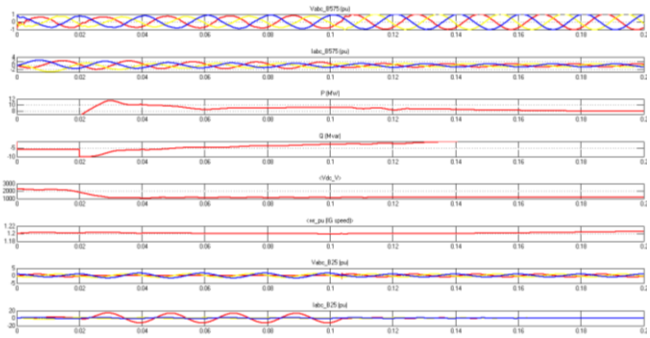

**Fig 18. Performance with Three Level PWM converter under LLG fault**

**Table I. Comparison of performance of two Level PWM Converter & Multi Level (Three Level) PWM Converter in DFIG**

| | % Total Harmonic Distortion | |
|---|---|---|
| **Condition** | **Two Level PWM** | **Three Level PWM** |
| Normal | 88.15 | 55.60 |
| LLLG fault | 122.9 | 121.74 |
| LLG fault | 95.00 | 76.42 |

**Result & Conclusions**

Grid code requires wind farms connected to grid to ride-through grid faults and provide power at improved quality. The multi-level inverter technology has numerous advantages as low voltage switches can be used . These are faster , smaller and cheaper than high voltage switches used in two level inverters. When switches are in series, they withstand higher voltages. Multi-level inverter offer better sinusoidal voltage waveform than two level inverter due to the fact that output voltage is formed by more than two voltage levels. This results in reduced total harmonic distortion and improved quality of power in compliance with the grid code. Faster switching speed, lower conduction losses, lower dv/dt of the output voltage resulting in reduced stress on cable and machine are the other advantages of the multi- level inverter technology. Proposed method of incorporating three level PWM converter in the rotor circuit shows improved performance as compared to two level PWM inverter. In table-1 the comparison of the performance of the two level PWM and three level is shown.

The results show significance reduction in total harmonic distortion by implementing multi-level inverter i.e. three level inverter in the present system as compared to two level inverter technology. Thus wth the reduction in THD using multilevel inverter the power quality is improved .

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