

Voltage Sag-Swell and Harmonics Analysis of UPQC Control Based DFIG- Wind Integration

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Abstract— The incorporation of wind farms with grid connected system in advance to Power Quality (PQ) issue such as voltage unbalance, voltage sag, swell, harmonics, etc. the mostly for commercial and industrial loads is a non-linear type which certainly the starting place of harmonics. As 75% of PQ problems are voltage sag which is one of the most specific disturbances under sensitive loads. In the middle of many tradition power devices, Unified Power Quality Conditioner (UPQC) is the only device used to lessen both voltage sag and current harmonics. This paper deal with PQ problems, voltage sag-swell and current harmonics due to the interconnection of grid connected wind turbine and also provides PQ enhancement by introducing UPQC. To Improve the PQ performance through UPQC using fixed gains in conventional PI controller. From the simulation results of DFIG based grid connected wind turbine are presented by UPQC provides useful and efficient improvement of both voltage sag and current harmonics. Therefore assembly with grid connected wind power system more dependable by provided that good quality of power.

Key Words— Doubly Fed Induction Generator (DFIG), Unified Power Quality Conditioner (UPQC), Power Quality(PQ), voltage sag, voltage swell,

1. INTRODUCTION

Now a day's power demand is increasing by faster rate than power generation. Hence the utilities are determined on power generation in order to meet up the increased demand. Out of the total energy demand, 75% load is supplied through fossil fuels. Because of this, there are so many problems related to environment such as greenhouse effect, air pollution, lessening fossil fuels. Hence it is essential to check for another alternative for power generation i.e.

Renewable energy sources. From past ten years, lots of countries have concentrated on these renewable energy sources for power generation. Presently, the government also motivating the public towards the use of renewable energy sources

accelerated the renewable energy sector growth. Injecting wind power into the power system grid effects power quality problems such as voltage regulation, reactive power compensation, harmonics produced in the grid[1].

For the mitigation of both voltage sag and current harmonics, tradition power technology comes into representation. The commonly exercised tradition power device by plentiful researchers for relieving voltage related problems is Dynamic Voltage Restorer (DVR). Due to its tremendous dynamic capability, DVR is well suited to protect sensitive loads from short duration voltage dips or swells [2]. The device STATCOM is mostly used for the restraint of load current harmonics in addition to the involvement of reactive power control [3], but it doesn't take care of voltage related problems. UPQC is the only device widely used for the mitigation of both voltage sag and load current harmonics, thus replacing the functions of two strategy DVR and STATCOM [4].

Due to the fast improvement and development in manufacture of power electronic converter technology as well as the progress of induction machines specially Double Fed Induction Generators and its advantages of small capacity of converters, high energy and flexible power control, DFIG has been widely used for large-scale wind power generation systems due to its various advantages, such as variable speed operation, controllable power factor, improved power quality and system efficiency. The amount of energy extracted from the wind depends not only on the occurrence wind speed, but also on the control system applied on the wind energy conversion system [5]

The improvement of the fault ride through capability of the WG with the facilitate of a Unified Power Quality Conditioner (UPQC). In particular, the relationship between the severity of the voltage sag and the rating requirements of the UPQC with respect to the installed wind generation is investigated. The study is initiate to be useful in retrofitting the presented installed fixed speed wind generators (FSIG), which lack the adequate system fault ride through capability on their own. The study also provides a guideline of choosing the rating of

UPQC in accord to the demanded level of fault-ride-through capability [6].

Considering the prime mover quality, the wound rotor induction machine with field-oriented control is very attractive for high performance variable speed generation application. In this electric generator group, the speed of the prime mover is permissible to be different within a certain range (subsynchronous and supersynchronous mode) and the output of electrical power is all times maintained at constant voltage and constant frequency by controlling the slip power from the rotor terminals. Another fundamental feature of this arrangement is that the power converters have to handle the slip power and thus their rating is only a fraction of the total power system. The active and reactive power control system of the wind turbine with DFIG and back-to back converter connected to the electric grid is shown in Fig. 1.

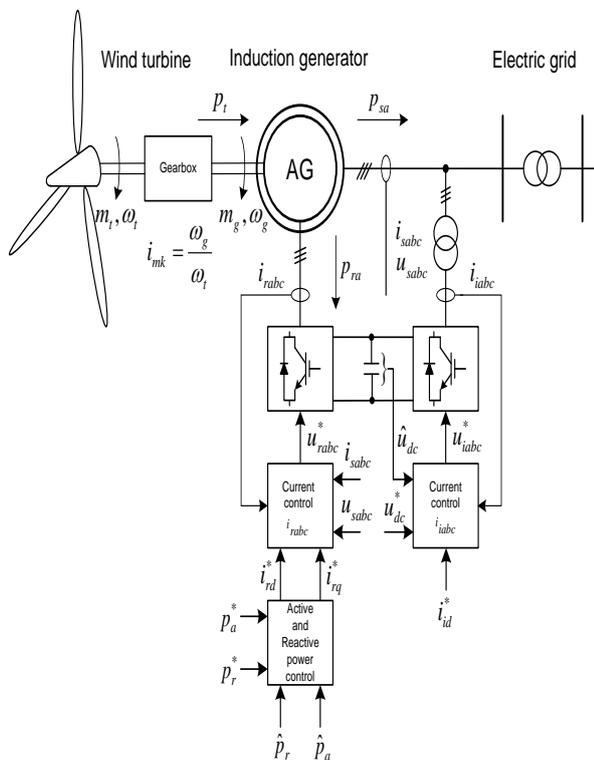


Fig.1. Wind turbine control system with DFIG

The main rule of DFIG is alteration of power given from the wind turbine p_t to the electric power p_{sr} and electric power delivery from DFIG stator to the electric grid. The wind power is particularly variable value depending about the wind speed, so DFIG from the wind turbine side has variable turbine torque m_t and turbine angular speed ω_t , i. e. generator torque m_g and generator angular speed ω_g . Simplified observed, electric grid has basically constant voltage u_{mabc} and constant angular frequency ω_s . Operational conditions of the wind turbine based on primarily equation that describes relationship of the angular frequencies of the

stator and rotor speed $\omega_s = \omega_g + \omega_r$, give control system of the generator. Thereat, there are variable stator losses p_{Cus} , rotor losses p_{Cur} . And active rotor power p_{ra} . Stator active power p_{sa} determines set value of the reference active power p_a^* . So, rotor active power p_{ra} is the significance of reference value p_a^* for defined wind turbine power. Induction generator can work in all the mode as a super-synchronous mode ($p_{ra} < 0$), sub-synchronous mode ($p_{ra} > 0$) and synchronous mode ($p_{ra} = 0$).

II. MODELING OF DFIG WIND TURBINE

A) Modeling of the wind turbine drive train

Dynamical model of the wind turbine describes the major parts of the wind turbine drive train system and induction generator that contribute in interaction of the wind turbine with electric power system. By modeling of the drive train system it is require apply two-mass model. Accordingly, low frequency torsion fluctuations that dominate in dynamic performance of the wind turbine can be accepted. Model of the drive train include inertias of the wind turbine, generator and gearbox which attach two rotating masses.

In this paper is chosen well-known by two-mass model of the wind turbine and generator drive train. The small mass of the induction generator is represented by inertia J_g and the grate mass of the wind turbine is represented by inertia J_t .

The system of equations for simulation of the wind turbine drive train described in base quantities is:

$$\left. \begin{aligned} d\vartheta_t / dt &= \omega_t \\ d\vartheta_g / dt &= \omega_g \\ d\omega_t / dt &= (D_{vt} \omega_g + K_{vt} \vartheta_g - D_{vt} \omega_t - K_{vt} \vartheta_t - m_t) / T_t \\ d\omega_g / dt &= (-D_{vt} \omega_g - K_{vt} \vartheta_g + D_{vt} \omega_t + K_{vt} \vartheta_t + m_g) / T_g \end{aligned} \right\} \quad (1)$$

Where

$$m_t = P_t / \omega_t \quad (2)$$

Time constants of the induction generator T_g and wind turbine T_t , damping coefficient D_{vt} and shaft stiffness

K_{vt} in equations system (1) are:

$$\left. \begin{aligned} T_t &= (J_t \omega_b^2) / (P_b i_{mk}^2 p^2) \\ T_g &= (J_g \omega_b^2) / (P_b p^2) \\ D_{vt} &= (D_{vt} \omega_b^2) / (P_b i_{mk}^2 p^2) \end{aligned} \right\}$$

and $K_{vt} = (K_{vt} \omega_b) / (P_b i_{mk}^2 p^2)$ [pu], where i_{mk} is gearbox ratio.

Model input values are: v_w – wind speed that defines wind turbine electric power are shown in Fig. 1., m_g – electromagnetic torque and m_t – wind turbine torque of induction generator obtained

from dynamic model of DFIG. The state variable of wind turbine dynamic model, whose by the same time output values, are: ϑ_g – angle of rotor of induction generator, ϑ_r – angle of the wind turbine axis and ω_g – angular speed of the induction generator.

B) Dynamic model of the DFIG

In the wind turbine system connected to the grid side with vector control of active and reactive power of DFIG, usually is used transformation of current, voltage and magnetic fluxes vectors of stator and rotor from original abc reference frame into two-phase rotating dq reference frame.

Dynamic functioning modes of induction generator be able to described by the differential equations system for stator and rotor windings and the equation of rotor motion. The solutions of these equations describe dynamic characteristics of the machine.

The differential equations of the induction machine stator and rotor windings defined in vector mode and dq rotating reference frame through angular speed ω_k are [4]:

$$\bar{u}_{sdq} = \bar{i}_{sdq} R_s + \frac{d\bar{\psi}_{sdq}}{dt} + j\omega_k \bar{\psi}_{sdq}, \tag{3}$$

$$\bar{u}_{rdq} = \bar{i}_{rdq} R_r + \frac{d\bar{\psi}_{rdq}}{dt} + j(\omega_k - \omega) \bar{\psi}_{rdq}, \tag{4}$$

where: ω – angular rotor speed.

Relationships between vectors of magnetic fluxes and vectors of stator and rotor currents are:

$$\bar{\psi}_{sdq} = L_s \bar{i}_{sdq} + L_m \bar{i}_{rdq}, \tag{5}$$

$$\bar{\psi}_{rdq} = L_m \bar{i}_{sdq} + L_r \bar{i}_{rdq}.$$

By substituting vector of stator current \bar{i}_{sdq} and vector of rotor current \bar{i}_{rdq} in equations (3) and (4) with vectors of magnetic fluxes of stator $\bar{\psi}_{sdq}$ and rotor $\bar{\psi}_{rdq}$ become:

$$\bar{u}_{sdq} = \frac{d\bar{\psi}_{sdq}}{dt} + \left(\frac{1}{T_s'} + j\omega_k \right) \bar{\psi}_{sdq} - \frac{k_r}{T_s'} \bar{\psi}_{rdq}$$

$$\bar{u}_{rdq} = \frac{d\bar{\psi}_{rdq}}{dt} - \frac{k_s}{T_r'} \bar{\psi}_{sdq} + \left(\frac{1}{T_r'} + j(\omega_k - \omega) \right) \bar{\psi}_{rdq} \tag{6}$$

The equivalent diagram of the three-phase induction machine for dynamic states, given from equations (3) to (6), is shown in Fig. 3.

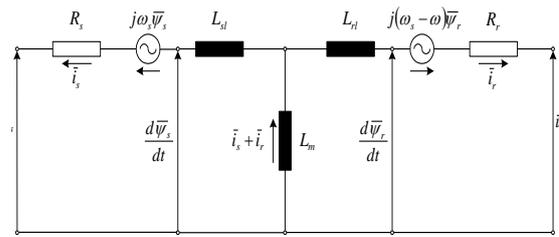


Fig.2 Equivalent diagram of the induction machine for dynamic states

The parameters presented in equations (3) to (6) are:

$$L_s' = \sigma L_s, L_r' = \sigma L_r,$$

$$\sigma = 1 - L_m^2 / L_s L_r, k_s = L_m / L_s,$$

$$k_r = L_m / L_r, T_s' = L_s' / R_s \text{ and } T_r' = L_r' / R_r.$$

Equation of electromagnetic generator expressed in base quantities is:

$$m_g = \frac{k_r}{L_s} (\psi_{sq} \psi_{rd} - \psi_{sd} \psi_{rq}). \tag{7}$$

Current active and reactive power of induction generator is specified from the product of stator voltage vector and complex conjugate vector of stator current:

$$p_a = u_{sd} i_{sd} + u_{sq} i_{sq}, \tag{8}$$

$$p_r = u_{sq} i_{sd} - u_{sd} i_{sq}. \tag{9}$$

Choice of the reference frame angular speed depends on preferred configuration of DFIG control system connected to the electric grid. Since, for control system realization of the converter connected to the rotor side and converter connected to the grid side necessary apply different reference frames it is selected $\alpha\beta$ reference frame ($\omega_k=0$) as a basic frame for mathematical model of the electric components in power circuits of the wind turbine.

The input values from vector equations (6) are vector of stator supply \bar{u}_{sdq} and vector of rotor supply \bar{u}_{rdq} . The state variables, at the similar time output values, are vectors of magnetic fluxes of stator $\bar{\psi}_{sdq}$ and rotor $\bar{\psi}_{rdq}$. Other output values are vectors of stator and rotor currents and electromagnetic torque of generator.

Dynamic model of the DFIG is expressed in $\alpha\beta$ reference frame, and all the inputs and outputs of model are expressed in that reference frame. The parameters of DFIG generator and base quantities are shown in appendix.

III. GRID INTEGRATED DFIG BASED WIND POWER SYSTEM - POWER QUALITY ISSUES AND THEIR IMPACTS

C) Proposed Methodology

The proposed work in the power grid is interconnected with Doubly Fed Induction Generator (DFIG) based wind Turbine and is coordinated in terms of voltage and frequency. The wind speed is kept as 15m/s which are

regarded as nominal value which may differ from 8 to 15 m/s due to fluctuations. The PQ problems voltage sag is simulated by creating three phase to ground fault and the load current harmonics are simulated by connecting Diode bridge rectifier load in the proposed grid connected wind power system. For PQ improvement, UPQC is designed for the above mentioned problems and the proposed control strategy using PI controller implemented for the generation of both reference voltage for series inverter and the reference current for shunt inverter which provides an efficient mitigation of both supply side and also loads side disturbances, thus keeps the PQ in a grid connected wind power system as per IEEE norms. The effectiveness of the proposed PI controller based UPQC by comparing with the simulation results.

D) Unified Power Quality Conditioner

UPQC is a tradition power device which is accountable for the alleviation PQ disturbances in both supply and load side. The schematic diagram of UPQC is shown in consists of two Voltage Source Inverters (VSI) series and shunt, tied back to back with each other sharing a common dc link. The shunt inverter is controlled in current control mode such that it delivers a current which is equal to the set value of the reference current as governed by the UPQC control algorithm and also to maintain the dc bus voltage at a set reference value

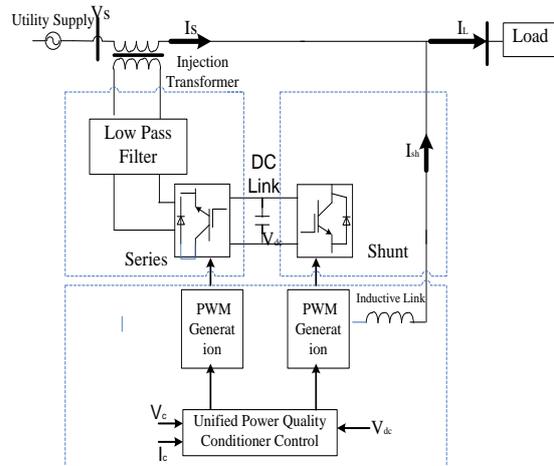


Fig.3 UPQC Controller

E) Methodology using UPFC Controller

1) Conventional PI Control Strategy

In this control strategy, both shunt and series APF in UPQC is controlled with conventional PI controller. In Series controller the gain values P and I are chosen as $K_p = 10$ and $K_i = 0.1$ using trial and error method. In Shunt It is $K_p = 18.3$ and $K_i = 4.3$. In series APF, the faulted sag voltage is compared with the reference voltage. The error voltage is processed through PI controller and its output is converted to three phase through unit vector generation, then it is fed into Pulse Width Modulation (PWM) generator to provide gate pulses to Series APF

such that this can be able to inject the required voltage for the mitigation of voltage sag.

In Shunt APF, the harmonic load current is compared with the reference current and the error is processed through PI controller. Its output is converted to three phase and it is fed into Hysteresis controller for providing gate pulses to Shunt APF which is capable of mitigating load current harmonics.

IV. SIMULATION RESULTS

The proposed system is implemented by integrating 120 kV power grid with 1.5 MW, 575 V DFIG based wind turbine and also synchronized with respect to voltage and frequency using MATLAB Simulink. The effectiveness of the proposed system is validated by three different cases. The simulation of PQ problems and the execution of UPQC along with conventional PI controller are shown by the subsequent cases.

F) Uncompensated System

In the proposed system, the voltage sag and swell is simulated by creating three phase to ground fault in the time interval of 2.5s to 5×10^{-4} sec and is shown in Fig.4 . The Total Harmonic Distortion (THD) of the source current without uncompensated system and with different types controller are obtained by the FFT analysis as shown in Fig.5.

G) Analysis of UPQC-DFIG with PI Controller

The tradition power device UPQC-DFIG is implemented with conventional PI controller to compensate both voltage sag and load current harmonics in the proposed system. The values of P and I are chosen by trial and error method appropriate for compensation. The simulation results for both load voltage and source current is shown in Fig 6. The THD spectrum for Source current is also shown in Fig 7. Fig 6 show in the Voltage and Current Waveforms of Compensated System.

H) Performance Comparison of Different Control Strategies

The implementation of UPQC controller with different control strategies for alleviating both voltage sag and load current harmonics is implemented in a DFIG based grid connected wind power system. The success of system is proven by comparing the proposed control strategy with conventional PI controller. The performance comparison results in source current THD with PI Controller and without UPQC are are shown in Table 1.

Table 1. THD of Source Current

Different System	Configuration	Source Current THD in Percent
Uncompensated System		57.55
UPQC with PI Controller		6.80

By comparing the THD of load current, UPQC with PI Controller the source current harmonics achieved is 6.80%. Thus the performance of UPQC is greatly improved by completely mitigating voltage sag and also the THD of load current is drastically diminished. Without controller sag_swell.

(i) Without UPQC Controller

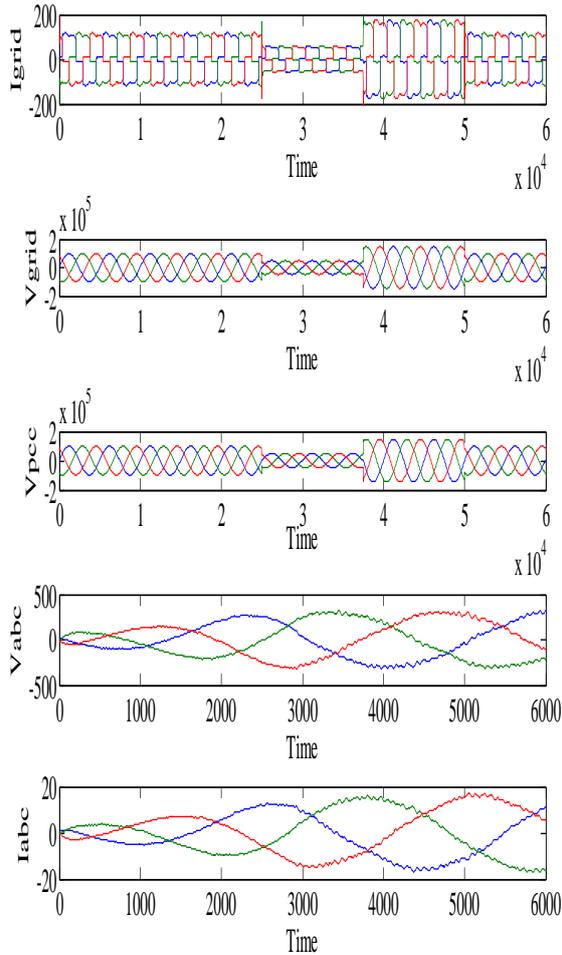


Fig.4 voltage and current waveform of load side, source side and point of common coupling without controller

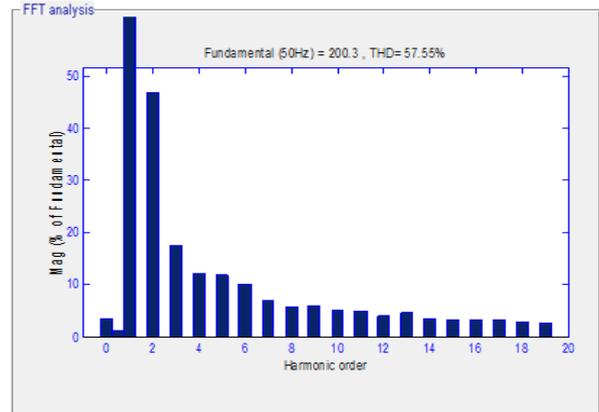


Fig.5 THD of Source Current without Controller

(ii) UPQC With PI Controller

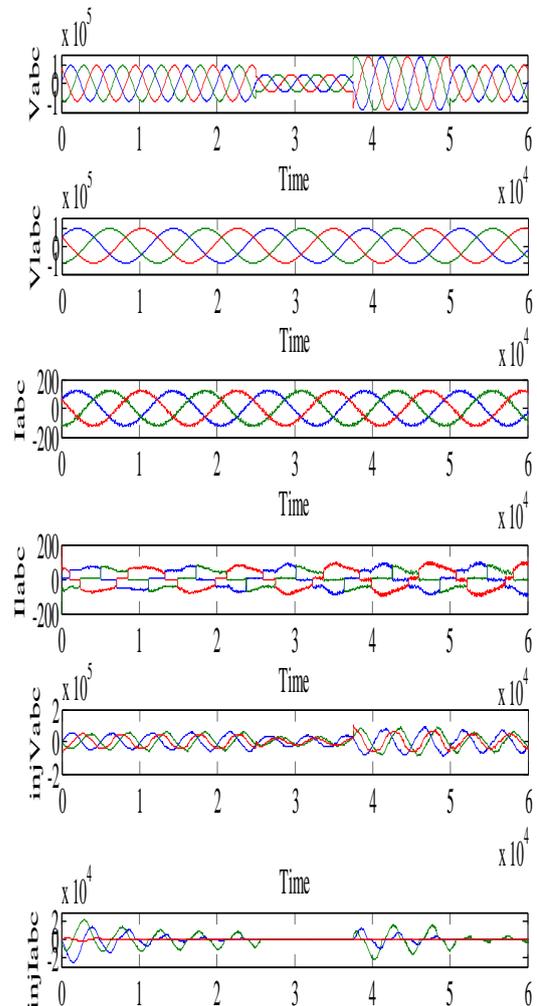


Fig.6 Voltage and Current Waveform of Load Side, Source Side and Injected Side with PI Controller

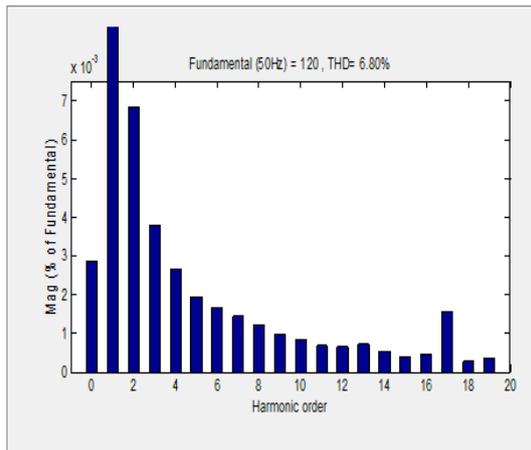


Fig.7 THD of Source Current with PI Controller

V. CONCLUSION

This paper improved that both Voltage and Current quality in a Grid connected DFIG based wind power system. The PQ problems -voltage sag and current harmonics are simulated using MATLAB in a grid connected wind power system. The UPQC is implemented for PQ enhancement to diminish both voltage sag and current harmonics and the simulation results are compared with conventional PI controller. From the simulation results, the PI controlled UPQC completely mitigates voltage sag but the load current harmonics obtained is not within the acceptable limits. In addition, the source current harmonics are mitigated in a better-quality way by keeping THD level of source current within

acceptable limits as per IEEE norms. Thus the PI controlled UPQC is successfully proven as an efficient device through its excellent Performance for improving PQ in a grid connected power system.

Parameters used in Simulation Model

DFIG, 1.5 MW, 575V, 50Hz

Injection Transformer Turns Ratio=1:1

Shunt APF Filter Inductance L = 3mH

Filter Capacitance C = 10 F

DC Link Capacitor = 3000 F

Inverter

IGBT based, 6 Pulse, Carrier Frequency = 10000 Hz

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