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Power quality improvement of self- excited induction generator using Multipulse AC-DC converters - A comparison

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ABSTRACT

This paper presents the comparison between multi pulse AC-DC converters for improving the power quality in wind driven self-excited induction generator. This paper applicable for improving power quality by regulation of voltage and frequency of an isolated wind power generation based on a capacitor excited asynchronous generator and feeding to a grid. The 12/18/24 pulse AC-DC converter is designed and developed for harmonic current reduction to meet the power quality requirements. For an effective harmonic mitigation DC ripple reinjection is used. The proposed AC-DC converter is able to eliminate up to 21st harmonics in the supply current. A set of power quality indices on input AC mains and on the DC bus for a SEIG fed from different AC-DC converters .The complete electromechanical system is modeled and simulated in MATLAB using Simulink. The simulated results are presented and compared with each other and also compared with the conventional six pulse converter regulating voltage and frequency of SEIG driven by wind turbine.

Key Words:

Autotransformer, Multipulse AC—DC converter, DC ripple reinjection, Pulse doubling, VCSEIG

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INTRODUCTION

Researches now day are concentrating more on conservative use of conventional energy sources and are exploring renewable energy resources to meet the ever growing power demand, to decrease environmental hazards and to provide an alternate solution to usage of fossil fuels. Till now energy sources like hydro, solar, wind, geo-thermal and bio-mass were explored. Due to availability in abundance the hydro, solar and wind energy sources are considered suitable renewable sources to fulfill the gap between power demand and generation.A thorough research on the induction generator operation in steady state and various transient conditions has to be conducted for its maximum utilization. For ensuring good quality power and assessing the suitability of the configuration for a particular application the steady state analysis is conducted, while for estimating the insulation strength, suitability of winding, shaft strength, value of capacitor, and to determine the protection strategy the transient analysis is performed.

An induction generator is a kind of electrical generator which is similar to an induction motor in its construction, generates the electrical energy when rotor the speed is greater than the synchronous speed. As they can generate power at variable speeds, these are frequently used in wind turbines. Due to its simple construction and low cost they found to be useful in the wind power generation.

Initially the induction generator is excited by the external capacitor bank or by the external grid. And once it starts generating the electrical power there is no need of any external capacitor bank. Magnetic field in the rotor is induced by the rotating magnetic field in stator.

For standalone induction generators, the external capacitor bank supplies the reactive power needed and generates the magnetic flux and when the capacitor bank fails to supply the reactive power needed, then the generator draws the magnetizing current from the grid. The selection of generator depends on a various factors such as the resource, linear/non linear load, and the turbine speed et. The advantages of this machine are Uncomplicated and strong construction, Self operating, Economical and Low maintenance with the disadvantages as Substantial reactive power requirement and Meager power factor.

Extensive usage of Self Excited Induction Generator relies on the techniques used to minimize its inadequacies such as impoverished voltage and frequency regulation, its ability to cope with the dynamic loading, and its ability to work under balanced/unbalanced conditions [5].

In multipulse converters, the autotransformer-based configurations provide the reduction in magnetic rating as the transformer magnetic coupling transfers only a small portion of the total kVA of the induction motor drive. Various 6-pulse-based rectification schemes have been reported and used in practice for the purpose of line current harmonic reduction [7]. With the use of a higher number of multiple converters, the power quality indices show an improvement, but at the cost of large magnetics resulting in a higher cost of the drive. To achieve similar performance in terms of harmonic current reduction, DC ripple reinjection has been used.

This paper investigates a control system for an induction generator that uses the stator flux orientation. Systematic analysis of this control system is carried out for wide ranges of both load and speed. The induction generator supplies a variable dc load. This paper presents an autotransformer-based 12/18/24-pulse AC-DC converter with reduced rating magnetics. A pulse multiplication technique is used to improve various power quality indices to comply with the IEEE standard 519 [8]. This arrangement results in elimination up to the 21^{st} harmonic in the input line current.Moreover, the effect of load variation on the vector-controlled induction motor drive (VCIMD) is also studied. The proposed AC—DC converter is able to achieve near unity PF in a wide operating range of the drive.

This paper mainly concentrated on improving the power quality using the power electronic oriented devices. The improvement is based on the vector control which uses the stator flux orientation technique. To validate this method the effect of load variation on Vector Controlled Self Excited Induction Generator (VCSEIG) is also presented. Here, along with the conventional six pulse converter, the performance of twelve, eighteen and twenty four pulse AC-DC converters are also tested and are compared with the conventional six pulse converter as well as with each other.

1. **System Configuration**

The proposed system is as shown in Fig.1

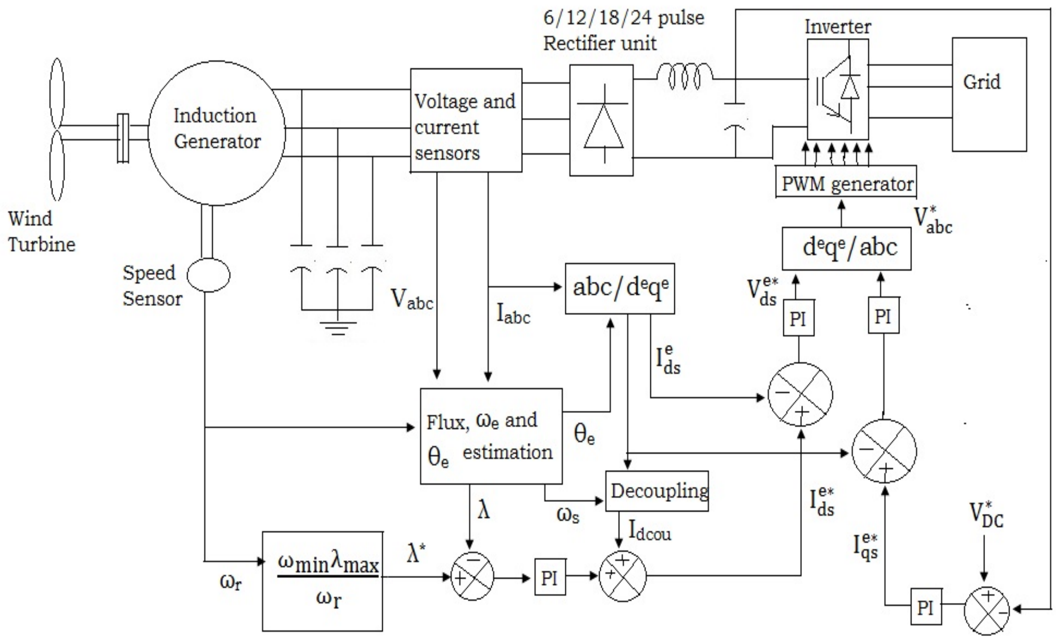

Fig.1.Overall system description

1.1. System Description

Fig. 1 shows the wind driven self excited induction generator with excitation capacitor, consumer loads, and conventional six-pulse diode rectifier. The diode bridge is used to convert ac terminal voltage of SEIG to dc voltage. The output dc voltage has the ripples, which should be filtered, and therefore, a filtering capacitor is used to smoothen the dc voltage. An inverter is used to provide AC voltage across the grid which is the load for SEIG. The sensed terminal voltage is compared with reference voltage and error signal is processed through PI controller. According to the principle of operation of the system, the suitable value of capacitors is connected to generate rated voltage at desired power. The input power of the SEIG is held constant at varying consumer loads.

2. **Control scheme**

In this paper Stator flux oriented control is used. Its accuracy is dependent only on the stator resistance variation. In addition, it is insensitive to the variation in the leakage inductance of the machine. In induction motor the application of stator flux oriented control the parameter variation of resistance R_s tends to reduce the accuracy of the estimated signal at low voltage [1]. However, at higher voltage the effect of parameter variation in R_s can be neglected. Flux estimation accuracy in rotor flux oriented control is affected by rotor parameters. The rotor resistance variation becomes dominant by temperature and skin effect in squirrel cage induction machines [3].Compensation of this parameter is difficult because of inaccessibility, but it easier to compensate R_s [4].

The reference flux linkage required at any speed is calculated based on this maximum flux linkage, λ_{max} which corresponds to the minimum rotor speed, ω_{rmin}. Hence at any rotor speed, ω_r, the reference stator flux linkage is given by,

$$\lambda = \frac{\omega_{rmin}}{\omega_r}\lambda_{max} \quad (1)$$

2.1. Design of the Proposed 12-Pulse AC–DC Converter

Twelve-pulse converter is a series connection of two fully controlled six pulse converter bridges and requires two 3-phase systems which are spaced apart from each other by 30 electrical degrees. The phase difference effected to cancel out the 6-pulse harmonics on the AC and DC side. The 12-pulse rectifier solution consists of two 6-pulse diode bridges combined with a multi-phase transformer. The output of two diode bridge rectifiers can be connected in parallel through a DC link choke as shown in figure 2 or separately connected to two isolated drives. The multi-phase transformer can be an autotransformer or an isolated transformer with 30° displacement to provide two three-phase voltage sources that cancel the 5th and 7^{th} harmonics. A 12-pulse rectifier with a delta-delta-wye isolation transformer and the resulting input current waveform where 11th and 13th harmonics are the dominant harmonic components. However, the values can vary depending on the source voltage distortion and imbalance. Two 30° displaced three-phase voltage sources can be achieved by several different approaches that include:

- a phase-shifting isolation transformer such as a delta-delta-wye or a Zig-Zag transformer
- a phase-shifting autotransformer
- a combination of a half-power transformer and a series reactor directly fed from power source (hybrid 12-pulse). Each approach has different features and performances.

2.2. Design of the Proposed 18-Pulse AC–DC Converter

The 18-pulse rectifier topology consists of a multi-phase transformer and three 6-pulse diode bridges, the output of which are connected in parallel through a DC link choke as shown in figure 3 or separately connected to three isolated drives. In the theoretical 18-pulse system, the three phase-shifted voltage sources connected to the three 6-diode bridges will cancel the 5th , 7th ,11th ,and 13th harmonics and the remaining dominant harmonic components are the 17th and 19th. The multi-phase transformer can be an autotransformer or a phase-shifting isolation transformer with 20° displacement used to provide three three-phase voltage sources that cancel the 5^{th},7th ,11th ,and 13th harmonics. In many cases, a phase-shifting autotransformer is a practical approach when considering the size and cost. If additional input AC reactors are combined with the 18-pulse rectifier, the input current THD is about 5%; however, this can vary based on voltage source distortion and imbalance. This 18 pulse rectifier solution complies with IEEE-519-1992 standard at the equipment level. In this 18-pulse topology, the magnetic circuit involved is same as that of a 6-pulse converter. Therefore this topology is comparatively a preferred one. The simulated results are in close agreement with any result obtained from an 18 pulse converters.

2.3. Design of the proposed 24-pulse AC-DC converter

This section presents the design technique for achieving 24-pulse rectification in the proposed AC-DC converter. To achieve the 24 pulse rectification, the necessary requirement is the generation of two sets of line voltages of equal magnitude that are 30^0 out of phase with respect to each other.The number of turns required for the 0^0 and 30^0phase shift is calculated as follows:

Consider phase A:

$$V_a' = V_a + K_1V_{ca} - K_2V_{bc} \qquad V_b' = V_b + K_1V_{ab} - K_2V_{ca} \qquad (2)$$

Assume the following set of voltages:

$$V_a = V\angle 0^0 \qquad V_b = V\angle -120^0 \qquad V_c = V\angle 120^0 \qquad (3)$$

$$V_{ab} = 1.732V\angle 30^0 \qquad V_b = 1.732V\angle 90^0 \qquad V_c = 1.732V\angle -30^0 \quad (4)$$

Similarly,

$$V_a' = V\angle 30^0 \qquad V_b' = V\angle -90^0 \qquad V_c' = V\angle 150^0 \qquad (5)$$

Where V is the RMS value of the phase voltage.Using the above equations, K_1, K_2 can be calculated.These equations result in $K_1 = 0.0843, K_2 = 0.229$ for the desired phase shift in the auto transformer.The phase-shifted voltages for phase A are:

$$V_a^{'} = V_a + 0.0843V_{bc} + 0.229V_{ca} \quad (6)$$

The kVA rating of the interphase transformer and the Zero Sequence Blocking Transformer(ZSBT) is also calculated.

The AC-DC converter output voltage V_{dc} and the voltage across the interphase reactor is given by:

$$V_{dc} = \frac{V_{d1}+V_{d2}}{2} \qquad V_m = V_{d1} - V_{d2} \quad (7)$$

V_m is an Ac voltage ripple of six times the source frequency.

3. MATLAB based Simulation and Results

The simulation stator oriented vector control is implemented using MATLAB/SIMULINK. The features in the Power Systems Blockset are used to model an inverter, rectifier and all circuit components. The induction machine model in the Power Systems Blockset is modified to include speed as an input and to update the variation of magnetizing inductance as the voltage builds up during self-excitation. To get the right control parameters and performance it is simply a matter of tuning the PI controllers in the DC voltage controller and flux linkage controller given in Fig. 1.

The dynamics of the DC voltage at the start of the voltage build up process, for a rotor speed of 1.48p.u with capacitance value of 3200µF is as shown in Fig.10(a). When the capacitance is large it takes longer to reach its steady state value. If the capacitance is too small there will not be enough exciting current and as a result there will not be voltage build up. Fig.10(b) shows the no load build up of generated line to line voltage at the terminals of the induction generator during the start of self excitation. The voltage build up process is under the no load condition. If there is load, with magnitude above a given minimum value, the voltage build up process will fail.

The frequency of the generated voltage is estimated as :

$$\omega_e = \frac{(V_{qs}-i_{qs}R_s)\lambda_{ds}-(V_{ds}-i_{ds}R_s)\lambda_{qs}}{\lambda_{qs}^2+\lambda_{ds}^2} \quad (8)$$

Here, transient waveforms of the generator voltage (Vabc), generator current (Igabc), Speed of the generator ,Electromagnetic torque, rectifier current , voltage at capacitor,inverter voltage, grid voltage, grid current are given under the sudden application and short circuit at grid for conventional 6/12/18/24 pulse rectifier are as shown in Fig.5,6,7,8 respectively. The Simulink model for the 6/12/18/24 pulse diode rectifier is as shown in Fig.4.

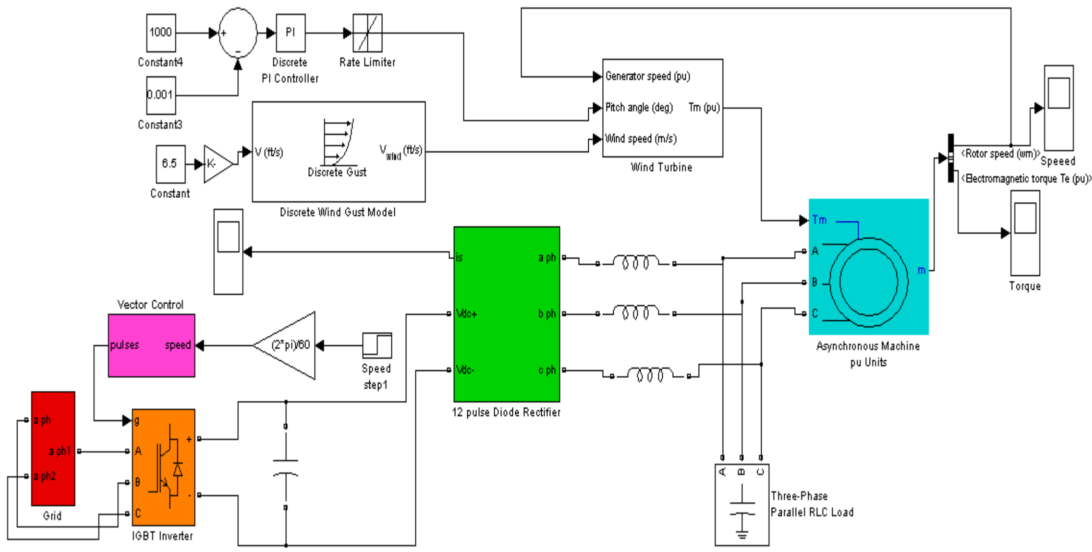

Fig. 4. Simulink/MATLAB model for 6/12/18/24pulse controller

3.1. Results of six pulse rectifier

3.2.

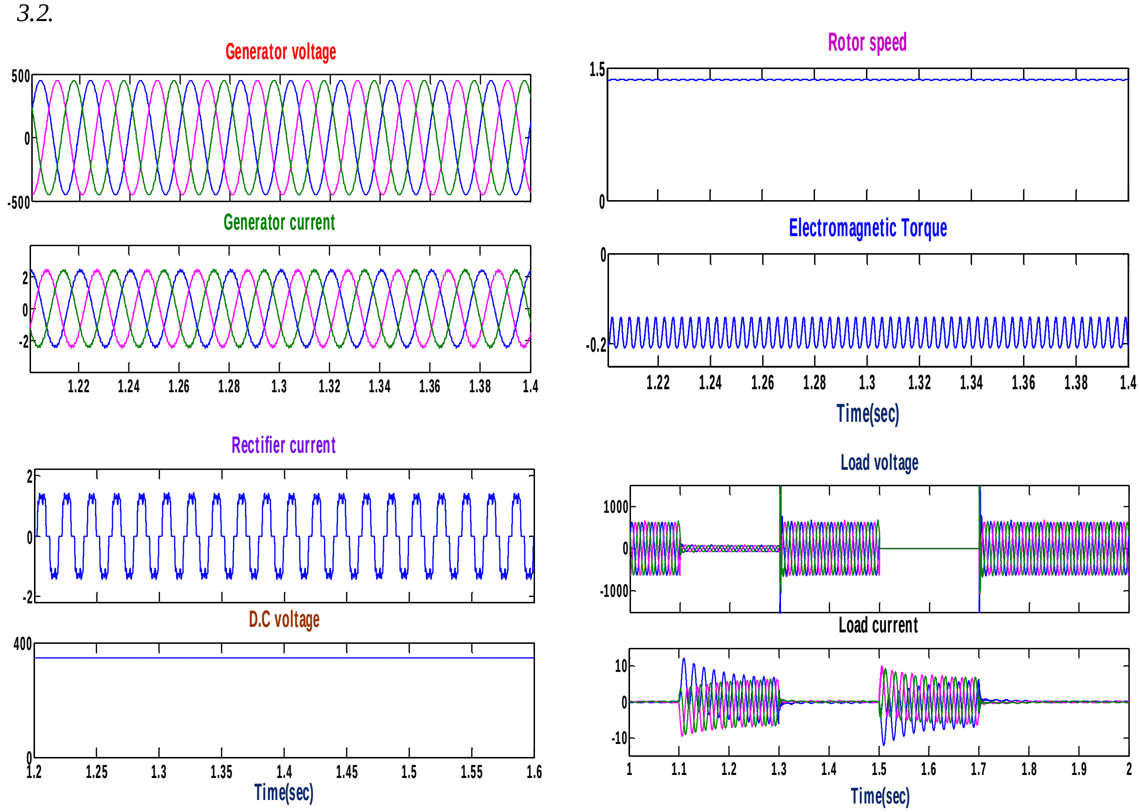

Fig.5. The transient waveforms for 6 pulse vector control of SEIG

The load is applied at grid suddenly at t=1.1 seconds. And short circuit fault is applied at load t=1.5 seconds. And the transient waveforms are observed as shown above.

3.3. *Results of twelve pulse rectifier*

3.4.

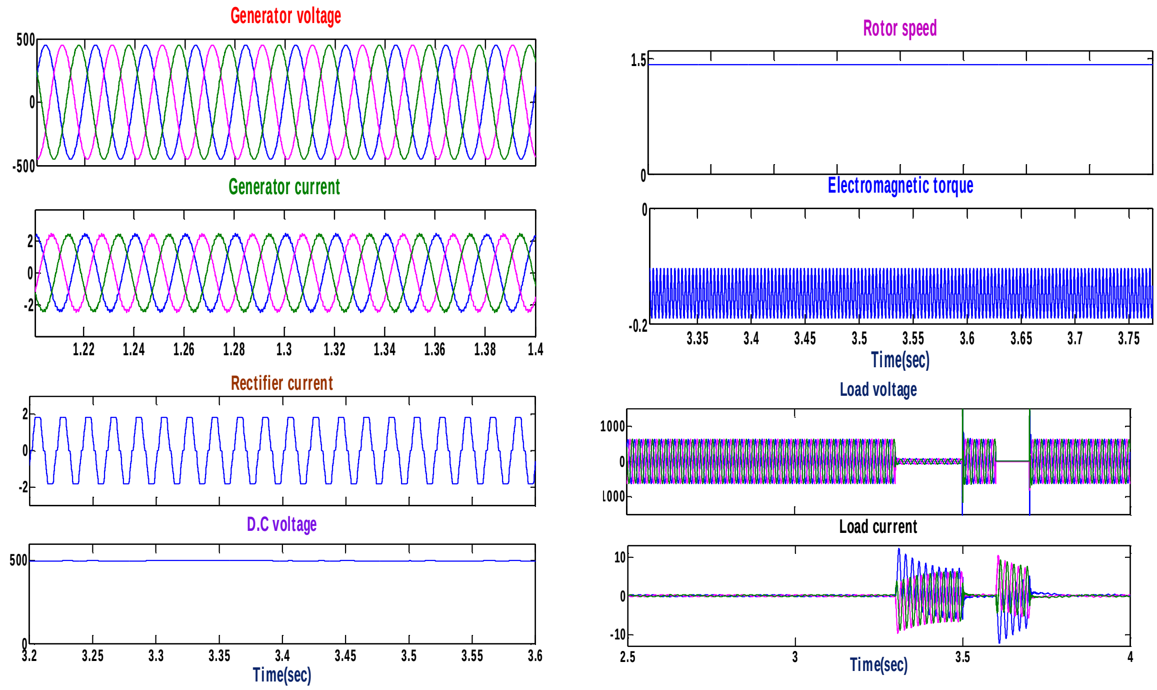

Fig.6. The transient waveforms for 12 pulse vector control of SEIG

The load is applied at grid suddenly at t=1.1 seconds. And short circuit is applied at load t=1.5 seconds. And the transient waveforms are observed as follows.

3.5. *Results of eighteen pulse rectifier*

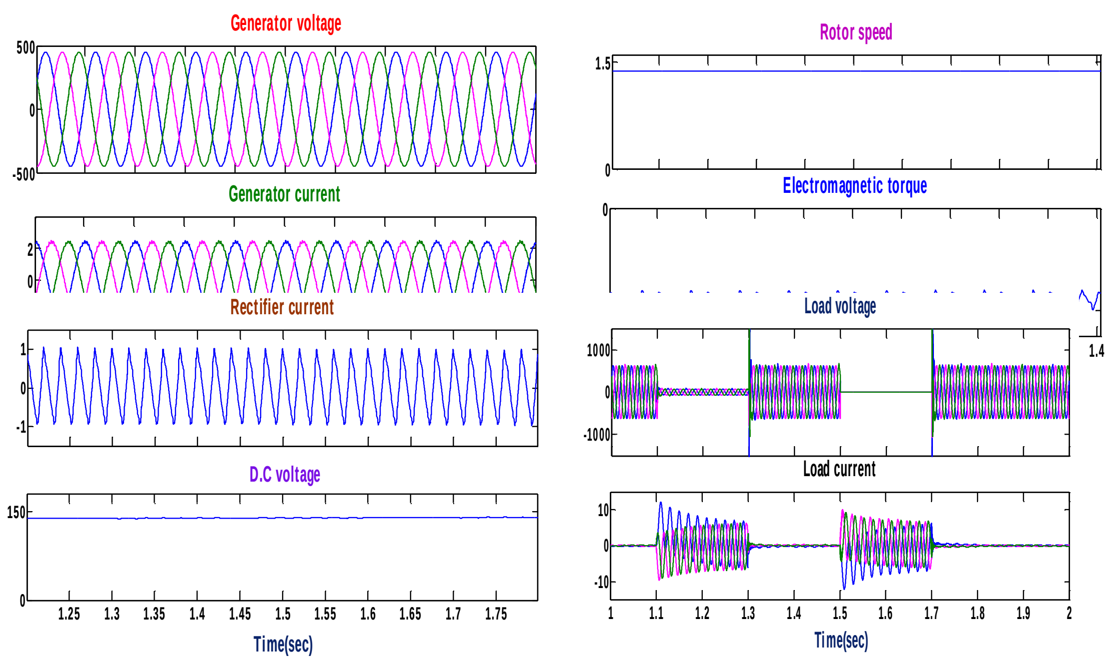

Fig.7.The transient waveforms for 18 pulse vector control of SEIG

The load is applied at grid suddenly at t=1.1 seconds. And short circuit fault is applied at load t=1.5 seconds.

4.4 Results of twenty four pulse rectifier

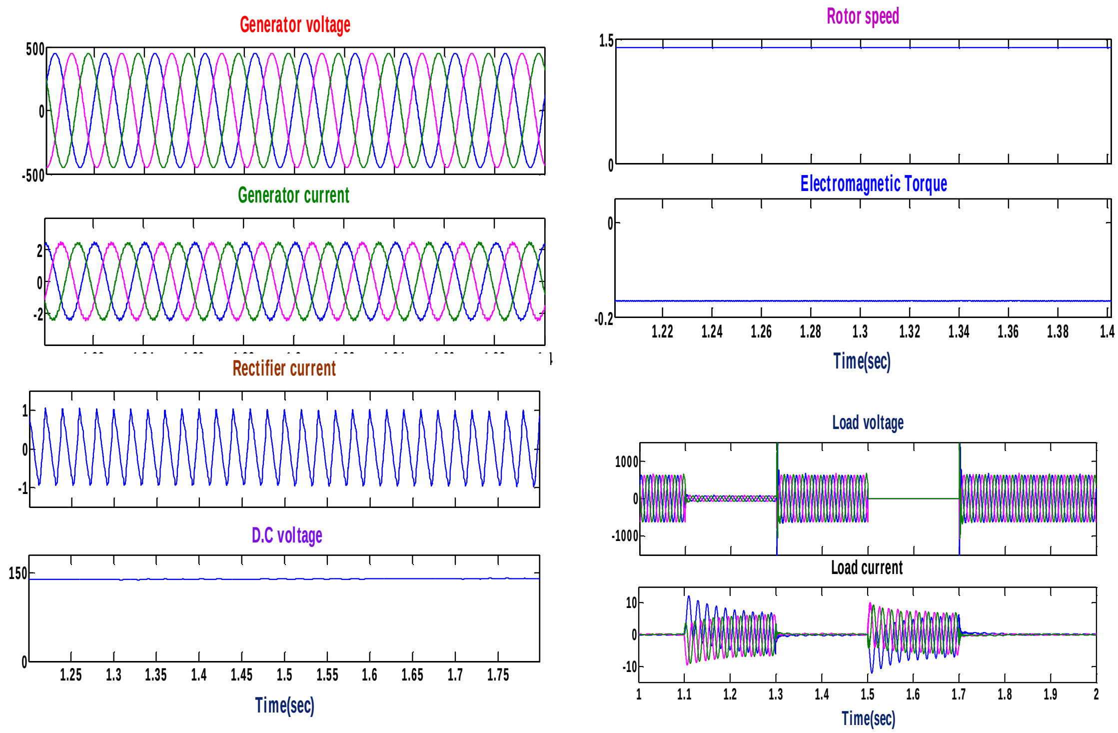

Fig.8.The transient waveforms for 24 pulse vector control of SEIG

The load is applied at grid suddenly at t=1.1 seconds. And short circuit fault is applied at load t=1.5 seconds.

CONCLUSIONS

The vector control of self excited induction generator was carried out under different mulipulse AC-DC converter. Analysis was carried out using three types of mulitpulse converter i.e. twelve pulse, eighteen pulse and twenty four pulse AC-DC converter and the results of these converters are compared with the conventional six pulse AC-DC converter. The input power of the SEIG is held constant at varying consumer loads. The power quality has been improved using 24pulse uncontrolled diode rectifier and an inverter and harmonics are reduced compared to 6, 12 and 18 pulse. With the 24 pulse, it can able to achieve unity PF with a good DC link voltage regulation in the wide operating range of the drive, and has resulted in a reduction in the rating of the magnetic, leading to the saving in the overall cost of the drive. It can easily replace the existing six-pulse converters without much alteration in the existing system layout and equipments.

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