Grid Interface Of Wind Power With Large Split-Winding Alternator Using Cascaded Multilevel Inverter

Palakurthy.Siddhartha [1] M.Divya Charitha [2] P. Pushpa Deepthi [3]

PG Student, CMR College of engg & technology

Associate Professor, CMR College of engg & technology

Assistant Professor, CMR College of engg & technology

1. ABSTRACT

In this paper, The Performance Of Cascaded Multilevel Inverter Interfaced With A Large Split Winding Alternator consists of major parts like cascaded multi level inverter and split winding alternator. Here the split winding alternator is considered as a de-rated machine. Where, the undesired response from the machine like unbalanced current response and unbalanced voltages and the transient nature of torque, are experienced by the machine ,because of the aging effect experienced by the machine so which leads to the de-rating of the winding quality of to the machine which in turn induces many harmonics in the machine leads to decrease in efficiency. There is a need to increase the system overall performance .so the special type of multi level inverter can be used to conjunction with machine so that dynamic response of the machine damped out .Major problem in interfacing such machines to the grid is the limitation imposed by the ratings of currently available switching devices in the converter. The ratings of the semiconductor devices used in the conventional two-level or three-level VSI topologies do not support the higher power ratings necessary for the grid interface of such large machines.

This has motivated designers to go for medium-voltage converters as these are more compact than low-voltage converters for power larger than 1.5 MW. The equal distribution of switching stress and power losses among H-bridge cells, reduction in their power ratings, and high quality of inverter output makes the proposed arrangement more efficient.[1]

Keywords:-cascaded H-bridge multi level inverter, split winding machine (SWM).

2. INTRODUCTION

The electrical machine candidates have advantages and drawbacks as well as the power converters, it is necessary to analysis this assembly based upon some indicators as:

- Overall efficiency.
- Power flow capability.
- Range of speed operation.
- Machine weight.
- Reliability and maintenance.

Trends and further research:-

At present, the Danish power grid holds more than 2 GW installed wind power as well as small Combined Heat and Power Plants with a capacity of more than 1.5 GW. Both types of plants are independently controlled and do not take part in the voltage and frequency control. Furthermore, a huge expansion of wind Power is planned. The power system stability limit in power systems with a High penetration of wind energy is important to identify and to improve in order to obtain the maximum value of the wind energy in the grid system.

The major investment of wind turbines will in the future be done in wind farms with hundreds of MW power capacity. In order to maintain system stability it is important that each wind farm can provide voltage and frequency control by means of power electronic systems. Furthermore, a high penetration of wind power in a power grid structure may test the limits of power stability in the grid system as well as cause power overflow in certain areas. During the last years the wind turbines have grown in size up to 2 MW and More and this trend in size up scaling is expected to continue.

Hence, the main challenges related to technology development are then to reduce the technical uncertainties relating to production and durability for future wind energy project all over the world, to maintain the development towards a more optimal, reliable and cost-optimized technology, to improve the power plant characteristics of the wind turbine plants (power regulations shared responsibility for power system stability etc.), develop the wind turbine technology for future applications, e.g. large highly reliable machines for offshore applications in shallow or deep waters, silent, .invisible. Machines for distributed installations on land or simple, easily maintained hybrid systems for smaller, isolated communities, and to develop technology that facilitates the integration of a variable energy source into the energy system such as HVDC transmission system, energy storage technologies, power flow control, compensations units (voltage, frequency, power factor, phase imbalance etc) and production forecasting and control of the wind power plants.

Issues discussed in this report are essential for meeting these challenges. In particular the rapid development of power electronics, which offers high power handling capability at lower price per kW, can benefit both the turbine development and the integration of wind farms into the power system. Hence it is expected that the application of power electronics in wind turbine will increase further.

Wind energy has proved to be the most promising renewable energy source because of its environment friendliness, sufficient availability, and good conversion efficiency. The current trend in wind turbines is to increase the size of the turbine in order to harvest more energy and thus reduce cost per megawatt of capacity. Power ratings of 3–5 MW per machine are becoming common in areas with large wind potentials, especially offshore wind installations . The major problem in interfacing such machines to the grid is the limitation imposed by the ratings of currently available switching devices in the converter. The ratings of the semiconductor devices used in the conventional two-level or three-level VSI topologies do not support the higher power ratings necessary for the grid interface of such large machines. This has motivated designers to go for medium-voltage converters as these are more compact than low-voltage converters for power larger than 1.5 MW. The use of multilevel VSI topology for distributing voltage stress and power losses between a numbers of devices has been well reported and the multilevel inverters are suitable for modern high-power wind-turbine applications. Due to the great demand of medium-voltage high-power converters in industry, the cascade H-bridge multilevel inverter (CHBMLI) has drawn tremendous interest ever since its inception. Five-level CHBMLI is very common in industrial medium-voltage drives applications. This converter topology is based on the series connection of single-phase H-bridge cells with separate dc sources. It requires the least number of components and is known to eliminate the excessively large number of bulky transformers required by the multi pulse inverters, clamping diodes required by the diode-clamped multilevel inverters (DCMLIs), and additional capacitors required by the flying-capacitor multilevel inverters (FCMLIs). The CHBMLI topology with equal dc-link voltages for each H-bridge cells and fixed switching frequency will be able to provide equal switching stress and power handling for all the CHB cells.

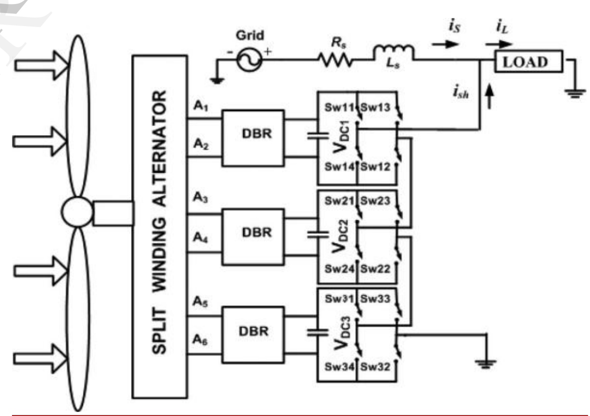
Traditionally, wind turbines have been operated only as energy sources and have not been expected to provide grid support functions like voltage support, frequency control, fault ride through, and spinning reserve, but as the penetration of wind in the overall generation mix increases, new grid codes have been constituted, which stipulate that wind farms must provide some of these functionalities. Recently, it has been suggested that wind farms may be used to provide reactive power support to the grid as a part of the ancillary service provisions. In addition, control of doubly fed induction generator for compensating torque pulsation under unbalanced supply voltage has also been investigated and reported. In addition, when located close to load centers as considered in this paper, and connected to the distribution system, they may be even required to perform harmonic compensation. It has been earlier suggested to use split-winding alternators (SWAs) for electrical vehicle drive systems for synchronous reluctance machines [20] and for obtaining higher phase-order induction machines. Recently, multiple-pole permanent magnet alternators (PMAs) have been suggested for the grid interface of the wind power through five-level cascaded multilevel inverters using power electronics building blocks (PEBBs). Each PEBB in this application consists of a rectifier, a dc link, and an H-bridge cell.

The split windings in the three phases produce ac voltages with equal peak values that can be rectified and used as independent and isolated dc sources for the CHB cells of the multilevel inverter. With PMA, the independent control of terminal voltage is not possible as the main field is setup by permanent magnets. A conventional synchronous generator with external excitation has the capability of terminal voltage control and hence gives an additional control over dc-link voltages. Additionally, splitting of the windings of the alternator in equal number of parts in each phase helps in reducing the voltage and power ratings of the $\mathbf{3(}\boldsymbol{n}\mathbf{-1)/2}$ numbers of PEBBs for an n-level inverter. In particular, for a three-phase seven-level inverter using three split windings per phase of an alternator, total nine such units are required. Since all the dc sources feeding the CHBMLI are equal in magnitude, an equal voltage CHBMLI can be appropriately used to equally distribute losses among the different switching devices. The block diagram shown in figure 2.

This is achieved by using a constant switching frequency for all the CHB cells. The symmetry involved in SWA with equal voltages obtained at the output suits the modular structure of H-bridges in the cascaded multilevel inverter.

In this paper, a CHB multilevel inverter has been proposed with an SWA in order to interface the high power available from a large wind turbine to the grid. A new method has been suggested for the generation of reference currents for the voltage source inverter (VSI), depending upon the available wind power. The current control mode of operation of the CHBMLI-based VSI fulfills the need of real power injection and load compensation based upon the proposed reference-generation scheme. The cascaded multilevel inverter is modulated using phase-shifted multicarrier pulse width modulation (PWM) under closed loop to maintain symmetry of switching among all the H-bridges.

The additional control provided by the dc field voltage of the alternator gives a slower control loop, which can respond to steady-state changes in the demand for power at the point of common coupling (PCC) in addition to the faster real-time control provided by the CHBMLI current control loop. The faster control loop helps in compensating for imbalances in loading, harmonics, and poor load power factor. The closed-loop performance of this latter current control loop has been shown to be adequate and fully achieves the control objectives, i.e., grid interface of distributed energy resource (wind) in addition to the load compensation with changing load and wind conditions.



Proposed SWA and cascaded multilevel inverter connections (shown)for one phase only).

3. SPLIT-WINDING ALTERNATOR:-

A synchronous generator has been proposed for this application with each phase split into three windings having equal number of turns and equal current ratings. Since the three split windings in each phase are electrically isolated from each other, they can be used to feed three separate rectifiers and thus can
Form three isolated dc sources for each phase of the CHBMLI.

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Since the peak values of the ac voltages of each of the nine split Windings are equal, for balanced load condition, the dc-link voltages for all cells will be equal. The alternator will operate within its rated duty if the individual winding voltages and currents are restricted to their rated limits and the three-phase loads on the Ac side are kept balanced**. Figure. 3** show the stator of a split-winding three-phase alternator.

With three split windings per phase. Each of the three phases have been split into three equally rated windings and all the six terminals per phase (total eighteen terminals for all the three phases of the stator) have been brought out so that they can be

Connected independently to nine DBRs. The field winding is on the rotor and is supplied through two slip rings as usual.

The split winding machine is designed by using the machine modeling theory.

Figure 2 shows a schematic diagram of a 3-phase induction motor with the d,q axes superimposed. The q-axis lags the d-axis by 90°. A voltage *Vas*is applied to stator phase A while the current flowing through it is ias. Phases Band C are not shown on the diagram in an attempt to maintain clarity. In the d,q model, coils DS and QS replace the stator phase coils AS, BS and CS, while coils DR and QR replace the rotor phase coils AR, BR and CR.

Although the d,-q axes can rotate at an Arbitrary speed, there is no relative speed between the four coils DS, QS, DR and QR. The Physical significance of showing the D,Q coils in Fig. 1 is to illustrate that in effect the 3-Phase induction motor with its six coils is replaced by a new machine with four coils. In order to predict the mechanical and electrical behavior of the original machine correctly, the original ABC variables must be transformed into d,q variables, but this transformation depends on the speed of rotation of The D,Q coils, hence each reference frame has its own transformation. In general, for any arbitrary value of *0'*, the transformation of stator ABC phase variables *[F* ABcJ to d,q stator variables *[FOdq]*is carried Out through Park's transform as follows:

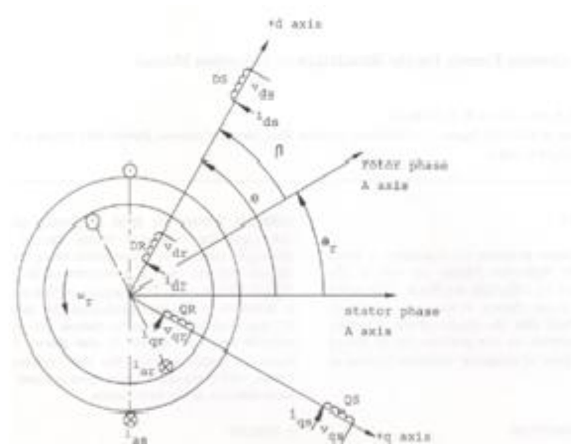


Figure-2 :-D-Q axis superimposed onto a three phase machine

It has been shown [2] that the speed of rotation of the d,q axes can be arbitrary although there are three preferred speeds or reference frames as follows:

(a) The stationary reference frame when the d,q axes do not rotate;

(b) The synchronously rotating reference frame when the d,q axes rotate at synchronous speed;

(c) The rotor reference frame when the d,q axes rotate at rotor speed.

$$[F_{0dq}] = [P_\theta][F_{ABC}]$$

where

$$[P_\theta] = 2/3\begin{bmatrix} 1/2 & 1/2 & 1/2 \\ \cos\theta & \cos(\theta-\lambda) & \cos(\theta+\lambda) \\ \sin\theta & \sin(\theta-\lambda) & \sin(\theta+\lambda) \end{bmatrix}$$

$$v_{ds} = R_s i_{ds} + p\psi_{ds} + \psi_{qs} p\theta$$
$$v_{qs} = R_s i_{qs} + p\psi_{qs} - \psi_{ds} p\theta$$
$$v_{dr} = R_r i_{dr} + p\psi_{dr} + \psi_{qr} p\beta$$
$$v_{qr} = R_r i_{qr} + p\psi_{qr} - \psi_{dr} p\beta$$

where

$$\begin{bmatrix}\psi_{ds}\\ \psi_{dr}\\ \psi_{qs}\\ \psi_{qr}\end{bmatrix}=\begin{bmatrix}L_{ss} & L_m & 0 & 0\\ L_m & L_{rr} & 0 & 0\\ 0 & 0 & L_{ss} & L_m\\ 0 & 0 & L_m & L_{rr}\end{bmatrix}\begin{bmatrix}i_{ds}\\ i_{dr}\\ i_{qs}\\ i_{qr}\end{bmatrix}$$

A new variable called the zero sequence components is included with the d,q variables in order to handle unbalanced voltages and to invert Parks transform.

The transformation of rotor ABC variables to rotor d,q variables is again carried out using Park's transform, but this time the angle beta in figure 2 is used instead of theta.

The voltage balance equations for the d,q coils are as follows:

$$v_{ds}=R_s i_{ds}+p\psi_{ds}+\psi_{qs}p\theta$$
$$v_{qs}=R_s i_{qs}+p\psi_{qs}-\psi_{ds}p\theta$$
$$v_{dr}=R_r i_{dr}+p\psi_{dr}+\psi_{qr}p\beta$$
$$v_{qr}=R_r i_{qr}+p\psi_{qr}-\psi_{dr}p\beta$$

Finally, from the above equations, the electrical torque of the split winding machine is

$$T_e=\frac{3}{2}\left(\frac{P}{2}\right)\frac{1}{\omega_b}(F_{ds}i_{qs}-F_{qs}i_{ds})$$

4.SIMULATION CIRCUIT OF THE SPLIT WINDING MACHINE.

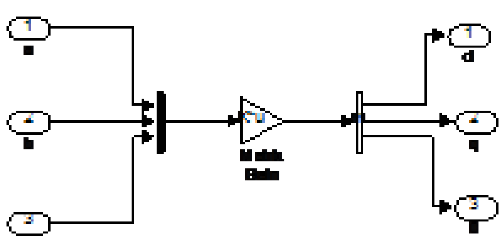


Figure : 3 phases to 2 phase conversion circuit.
K=[2/3 -1/3 -1/3;0 1/√3 -1/√3; 1/3 1/3 1/3];

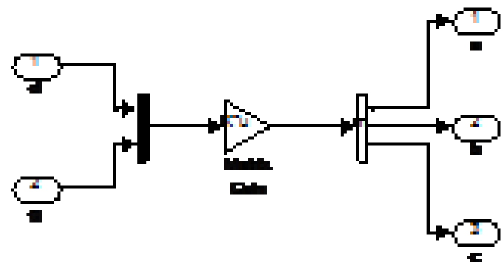


Figure :- Two phase to three phase conversion circuit.
K= [1 0; -1/2 √3/2; -1/2 -√3/2].

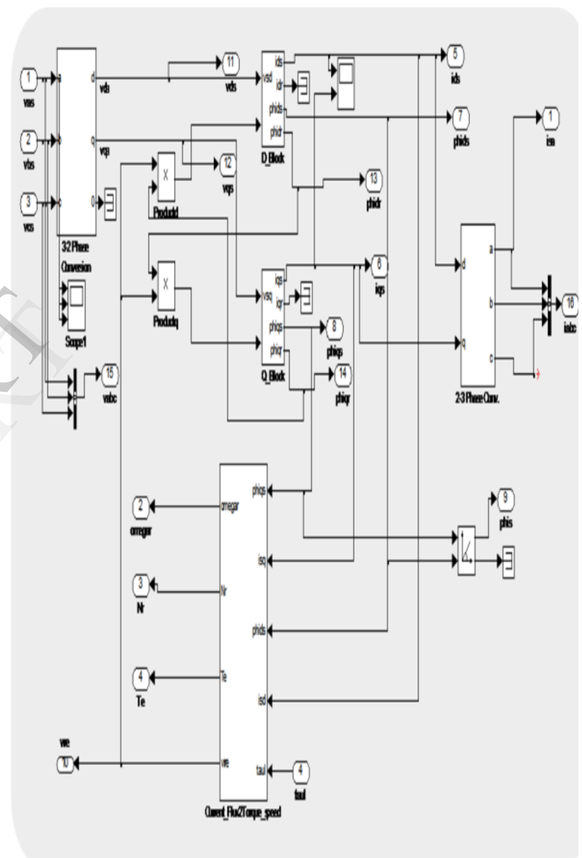


Figure : Split Winding Alternator Modeling Circuit.

5. MULTILEVEL INVERTERS

Cons of conventional system of multi level inverters:-

Higher thermal stress on power semi conductor devices used in VSI.

Difficulty in loss distribution among the switches and power sharing among the switches.

Produces output which has higher, lower order harmonics.

Discrete values of high (dv/dt) at the output AC side of inverter which is fed directly to machine, leads to bearing and isolation problems.

So, we prefer the CASCADED MULTI LEVEL INVERTERS TOPOLOGY.[3]

The concept of MLI has been introduced since 1995.The ELEMENTARY CONCEPT of a MLI to use a series of power semi conductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. The working of the power switches aggregates these multiple DC sources in order to achieve high voltage at the output.

A MLI has several advantages over a conventional two level converter that uses a high switching frequency PWM.

The attractive features of a MLI are:-

1. Staircase waveform quality.
2. Common mode voltage.
3. Input current.
4. Switching frequency.

The circuit diagram of the CHBMLI is given as follows:-

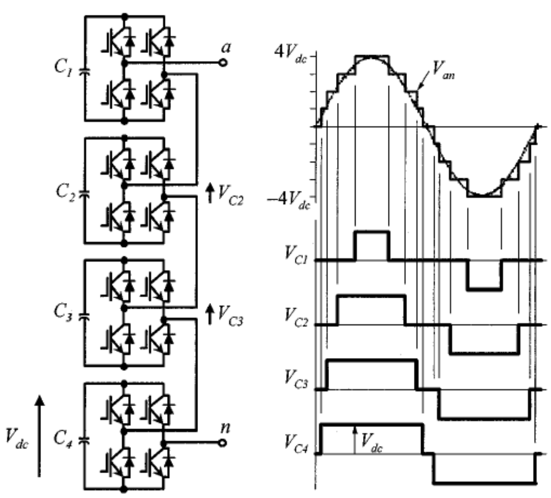
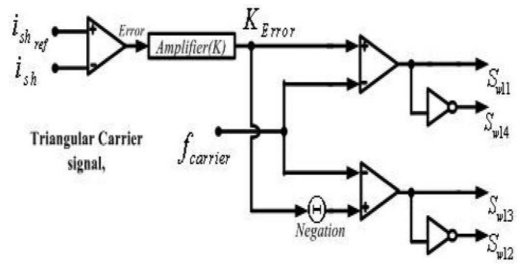


Figure3.1 (a) A Cascaded H-Bridge Multilevel Converter (one phase leg) and its 9-level output waveform

ADVANTAGES OF THE CHBMLI:-

Device voltage sharing is automatic because of the independent dc supplies. There is no restriction on switching pattern..With n devices each per Phase, the circuit can output voltage varying between±**(n/2)*(vdc/2).**By using a lot of H bridges ,very high voltage converters can be made this way.

5. Closed-Loop Multicarrier Modulation of CHBMLI



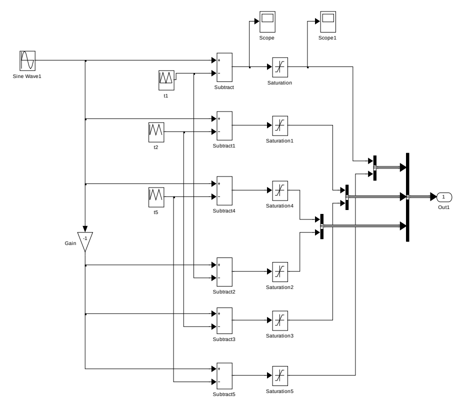


Figure :-The simulation circuit of PWM circuit

In this proposed scheme, the SWA gives three dc sources per phase, which have been used to build a seven-level CHBMLI. Each phase of the inverter has seven levels and hence a three phase CHBMLI has been achieved by connecting all the nine dc sources in appropriate fashion to a seven-level CHBMLI.

The proposed inverter has the internal method of current control together with the external control of the dc input voltages, and hence the flexibility of control is extended. A dc-link capacitor has been used after each DBR to hold the dc input voltages to the CHBMLI. The three H-bridge cells per phase are connected in series on the ac side, and the output is connected straight to the medium-voltage distribution grid without the need of any interfacing transformer.

The cascaded multilevel inverter is controlled using closedloop multicarrier PWM method, as proposed in [4]The phase-shifted PWM (PS-PWM) uses multiple carriers to Control each power switch of the converter. In this method, multiple triangular carrier signals of frequency *f*carrier and amplitude *Ac* are used to generate four unipolar PWM signals needed for the four semiconductor switches in each H-bridge cell, as shown in Fig. 4. The advantage of this method is that the switches in the multilevel converter operate at a fixed switching frequency *f*carrier . Consider the modulation of a single H-bridge of a seven-level CHBMLI, as shown in Fig. 4. It is assumed that the converter has to inject the current *i*sh . This current *i*sh is compared with the reference current *i*sh ref and generates an error signal. This error is amplified by a suitable gain *K* to generate the switching function signal *K*Error . This signal is then compared with the carrier, as shown in Fig. 4, to generate the gating signals for the switches *Sw* 11, *Sw* 12, *Sw* 13, and *Sw* 14 of

the first H-bridge [4].The resultant voltage levels for this H-bridge are obtained as +*V*dc, 0, and −*V*dc. The same process is repeated with the remaining Hbridges with the carriers phase-shifted by predefined angles. For phase-shifted cascaded PWM, the phase shift of each carrier is $(i-1)\pi/N$, (where i is the ith converter and N is the total number of H-bridge cells per phase). This leads to a total $n = (2N + 1)$ number of levels in the output. For the seven-level inverter, the phase shifts of carriers required are 0, $\pi/3$, and $2\pi/3$ rad [23], [24]. This modulation method tracks the reference current *i*sh ref and also leads to a seven-level output at fixed switching frequency (*f*carrier). The advantage of using this modulation method is that it eliminates the switching harmonic components up to the $(n-1)f$carrier frequency , and hence improves the total harmonic distortion (THD) of the output quantities.

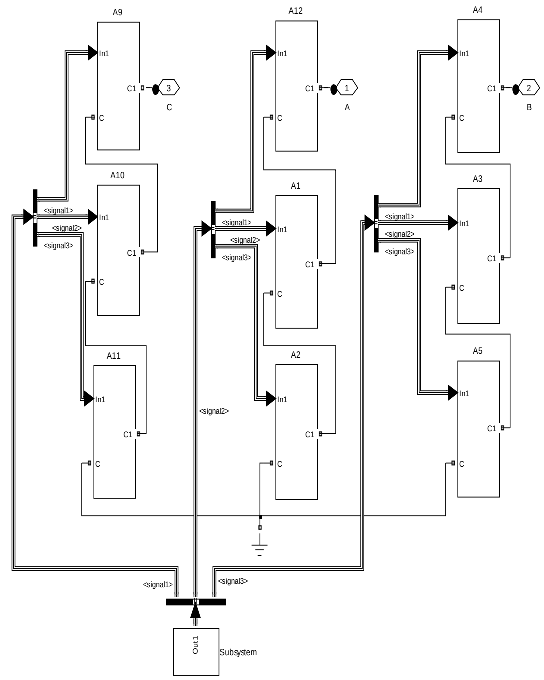


Figure:-The simulation circuit of CHBMLI.

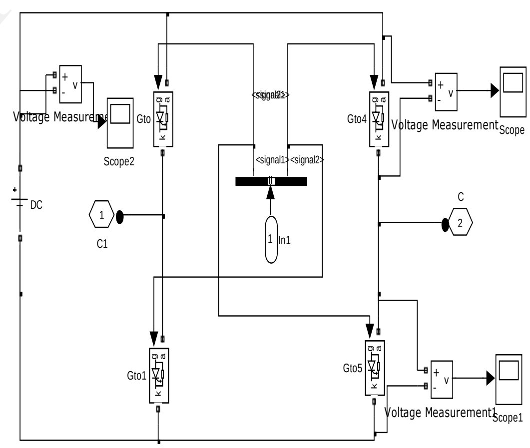
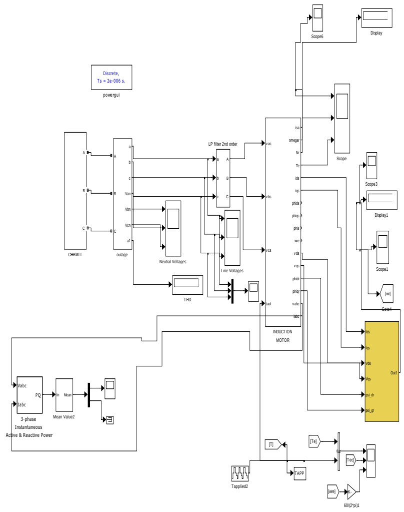


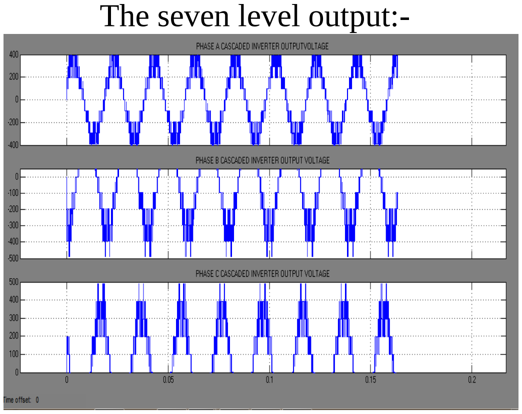
Figure: - Each inverter of CHBMLI circuit

6. THE SIMULATION CIRCUIT OF PROJECT:-

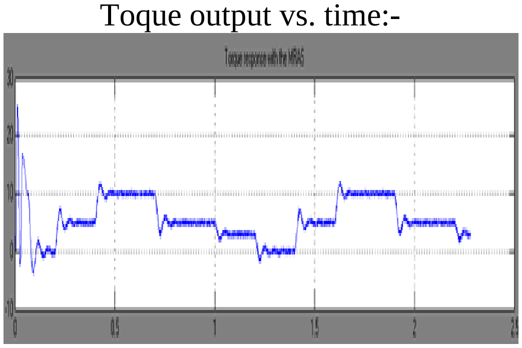


7. SIMULATION RESULTS:-

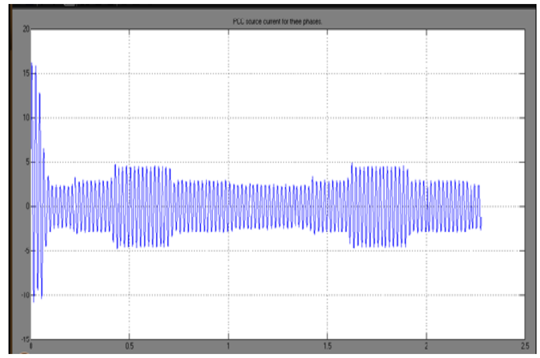
The seven level output:-



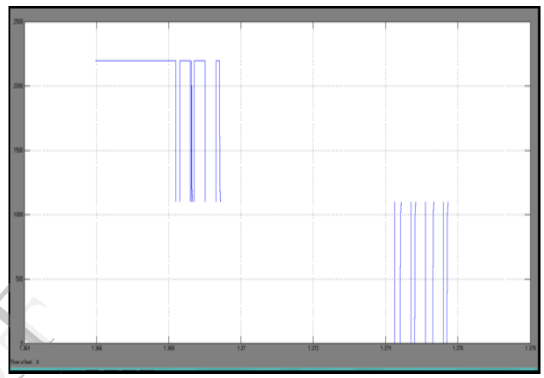
Toque output vs. time:-



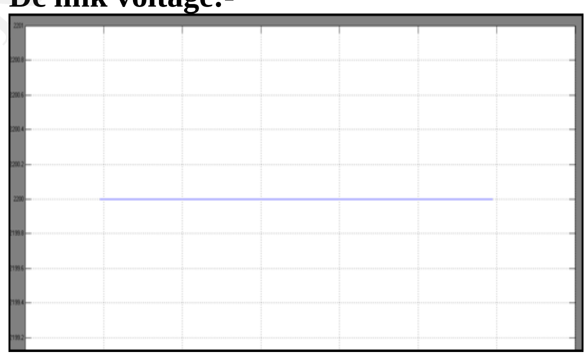
Stator current vs time:-

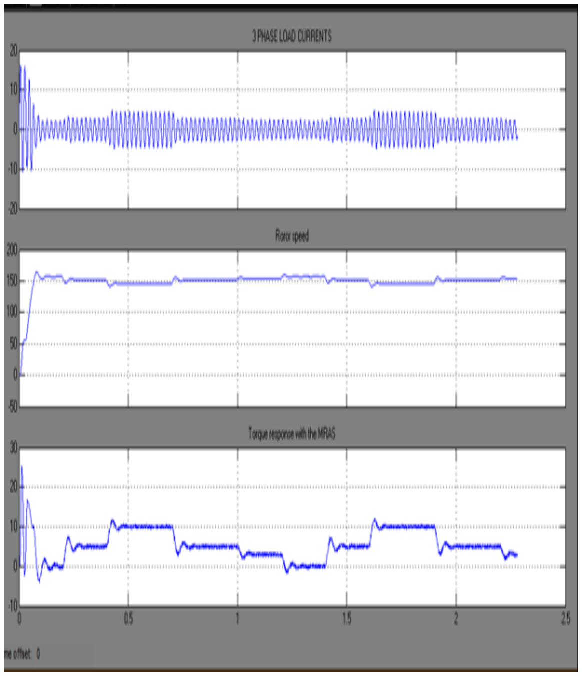


Voltage stress across the device:-

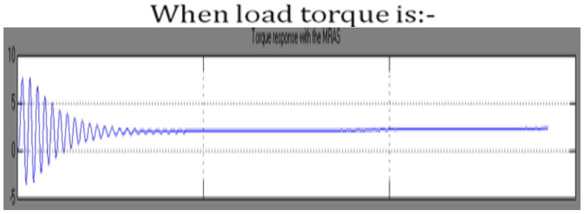


Dc link voltage:-

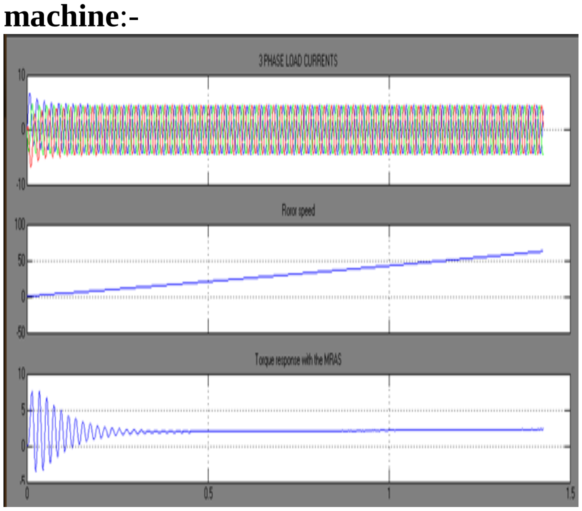


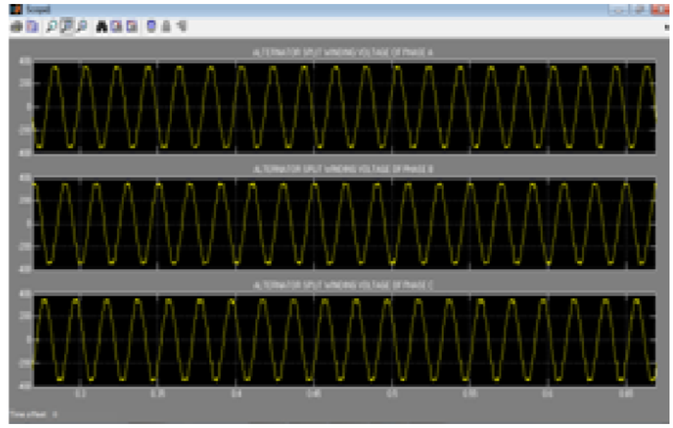


When load torque is:-



The corresponding output quantities of the machine:-





The split winding machine wave form .

8. Conclusion :-

In this dissertation report, main characteristics for induction machine cascaded to CHBMLI are studied with a view of highlighting the advantages and disadvantages of the CHBMLI cascaded to split winding alternator.

Initially, the model of an induction machine is analyzed with its complete theoretical details and the required equations. A thorough understanding of this model is essential to understand the performance analysis if the induction machine. With this scheme employing a CHBMLI, it is possible to control the efficiency of the machine by improving the THD value of the system so that this achieves a fast torque response, low inverter switching frequency and low harmonic losses. The performance of induction machine cascaded to CHBMLI is observed using MATLAB/SIMULINK.

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