Sixth International Conference on Emerging trends in Engineering and Technology (ICETET'16)
www.ijera.com
ISSN: 2248-9622, pp.01-13

RESEARCH ARTICLE OPEN ACCESS

A Switched -Reluctance Generator with Interleaved Interface Dc-Dc Converter

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Abstract: A wind switched-reluctance generator (SRG) with interleaved interface dc–dc converter is developed. The hysteresis current-controlled pulse width modulation (PWM) scheme is designed to achieve good winding current tracking control, and the robust voltage control scheme is developed to yield well-regulated dc output voltage under varying prime mover driving speed and load conditions. Moreover, the voltage regulation and the developed power performances of SRG are further enhanced using the commutation shift approach. Next, an interleaved current-fed push–pull interface dc– dc converter with two modules is developed to establish the boosted common dc bus voltage of a dc micro grid from the SRG output having fault-tolerant capability. The circuit component design are conducted in detail. Similarly, well-regulated voltage with lower ripples is also yielded via the properly designed schematic and control scheme.

Index Terms**:** Current-fed push–pull (CFPP) dc–dc converter, commutation, tuning, hysteresis current control, interleaved, microgrid, robust control, switched- reluctance generator (SRG), voltage control, wind generator.

I. INTRODUCTION

In the industrial perspective, an unblemished, non defect, high efficient variable speed drive (VSD) has always been a far catch in terms of its model and operation. Concentration has been given highly for DC motors and Induction motors solely for this purpose, yet both the types have their own measure of drawbacks. The closest match that can be provided to the ideal VSDs are the Switched Reluctance Motors (SRM), considering the elimination of a few drawbacks. The inherent simplicity, ruggedness and low cost of a SRM make it viable and a machine more apt for various general purpose adjustable speed drive applications.

The construction of SRM is very simple and straight forward compared to all other electrical machines. In the SRM only the stator construction has windings. The construction in the rotor consists of neither the conductor nor the permanent magnets, which make SRM stand apart. The rotor is constructed from a simple construction. It consists of steel laminations stacked onto a shaft. It is because of this simple mechanical construction that SRMs carry the promise of low cost, which in turn has motivated a large amount of research on SRMs in the last decade. This mechanical simplicity, however, results in some limitations on the machine side. For

instance, the SRMs cannot run directly from a DC bus or an AC line, like the brushless DC motor, but always seek the help of electronic commutation switches.Also, the double saliency of the stator and rotor, which is necessary for themachine to produce the required reluctance torque, is responsible for the strong non- linear magnetic characteristics. This complicates the analysis and control of the SRM. This assures to the well known fact that, industrial acceptance for a SRM has been slow.There is also a combination of perceived difficulties that lead to the stagnation of the SRM in the industries, the foremost problem being the lack of commercially available electronic technology with which to operate them, and the flood of commercially available AC and DC machines filling the depths of the industries in the marketplace. However, SRMs offer some advantages to the industries along with option of low cost and more efficiency. They can be considered to be very reliable machines since each phase of the SRM is independent from other phases physically, magnetically, and electrically. Also, the lack of conductors or magnets on the rotor constitutes to the very high speeds achieved when compared to other special motors.
Disadvantages usually yet with operating the SRM are that they are often difficult to control, and they require continuous rotor position sensing using a shaft position sensor to operate. Hence, they mostly tend to be noisy, and the mere fact that they have more torque ripple than other types of motors can be easily downplayed with a better understanding of SRM mechanical design and the a linear mathematical model and development of algorithms to compensate for the aforementioned problems.

MATLAB is an interactive system for numerical computation. Numerical analyst Cleve Moler wrote the initial Fortran version of MATLAB in the late 1970's as a teaching aid. It became popular for both teaching and research and evolved into a commercial software package written in C. For many years now, MATLAB has been widely used in universities and industry. MATLAB has several advantages over more traditional means of numerical computing (e.g writing Fortran or C programs and calling numerical libraries).It allows quick and easy coding in a high level language. Data structures require minimal attention, in particular, arrays need not be declared before first use. An interactive interface allows rapid experimentation and easy debugging Highquality graphics and visualisation facilities are available.

MATLAB M-files are completely portable across a wide range of platforms. Toolboxes can be added to extend the system, giving, for example, specialised signal processing facilities and a symbolic manipulation capability. A wide range of user – contributed M-files is freely available on the internet. Furthermore, MATLAB is a modern programming language and problem solving environment. It has sophisticated data structures, contains built in editing and debugging tools, and supports object oriented programming.

II. Switched Reluctance Generator A .Introduction To Srm

One of the earliest motor during the 1830s was the reluctance motor based on the concept of electromagnet. Its development was hindered due to the requirements of complicated control circuits and high cost of power electronic devices. Furthermore, the emergence of a commutator motor in 1870s and the introduction of the magnetic circuit law in 1880s has given way to motors that out- weigh the performance of the reluctance motor. The Switched Reluctance Machine (SRM) made its come back only in 1960s due to the rapid development of power electronic devices and also the availability of high speed computers coupled with advance programming languages.

The SRM is referred to as a doubly salient pole due to the salient pole of its stator and rotor structure. Salient pole refers to the structure of the element protruding from the yoke into the air gap. The rotor and the stator are made of steel laminations, and only the stator poles have windings concentrated around it. The rotor, on the other hand, is free from windings, magnets and brushes. The windings on one of the stator pole are connected in series with the opposite stator to form one phase. It can be arranged in such a way that more than 2 opposite stator poles can form one phase. The typical configuration of the machine includes 3 phase 6 stator or 4 rotor (6 /4) or 12 /8 and 4 phase 8 /6 or 16 /12 . Figure 1(a) is showing an example of the 4 phase SR machine with 8 /6 poles configuration while Figure 1(b) is showing a 3 phase machine with 12 /8 poles configuration.

The following characteristics of the SRM have attracted researchers to investigate its potential for variable speed application.

1) Simplified construction with rotor only consists of laminated steel.
2) Concentrated phase winding is only on the stator poles.
3) Absence of permanent magnet which gives low manufacturing cost.
4) Machine can operate at high speed and high temperature operation since the rotor can act as a cooling source to the stator.
5) Has higher reliability since each phase is electrically and magnetically independent.
6) Low inertia since it does not have windings or magnets on the rotor hence machine can operate at low wind speed and respond to rapid variations in loads.

B. Operating Principle of SRM

The operation of SRM depends entirely on synchronized excitation of the set of stator windings to create continuous rotation of the rotor poles. The movement of the rotor with respect to the excited stator phase varies the inductance of the machine periodically from maxi-mum, where rotor and stator poles are aligned, to mini-mum unaligned rotor and stator poles. The inductance is maximum at the aligned position and minimum during the unaligned position. By proper positioning of current pulses, the machine can operate either as motor during increasing inductance profile or as generator during decreasing inductance profile.

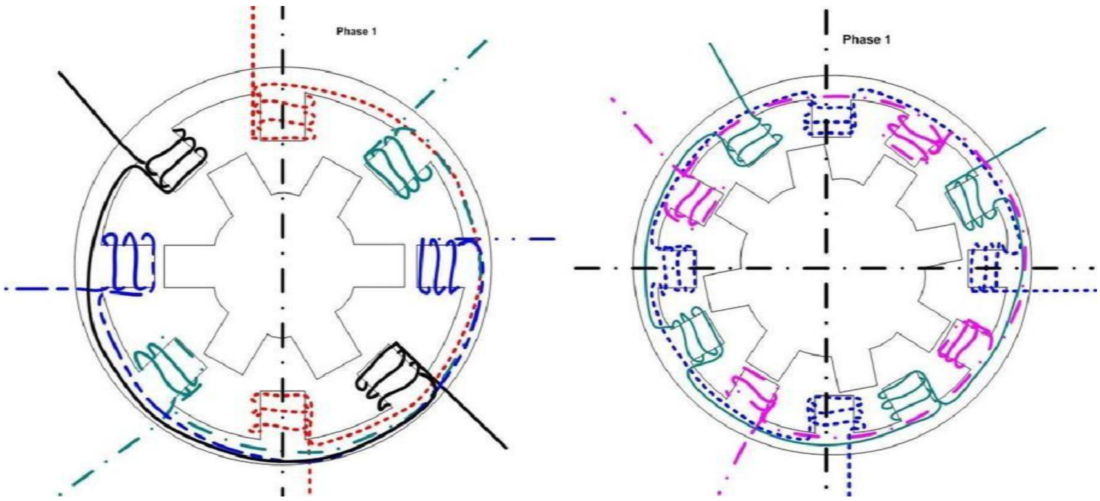

Fig 1. Configuration of a switched reluctance machine: (a) 4 phase 8/6 and (b) 3 phase 12 /8

Its commercial application can be seen in vacuum cleaner, refrigerator, washing machine and also electric vehicles. We can conclude that the operation of SRM as motor has made a good progress however, despite its advantages the operation in generating mode is slowly evolving.

C. Introduction to SRG

In the last decades the SRM has become an important alternative in various applications both within the industrial and domestic markets, namely as a motor showing good mechanical reliability, high torque-volume ratio and high efficiency, plus low cost. Although less evangelized as a generator, there are a few studies of its application in the aeronautical industry and in integrated applications in wind based energy generators.

Although easy to build, the SRM in the past was a source of complaints concerning to its dynamic performance and the peculiar characteristics of its command and control. At the time, these arguments were sufficiently convincing to stop a sustained development and research of this kind of machine. The development of power electronics, and specially the advancements in the field of semiconductors brought improvements in the command and control technology of this kind of machine, thus spearheading a diversified application of SRMs.

Currently the synchronous and induction machines dominate the market of wind energy applications, although, the SRM has been the subject of current investigation and it shows to be a valid alternative for this field .

Comparing with the classical solutions of machines integrated in wind applications, a Switched Reluctance Generator (SRG) shows a simplified construction associated with the inexistence of permanent magnets or conductors in the rotor, which results in lower manufacturing costs; in addition both the machine and the power converter are robust. The low inertia of the rotor allows the machine to respond to rapid variations in the load.

Associated with these characteristics, these machines have a control system that allows rapid changes in the control strategy such that the performance of the machine is optimized. The structure of the SRM is not as stiff as the synchronous machines, and due to its flexible control system, it is capable of absorbing transient conditions, thus supplying more resilience to the mechanical system. The machine has an inherent fault tolerance, especially when under an open-coil fault (in the windings) and in the power converter (external faults). Under normal operation, each phase of SRG is electrically and magnetically independent from others.

The SRM is generally felt to be louder than conventional machines. However an adequate mechanical design can do a lot to improve these figures and new control techniques – current control strategy with a torque reference – permits further improvements.

D. Construction of SRG

The doubly salient pole Switched Reluctance Machine consists of salient

ISSN: 2248-9622, pp.01-13

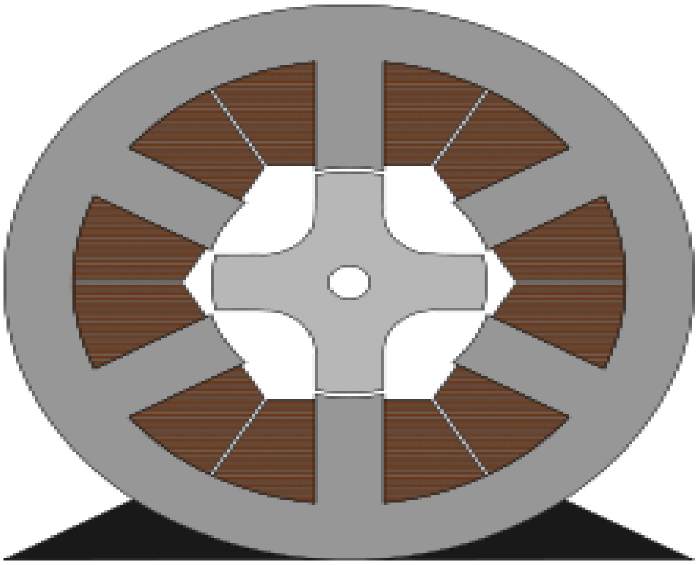

Fig 2. Structure of SRG

poles both on stator and rotor but the windings are present only on the stator which is represented in figure 2 and figure 3 represents a simplified diagram showing the main components which form the SRG system. For the same frame size a doubly salient machine produces more torque and hence, doubly salient construction is widely used. The Switched Reluctance Generators are generally made with unequal number of poles on stator and rotor. The inductance of each stator phase winding coincides with rotor axis. The concentrated windings which are rapidly opposite poles are connected either in series or parallel to result in two phase winding on stator. Stator and rotor magnetic circuits of these generators are laminated to reduce the core losses and to achieve higher efficiency.

better fault tolerance. Another reason of its reliability during fault conditions is the electrical independence among phases.The control system of this converter must regulate the magnitude and even the waveshapes of the phase currents to fulfil the requirements of torque and output power available and to ensure safe operation of the generator. This implies that the electronic switches associated with controller are fully controlled devices. These devices work to invert the voltage applied to the phases in certain angular positions of the rotor and also assist phases' commutations.

If losses are neglected the output energy over each stroke exceeds the excitation by the mechanical energy supplied . It is considered that there is no magnetic saturation and each phase is magnetically independent from others.In these terms, the expression of the instantaneous power (p) available in a SRG is expressed as in (1), where:

n- number of phases;
j- Phase number;
θ - Rotor position;

p(θ,i1,i2……in)=[∑ (θ)] (1)

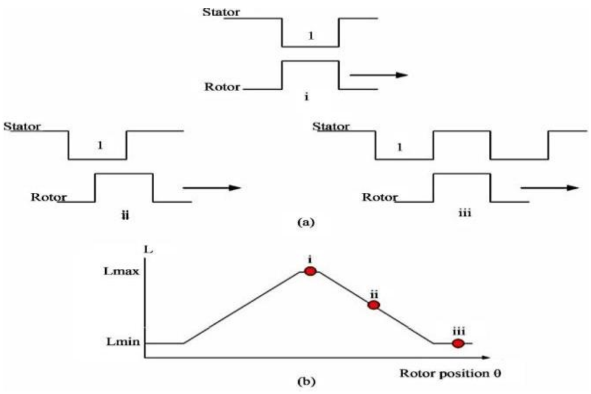

Fig 3. A simplified diagram showing the main components which form the SRGsystem

E. ***Operating Principle of SRG***

In electrical drives with variable reluctance, the torque is function of the
The average power available P, resulting from the operation of the machine as a generator, is (excluding losses) equal to the mechanical average value of the torque Tm using equations (2) and (3), where Nr is the number of rotor poles.

$P=Tm\omega$ (2)

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angular position of the rotor due to the double salient poles. The operation of this —
N_r N �
� � �
machine as a generator is obtained by energising the windings of the stator when the
salient poles of the rotor are away from their aligned position due to the rotating motion of the prime mover. A commercially available switched reluctance machine
T���∫�

r [Σ
� �
�]��θ (3)
��θ

The above equations enable us to infer that the obtained power is
used in this study was a 3-phase 6/4 machine.

The principles of operation of this machine are simple, well known and based on reluctance torque. The machine has a stator of wound-up salient poles that after energising synchronized with the position of the rotor develops a torque that tends to align the poles in a way that diminishes the reluctance in the magnetic circuit.

The Switched Reluctance Machine (SRM), although being simple from the construction point of view, it's characterized by a peculiar mode of controlling its phase currents. For that matter a power electronic converter is used, which functions in a way that the phase currents of the machine are imposed for certain positions of the rotor. In this study is used a standard topology of the converter usually applied in SRM drives, given that it provides a greater flexibility regarding its control and
approximately constant and it reaches a maximum when the dwell angle is located, entirely, in the descending section of the phase inductance profile, which corresponds to the highest average torque. For this kind of machines the torque ripple appears mainly in the commutation zones related with the sequential process of establishing and removing the phase currents. The imposition of phase current waveform using a current control with an adjusted hysteresis band and a sufficient input voltage, allow
a torque ripple reduction. In this way the ripple can be minimized, thus controlling the phases currents commutation precisely phased relative to the rotor position. For
that effect the current control is done using a trapezoidal phase reference torque model; two adjacent
phases can be supplied at the same time to ensure continuity in the generated torque. The SRM is capable of

ISSN: 2248-9622, pp.01-13

operating continuously as a generator by keeping the dwell angle so that the bulk of the winding conduction period comes
after the aligned position, when $dL_j/d\theta <$ �

(a) Advantages of SRG

SRG, when compared with the ac and dc machines, shows two main advantages.

1) It is a very reliable machine since each phase is largely independent physically, magnetically and electrically from the other machine phases.
2) It can achieve very high speeds (2000-5000rev/m) because of the lack of conductors or magnets on the rotor.

(b). Limitations of SRG

The SRG has some limitations

1) It must always be electronically commutated and thus cannot run directly from a dc bus or an ac line.
2) Its salient structure strong nonlinear magnetic characteristics, complicating its analysis and control.
3) The SRG shows strong torque ripple and noisy effects.

F. *Power Converter for SRG and Need of Voltage Regulation*

As the control between the motoring and generating operation differs in terms phase will be connected to a converter circuit. The converter circuit controls the phase current through the windings by providing a path through the switches during excitation and diodes during generating operation. Therefore, the operation of the machine during one cycle can be categorized as two stages: excitation and generation. The switching strategy has an impact on the efficiency of the SRG. The wind SRG, is followed by the interleaved CFPP dc/dc converter to establish the micro grid common dc bus voltage with rigid load regulation characteristics. The establishment of a wind SRG and its performance enhancement has to be done. An experimental DSP-based SRG drive is established with its power circuit and control scheme being properly designed and implemented. The commutation shift, robust current, and voltage controls are made to improve the generating characteristics of the established SRG.

So, an interleaved CFPP dc/dc converter consisting of two modules is developed. It is employed to boost and regulate the varied SRG output voltage to establish the 400V common dc bus of the micro grid with fault-tolerant capability.

Well-regulated dc bus voltage is obtained by the designed control scheme. And lower dc-link ripples are yielded due to the interleaving operation.

G .*Block Diagram*

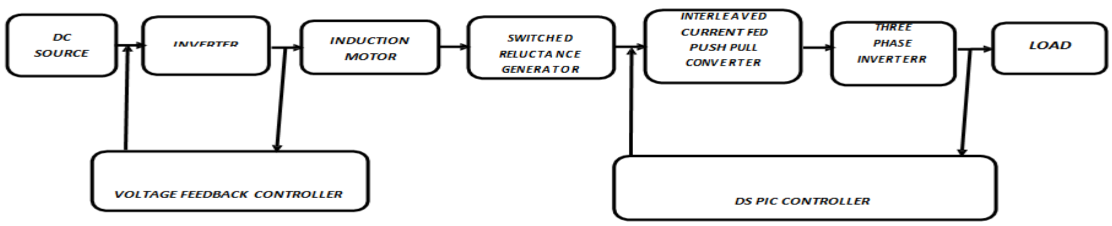

Fig 4. Block diagram

1) The system represented in figure4 ,consists of inverter, induction motor, switched reluctance generator, push pull converter and ac loads.
2) The inverter is converting the dc into ac and send to the induction motor, which is the prime mover part
3) Switched reluctance generator is converting the mechanical energy from the induction motor into electrical energy.
4) The push pull converter is to step up the dc voltage from the generator and send to the three phase voltage source inverter.
5) In this system two controlled techniques are used voltage feedback controller for inverter and DS PIC controller for push pull converter and the three phase load inverter.

H. Prime Mover
(a) Voltage Source Inverter

The main objective of static power converters is to produce an ac output waveform from a dc power supply. These are the types of waveforms required in adjustable speed drives (ASDs), uninterruptible power supplies (UPS), static var compensators, active filters, flexible ac transmission systems (FACTS), and voltage compensators, which are only a few applications. For sinusoidal ac outputs, the magnitude, frequency, and phase should be controllable.

According to the type of ac output waveform, these topologies can be considered as voltage source inverters (VSIs), where the independently controlled
ac output is a voltage waveform. These structures are the most widely used because they naturally behave as voltage sources as required by many industrial applications, such as adjustable speed drives (ASDs), which are the most popular application of inverters. Similarly, these topologies can be found as current source inverters (CSIs), where the independently controlled ac output is a current waveform. These structures are still widely used in medium-voltage industrial applications, where high-quality voltage waveforms are required. Static power converters, specifically inverters, are constructed from power switches and the ac output waveforms are therefore made up of discrete values. This leads to the generation of waveforms that feature fast transitions rather than smooth ones.

(b)Three Phase Voltage Source Inverters

Single-phase VSIs cover low-range power applications and three-phase VSIs cover the medium- to high-power applications. The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable. Although most of the applications require sinusoidal voltage waveforms (e.g., ASDs, UPSs, FACTS, VAR compensators), arbitrary voltages are also required in some emerging applications (e.g., active filters, voltage compensators).

The standard three-phase VSI topology is shown in figure 5 and the eight valid switch states. As in single-phase VSIs, the switches of any leg of the inverter (S1 and S4, S3 and S6, or S5 and S2) cannot be switched on simultaneously because this would result in a short circuit across the dc link voltage supply. Similarly, in order to avoid undefined states in the VSI, and thus undefined ac output line voltages, the switches of any leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon the respective line current polarity. Of the eight valid states, two of them produce zero ac line voltages. In this case, the ac line currents freewheel through either the upper or lower components. The remaining states produce non-zero ac output voltages. In order to generate a given voltage waveform, the inverter moves from one state to another. Thus the resulting ac output line voltages consist of discrete values of voltages that are Vi, 0, and -Vi for the topology. The selection of the states in order to generate the given waveform is done by the modulating technique that should ensure the use of only the valid states.
Need For Isolated Gate-Control Signals for the Switches:

As already mentioned the switches in bridge configurations of inverters need to be provided with isolated gate (or base) drive signals. The individual control signal for the switches needs to be provided across the gate (base) and source (or emitter) terminals of the particular switch. The gate control signals are low voltage signals referred to the source (emitter) terminal of the switch. For n-channel IGBT and MOSFET switches, when gate to source voltage is more than threshold voltage for turn-on, the switch turns on and when it is less than threshold voltage the switch turns off. The threshold voltage is generally of the order of +5 volts but for quicker switching the turn-on gate voltage magnitude is kept around +15 volts

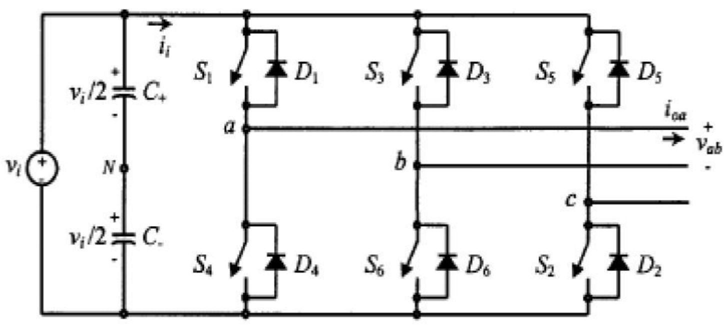

Fig5. Three-phaseVSItopology

(c) Induction Motor:

The AC induction motor is well suited to applications requiring constant speed operation. In general, the induction motor is cheaper and easier to maintain compared to other alternatives. The induction motor is made up of the stator, or stationary windings, and the rotor. The stator consists of a series of wire windings of very low resistance permanently attached to the motor frame. As a voltage and a current is applied to the stator winding terminals, a magnetic field is developed in the windings. By the way the stator windings are arranged, the magnetic field appears to synchronously rotate electrically around the inside of the motor housing. The rotor is comprised of a number of thin bars, usually aluminum, mounted in a laminated

cylinder. The bars are arranged horizontally and almost parallel to the rotor shaft. At the ends of the rotor, the bars are connected together with a "shorting ring."The rotor and stator are separated by an air gap which allows free rotation of the rotor. In typical Induction Motor Rotors the magnetic field generated in the stator induces an EMF in the rotor bars. In turn, a current is produced in the rotor bars and shorting ring and another magnetic field is induced in the rotor with an opposite polarity of that in the stator. The magnetic field, revolving in the stator, will then produces the torque which will "pull" on the field in the rotor and establish rotor rotation. In thedesign of the induction motor, operational characteristics can be determined through a series of calculations.

I . ***Circuit Diagram***

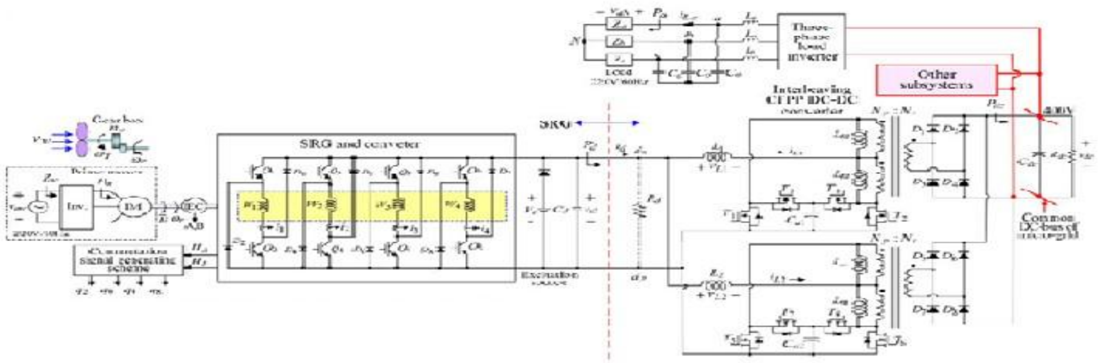

Fig .6 Schematic Circuit Diagram

The Circuit diagram shown in figure 6 reveals the system configuration and control schemes of the developed SRG, its followed interleaved CFPP boost dc/dc converter and a test load inverter. An experimental DSP-based SRG drive is established with its power circuit and control scheme being properly designed and implemented. The commutation shift, robust current, and voltage controls are made to improve the generating characteristics of the established SRG. Next, an interleaved CFPP dc/dc converter consisting of two modules is developed. It is employed to boost and regulate the varied SRG output voltage to establish the 400V common dc bus of the microgrid with fault-tolerant capability. Well-regulated dc bus voltage is obtained by the designed control scheme and lower dc-link ripples are yielded.

J. ***Control Strategies***

The proper choice of converter and its pulse width modulation (PWM) switching control should be first treated. Among the commonly used converters, the asymmetric bridge converter is preferred for the SRG owing to its high winding current PWM switching control flexibility. It is well known that the SRG generation performance is highly affected by nonlinear winding inductance, back electromotive force (EMF), generated voltage ripples, driven speed, loading condition, and commutation instant setting. Especially for the back- EMF, which is negative and dependent on both speed and current. Open-loop instability caused by back-EMF is prone to occur under high speed and/or heavier load. In this case, the PWM switching control may fail and enter single-pulse mode. The commutation instant should be properly tuned to alleviate these problems. Some existing researches concerning the performance improvement for SRG include.

1) Excitation control: the excitation control is designed considering the machine electric dynamics in single pulse mode operation under different speeds. And the conduction period is dynamically located to a predefined region of the inductance profile to yield higher efficiency.

2) Voltage control: to consider nonlinear magnetic characteristics, the fuzzy logic controller is designed to control the dc-link voltage of an SRG system. In the
terminal voltage control strategy presented in, an appropriate sequence of turning off the switches of each phase is proposed to allow better usage of mechanical power in the electromechanical conversion process.
3) Power maximization control: in the online determination of firing angles
is made to obtain the compromised performance in high efficiency and low torque ripple. In maximization of power throughput of an SRG considering dc-link and speed variations is achieved via properly arranging switching angles. Similarly, in the other researches, the pursued voltage and power control performances are generally achieved via the tunings for commutation angles.

As generally recognized, the use of microgrid is effective in the reductions of fossil energy utilization and carbon-oxide emission. Some microgrid systems can be referred. Compared with ac microgrid, dc microgrid possesses the comparative
merits of: 1) having simpler interface power converters and controls; and 2) allowing

longer common dc bus length for the smaller voltage drops. However, microgrid is an interdisciplinary plant consisting of sources, energy storage devices, their interface power converters and suited controls. To yield satisfactory operation performance, all power stages should be properly designed and their proper match must be made. For the established wind SRG with lower output voltage (≤ 48V), a high-voltage step-up interface dc/dc converter with unidirectional power capability is needed to establish well regulated dc bus voltage (400 V).

III. Current Fed Push Pull Converter

A .*Introduction to Step up Current Fed Push Pull Converter*

There are many known transformer isolated dc-dc converter topologies, which could be suitable to perform the necessary voltage boost from the fuel cell voltage level to the inverter dc link voltage. Such converters are the full-bridge, half- bridge, the flyback, the forward and the push-pull basic topologies, as well as a number of their derived topologies . These can be divided into two groups – voltage fed converters and current fed converters. In this the current fed topology is preferred, since it is characterized by low input current ripple, which is more appropriate for proton exchange membrane.A double inductor boost push-pull converter which is shown in figure 7 is elaborated. Considering the necessity of high voltage boosting function with low input current ripple, the most appropriate converters are current fed full-bridge and push-pull configurations. Since the converter efficiency can be considerably improved by reducing the count of the primary switches and implementing a transformer of a simple structure (without split windings), a double inductor push-pull converter (DIC) was selected and is implemented .

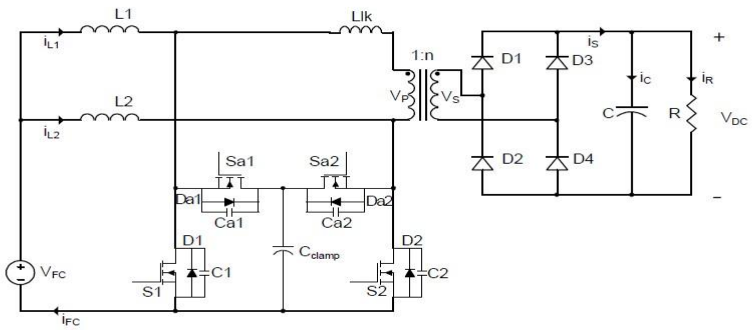

Fig7. Step up Current fed push pull converter

The step up current fed push pull converter has the same operation of a boost converter and having the same modes of operation of the interleaved current fed

CFPP, where as it has the four thyristors and four diodes working in the mode as,

1) In Mode1 the Thyristors & Diodes Sa1, Sa4, Da1, Da4 gets ON.
2) In Mode2 the Thyristors & Diodes Sa2, Sa3, Da2, Da3 gets ON.
3) Sa3 is the complimentary to Sa1.
4) Sa4 is the complimentary to Sa2.

B. *Introduction to Interleaved CFPP Converter*

The current-fed push–pull (CFPP) dc/dc converter is a good choice for its advantages of low-input current stress, high-voltage conversion ratio and without flux unbalance in isolation transformer, etc. The winding method presented and reduce the voltage spike caused by the transformer leakage inductance. And the clamp circuits developed and can applied to limit the voltage stress across the switch. In wind generator applications, the rating enlargement and fault tolerance are two important issues. The interleaving approach can be employed to achieve these goals. In addition, the interleaving operation of converters can yield the reduced ripples. Some applications of interleaving control in various power converters can be referred.

It is followed by the developed interleaved CFPP dc/dc converter to establish the microgrid common dc bus voltage with rigid load regulation characteristics.The
establishment of a wind SRG and its performance enhancement studies are presented.
First, an experimental DSP-based SRG drive is established with its power circuit and control scheme being properly designed and implemented. The commutation shift,
robust current, and voltage controls are made to improve the generating characteristics of the established SRG. Next, an interleaved CFPP dc/dc converter consisting of two modules is developed. It is employed to boost and regulate the varied SRG output voltage to establish the 400V common dc bus of the microgrid with fault-

tolerant capability. Well-regulated dc bus voltage is obtained by the designed control scheme. And lower dc-link ripples are yielded thanks to the interleaving operation.
In the field of power electronics, application of interleaving technique can be traced back to very early days, especially in high power applications. In high power
applications, the voltage and current stress can easily go beyond the range that one power device can handle. Multiple power devices connected in parallel and/or series could be one solution. However, voltage sharing and/or current sharing are still the concerns. Instead of paralleling power devices, paralleling power converters is
another solution which could be more beneficial.

Furthermore, with the power converter paralleling architecture, interleaving technique comes naturally. Benefits like harmonic cancellation, better
efficiency, better thermal performance, and high power density can be obtained. In
earlier days, for high power applications, in order to meet certain system requirement, interleaving multi-channel converter could be a superior solution especially considering the available power devices with limited performance at that time.

C. *Total Harmonic Distortion*

On the ac side, the total harmonic distortion (THD) in voltages and currents of the regulatory standards must be respected. A further constraint comes from the switching loss that is proportional to the valve switching frequency. The proposed solution in the referred paper consists of using multiple interleaved three-phase current-source converters. With this multi modular converters the current stress can be divided to a level that can be handled by gate turn-off thyristor (GTO), the static induction thyristor (SI), etc, and reduces the ohmic component of their conduction losses. The results shows interleaving technique was applied quite successful in this application.

D. *Modes of Operation*

In Current Fed Push Pull (CFPP) converter, there are two modes of operation which are DC-AC and AC-DC conversion, i.e., DC-DC conversion. It is current fed, so the inductors L1 and L2 are used. It is isolated dc-dc converter, so transformer is used. Due to the transformer connected, leakage inductance is present and so voltage and current ripples occur. Interleaved is done to reduce the voltage ripple.

1) In Mode1 the Thyristors & Diodes T1, T4, D1, D4 gets ON.
2) In Mode2 the Thyristors & Diodes T2, T3, D2, D3 gets ON.
3) T3 is the complimentary to T1.
4) T4 is the complimentary to T2.

E. *During Interleaving*

1) In Mode1 the Thyristors T1, T5 and T2, T6 gets ON. TI gets ON for 25% of total time period and then T5 gets ON. T2 gets ON for 25% of total time period and then T6 gets ON.
2) In Mode2 the Thyristors T3, T7 and T4, T8 gets ON. T3 gets ON for 25% of
total time period and then T7 gets ON. T4 gets ON for 25% of total time period and then T8 gets ON.

The comparision of step up current fed push pull converter and Interleaved current fed push pull converter is done and the advantages of using the interleaved current
fed Current fed Push Pull converter than the Step up Current Fed Push Pull
Converter are,

1) Low-input current stress.
2) High-voltage conversion ratio and without flux unbalance in isolation transformer.
3) Lower dc-link ripples.
4) High-energy conversion efficiency.

V. SIMULATION RESULTS

Matlab is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include, Math and computation, Algorithm development, Data acquisition Scientific and engineering graphics.

Matlab is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non interactive language such as C Or FORTRAN.

Matlab features a family of add-on application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control Systems, neural networks, fuzzy logic, wavelets, simulation, and many others.

A. *Simpower systems*

Sim Power Systems and other products of the Physical Modeling product family work together with Simulink to model electrical, mechanical, and control systems. Sim Power Systems operates in the Simulink environment. Therefore, before starting this user's guide, you should be familiar with Simulink.

(a) *The Role of Simulation in Design*

Electrical power systems are combinations of electrical circuits and electromechanical devices like motors and generators. Engineers working in this discipline are constantly improving the performance of the systems. Requirements for drastically increased efficiency have forced power system designers to use power electronic devices and sophisticated control system concepts that tax traditional analysis tools and techniques. Further complicating the analyst's role is the fact that the system is often so nonlinear that the only way to understand it is through simulation .Land-based power generation from hydroelectric, steam, or other devices is not the only use of power systems. A common attribute of these systems is their use of power electronics and control systems to achieve their performance Sim Power Systems is a modern design tool that allows scientists and engineers to rapidly and easily build models that simulate power systems. Sim Power Systems uses the Simulink environment, allowing you to build a model using simple click and drag procedures. Not only can you draw the circuit topology rapidly, but your analysis of the circuit can include its interactions with mechanical, thermal, control, and other disciplines. This is possible because all the electrical parts of the simulation interact with the extensive Simulink modeling library. Since Simulink uses MATLAB® as its computational engine, designers can also use MATLAB toolboxes and
Simulink block sets. Sim Power Systems and Sim Mechanics share a special Physical
Modeling block and connection line interface.

(b) *Sim power system Libraries*

The libraries contain models of typical power equipment such as transformers, lines, machines, and power electronics. The capabilities of Sim Power Systems for modeling a typical electrical system are illustrated in demonstration files.

And for users who want to refresh their knowledge of power system theory, there are also self-learning case studies. The Sim Power Systems main library, power lib, organizes its blocks into libraries according to their behavior. The power library window displays the block library icons and names. Double-click a library icon to open the library and accessthe blocks. The main Sim Power Systems power library window also contains the Powergui block that opens a graphical user interface for the steady-state analysis of electrical circuits. This is possible because all the electrical parts of the simulation interact with the extensive Simulink modeling library. Since Simulink uses MATLAB as its computational engine, designers can also use MATLAB toolboxes and Simulink block sets. Sim Power Systems and Sim Mechanics share a special Physical Modeling block and connection line interface.

B.*Simulation Results*

(a) *Step up current fed PushPull Converter*

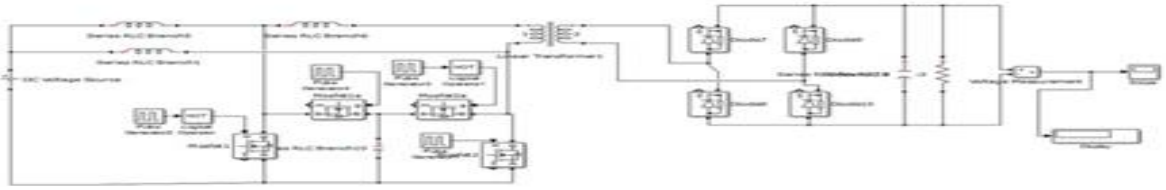

Fig 8. Simulation Diargram of step up CFPP converter

The simulation diagram of step up CFPP converter is shown in figure 8 which consists of a single module having four MOSFET switches,two inductors ,Isolated
transformer , four diodes and connected to the load.he output waveform of voltage and current is shown in figure 9 and figure 10 having almost 400v dc and current about 2.3A having ripples.

(b) *Output current waveform for cfpp stepup converter*

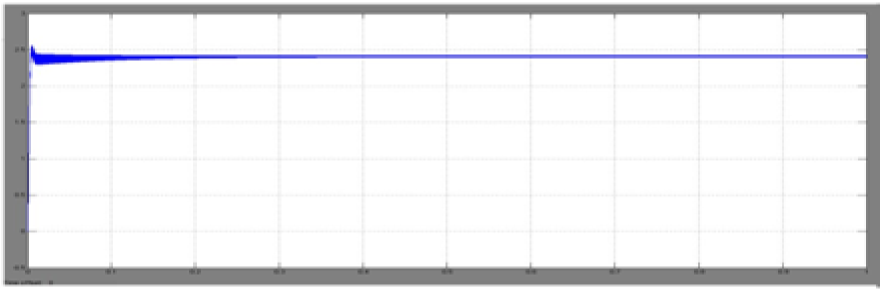

Fig 9. Current wave form for CFPP step up converter

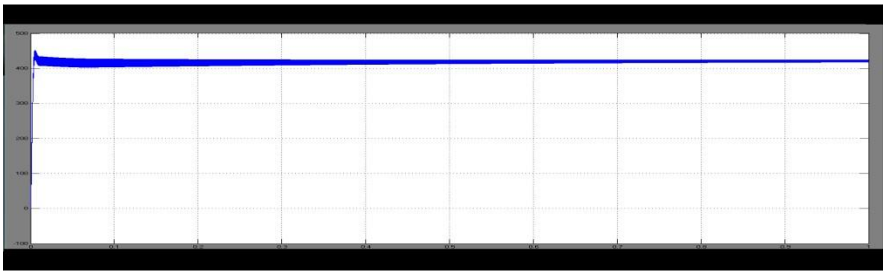

Fig 10. Voltage waveform of CFPP step up converter

(d) S*imulation diagram of interleaved CFPP*

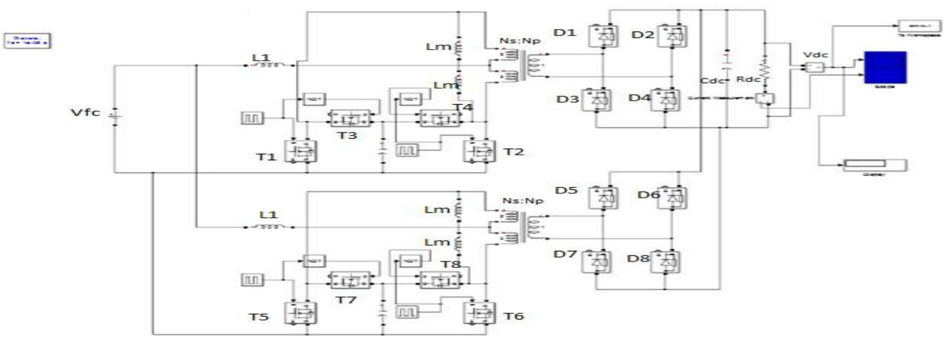

Fig 11. Simulation Diagram of interleaved CFPP

The simulation diagram of Interleaved CFPP is shown in figure 11 consists of two modules of CFPP converter which is in the form of interleave. Each converter consists of of four switches, Inductor, Isolated transformer and four diodes and load.The input voltage given here is about 48v and the output voltage about 400v dc is obtained

(e) Output voltage and current waveform of interleaved cfpp:

Fig 12. Output voltage and current waveform of interleaved CFPP.

The output voltage and current waveform of Interleaved CFPP is shown in figure 12.The peak voltage is about 410V dc and then it gradually decreases and settles in 380V dc .Where as currrent reaches 1.48A peak current then falls down slightly and settles at 1.3A .

V. CONCLUSION

The SRG output voltage (48VDC) is boosted by the developed isolated interleaved CFPP dc/dc converter to establish the high-voltage common dc-bus (400VDC) with fault-tolerant capability. The analysis, design, and dynamic control for the developed converter have been conducted in detail. And the experimental evaluation has been made to confirm the advantages possessed by the developed interleaved converter, such as redundancy, lower current ripples, well-regulated dc- bus voltage, etc.

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