# Simulation of replacing the Grid Interface transformer of windEnergy by Solid State Transformer

Er. Neeraj Kumar[1] (READER)
(UIET, CSJM UNIVERSITY, KANPUR)
Email. nirajkumar@ csjmu.ac.in

Aastha Gautam[2], Aastha Singh[3], Abhay Pratap Singh[4], Abhishek Kumar[5], Aditya Kumar Rai[6]
(Students of ECE department, UIET CSJM UNIVERSITY,)
Email:aasthagautam962@gmail.com,
nehaaastha1308@gmail.com, abhaypratapsingh551@gmail.com,
abhipal8369@gmail.com, adityarai0507@gmail.com,

## Abstract

A Solid state transformer is an advanced power electronic device that can replace the conventional power transformer used in power systems. A solid state transformer (SST) is able to transform and control power in an efficient, compact and reliable way. Recently ,there has been an emerging interest in using SSTs with Wind energy conversions system(WECs) due to their high efficiency, reliability and low maintenance requirements.

One of the key advantages of SSTs in WECs application is their ability to perform voltage and frequency regulations, as well as power factor correction. Over all , the combination of SSTs and WECs offers a promising solution for the development of efficient ,reliable and sustainable wind energy systems, which can help to address the growing energy demand and reduce the reliance on fossil fuels.

KEYWORDS: SST, WECs, PMSG, Convertors, transformers

## I. INTRODUCTION

With expansion and growth of our economy, power consumption has grown double folded in recent years and use of various sources of energy has increased the complications in our existing grid system. To cope up with this complexity new technologies are requires for better control and more reliable operations of the grid in order to manage the smart grid technologies that allow better control.

Solid state transformer is one such technology. The SSTs can achieve high power density as well as operation at high frequency. Solid-state transformers also acknowledged as "smart transformers," are advanced electrical energy devices that provide bi-directional power flow. It is a technology integrated with a transformer power control circuitry and electronics converters. Usually, an SST comprises of a transformer, within the DC-to-DC or AC-to-AC converter, which offers electrical isolation and transmits the complete power. An SST can actively control the current and voltage. Some SSTs can alter single-phase to three-phase power and the other way round. Even though an SST is more complex than a conventional converter, it is more proficient and smaller in size than the conventional transformer.

In the present power grids, energy is generated in large power stations and transmitted over high voltage lines. This energy is then delivered to consumers via medium and low-voltage lines. In these grid layouts, the power flow goes only in one direction: from central power stations to consumers. In recent years, many European countries have started to liberalize their electricity market. This liberalization brought with it an increased penetration of renewable energy and other distributed generation sources in the grid. These developments cause the network layout and operation to become much more complex. In order to better manage future grids, sometimes also called smart grids, new technologies are required that allow better control, an increased number of power inputs and bi-directional power flow.

A key enabler for smart grids is the solid-state transformer. The SST offers ways to control the routing of electricity and provides flexible methods for interfacing distributed generation with the grid. The solid-state transformer also allows for control of the power flow, which is needed to ensure a stable and secure operation of the grid. However, this comes at the cost of a more complex and expensive system . The advancement in semiconductor technology has provided a new alternative to the hundred year old conventional transformer technology by providing an elegant solution using Solid State Transformer. The SST is applied semiconductor technology for changing the voltage ratio. The SST can achieve high power density as well as operation at high frequency, thus reducing the size and the cost. This has provided a new opportunity for researchers, world over, to suggest new topologies, use of new material and experimentation in different environment and area of application. A typical SST consists of an AC/DC rectifier, a DC/DC converter with high-frequency transformer and a DC/AC inverter. One of the functions of a SST is similar to that of a traditional line frequency transformer (LFT), namely increasing or decreasing the voltage. In recent years, the costs of power electronics has decreased, and more reliable, low loss, high power, high frequency power electronics have become available. The cheaper price and the fact that the solid-state transformer can replace certain grid components along with the conventional transformer, makes the solid-state transformer potentially economically feasible. There is limited information available on grid behaviour of the SST due to its novel technology. Simulation software allows investigation of the SST's performance without having to build a prototype first. These simulations have one major drawback, namely the long computation times. This is caused by the complexity of the control algorithms and switching elements, the simulation waveforms require long computational times to generate. The overall computation time for obtaining simulation waveforms at steady-state also drastically increase with the increased number of switching elements and control loops. The main objective is to design a single ended primary

inductor converter for dc-dc conversion of the solid state transformer and to verify it under grid conditions using permanent magnet synchronous generator. By reducing the number of switching elements and control loops the overall computation time for obtaining the simulation waveforms will reduce.

## II. PROBLEMS WITH CONVENTIONAL TRANSFORMERS

- Large size
- High losses
- Less efficiency
- Required maintenance
- Costly

## III. PERMANENT MAGNET SYNCHRONOUS GENERATOR

A **permanent magnet synchronous generator** is a generator where the excitation field is provided by a permanent magnet instead of a coil. The term synchronous refers here to the fact that the rotor and magnetic field rotate with the same speed, because the magnetic field is generated through a shaft mounted permanent magnet mechanism and current is induced into the stationary armature.

Synchronous generators are the majority source of commercial electrical energy. They are commonly used to convert the mechanical power output of steam turbines, gas turbines, reciprocating engines and hydro turbines into electrical power for the grid. Some designs of Wind turbines also use this generator type

.

In the majority of designs the rotating assembly in the centre of the generator— the "rotor" contains the magnet, and the "stator" is the stationary armature that is electrically connected to a load. As shown in the diagram, the perpendicular component of the stator field affects the torque while the parallel component affects the voltage. The load supplied by the generator determines the voltage. If the load is inductive, then the angle between the rotor and stator fields will be greater than 90 degrees which corresponds to an increased generator voltage. This is known as an overexcited generator. The opposite is true for a generator supplying a capacitive load which is known as an under excited generator. A set of three conductors make up the armature winding in standard utility equipment, constituting three phases of a power circuit—that correspond to the three wires we are accustomed to see on transmission lines. The phases are wound such that they are 120 degrees apart spatially on the stator, providing for a uniform force or torque on the generator rotor. The uniformity of the torque arises because the magnetic fields resulting from the induced currents in the three conductors of the armature winding combine spatially in such a way as to resemble the magnetic field of a single, rotating magnet. This stator

magnetic field or "stator field" appears as a steady rotating field and spins at the same frequency as the rotor when the rotor contains a single dipole magnetic field.

They are known as synchronous generators because f, the frequency of the induced voltage in the stator (armature conductors) conventionally measured in hertz, is directly proportional to RPM, the rotation rate of the rotor usually given in revolutions per minute (or angular speed). If the rotor windings are arranged in such a way as to produce the effect of more than two magnetic poles, then each physical revolution of the rotor results in more magnetic poles moving past the armature windings. Each passing of a north and south pole corresponds to a complete "cycle" of a magnet field oscillation.

Therefore, the constant of proportionality is P|20 where P is the number of magnetic rotor poles (almost always an even number), and the factor of 120 comes from 60 seconds per minute and two poles in a single magnet.



Rotor field (physical rotation)

Stator field (apparent rotation)
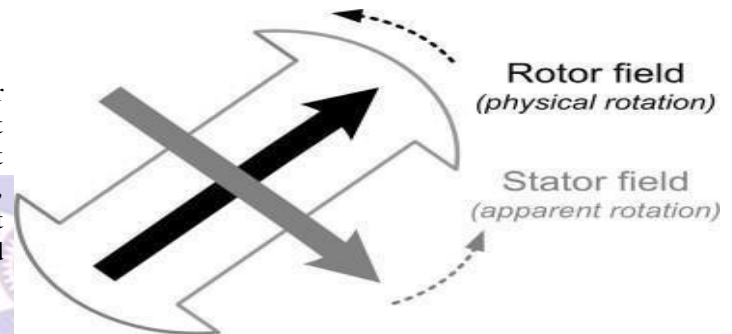
Permanent magnet generators (PMGs) or alternators (PMAs) do not require a DC supply for the excitation circuit, nor do they have slip rings and contact brushes. A key disadvantage in PMAs or PMGs is that the air gap flux is not controllable, so the voltage of the machine cannot be easily regulated. A persistent magnetic field imposes safety issues during assembly, field service or repair. High performance permanent magnets, themselves, have structural and thermal issues. Torque current MMF vectorially combines with the persistent flux of permanent magnets, which leads to higher air
– gap flux density and eventually , core saturation. In the permanent magnet alternators , the output voltage is directly proportional to the speed.

For small pilots generator s used for speed measurements , voltage regulation may not be required. Where a permanent magnet generator is used to supply excitation current control and voltage regulation of the main machine.

This may be done with slip rings connecting the rotating system to external control circuits, or by control through power electronics devices mounted on the rotating system and controlled externally.

## IV. SOLID STATE TRANSFORMER

Solid-state transformer (SST) is a collection of high-powered semiconductor components, conventional high-frequency transformers and control circuitry which is used to provide a high level of flexible control to power distribution networks add some communication capability

and the entire package is often referred to as a solid state transformer (SST).

SST technology can step up or step down AC

voltage levels just like that of the traditional transformer but it also offers several significant advantages. These include:

- allow two way power flow
- input or output AC or DC power
- actively change power characteristics such as voltage and frequency levels
- improve power quality (reactive power compensation and harmonic filtering)
- provide efficient routing of electricity based on communication between utility provider, end user site and other transformers in the network
- greatly reduce the physical size and weight of individual transformer packages with equivalent power ratings
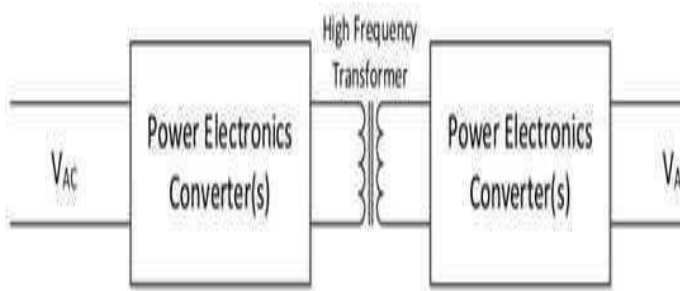


When SSTs are implemented, they will radically change the way utility power is distributed. They will also become integral components in the future Smart Grid - enabling it to direct power from any source to any destination by the most efficient route possible.

## V. ANALYSIS

By definition, the SST consists of one or more power electronics converters and an integrated high- frequency transformer. There are several SST architectures, but based on the topologies, they can be classified in four categories

1. Single-stage with no DC link
2. Two-stage with a DC link on the secondary side
3. Two-stage with a DC link on the primary side
4. Three-stage with a DC link on both the primary and secondary side .

Of the four possible classifications, the three-stage architecture, with two DCs, is the most feasible because of its high flexibility and control performance. The DC links decouple the MV from the LV-side, allowing for independent reactive power control and input voltage sag ride- though. This topology also allows better control of voltages and currents on both primary and secondary side.
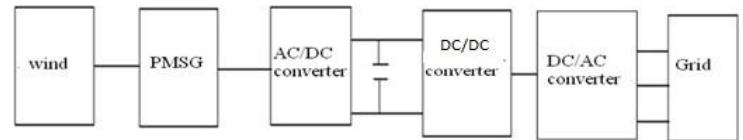


Analysis consists of a permanent magnet synchronous generator, AC-DC conversion stage , DC-DC conversion stage and a DC-AC conversion stage. ACDC conversion stage and DC-DC conversion stage are controlled by using some kind of controllers. It is sometimes claimed that permanent magnet generator (PMG) is more expensive than double-fed induction generator (DFIG) drive trains. However, research has established that when every investment and operational factor is taken into account, PMG drive trains work out to be a cheaper, more cost-effective option over the total life cycle of the turbine. PMG drive trains actually improve efficiency over the full operational range of the turbines. PMG has a much higher efficiency curve, and this is especially true when operating at partial power, where the highest number of operational hours is spent. As the Next Wind report states: "A significant difference in power output becomes apparent when the operating speed range is taken into account.

The PMG can begin producing power at very low rpms, but the DFIG is limited to a synchronous speed of less than 30%."
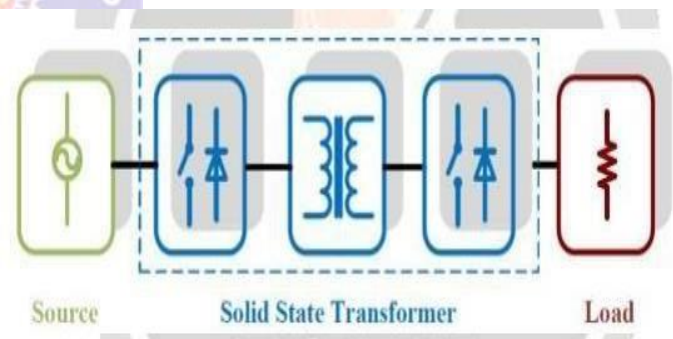


The SST concept will improve power quality. Although the major improvement will benefit the costumers connected to the SST, the concept will also marginally improve the power quality of other users on the same network. The power electronic converters on both sides of the isolation barrier, effectively separate the input voltage shape from the output voltage shape. This separation brings immediate benefits to the consumer connected to the low voltage side of the SST. Some of the more important advantages include:

1. The SST operates with an intermediate DC energy storage capacitor from where the output voltage is created. The voltage of the DC capacitor can be regulated by the front end converters through a wide range of input voltages. Therefore the output voltage will be immune from input voltage sags and dips within a designed band.

2.      The output inverter operates with an output voltage control loop, implying that the output voltage will be regulated throughout the load range. This results in a near perfect voltage regulation. 3. The output voltage will also be pure sinusoidal and free of power frequency harmonics, regardless of input voltage shape SWER systems are generally an economic choice for feeders with load densities lower than 0.5kVA/km.

However, the system has several inherent disadvantages such as: the imbalance of load currents on the primary distribution line, inability to provide three phase voltages at point of use and voltage regulation. The charging currents of a SWER system can be as high as 0.025 A/km for a 12.7 kV system. This high reactive current component coupled with a relatively small load current result in a leading power factor. As a result, the load voltage is very dependent on the load current. To provide better voltage regulation, SWER distribution systems are often fitted with a voltage regulator. The SST concept will benefit distributions systems utilising SWER technology in that: interface.

### Functionalities:
1) Protects load from power supply disturbances
2) Voltage Harmonics and sag compensations
3) Outage compensation
4) Protects power systems from the load disturbances
5) Load transients and harmonic regulations
6) Unity input power factor under reactive load
7) Sinusoidal input current for non linear loads
8) Protection against output short circuit
9) Operates on distributed voltage level
10) Integrates energy storage
11) Medium frequency isolation.

### VI. WORKING:

1) The SST can deliver rated voltage for a wide range of input voltages, resulting in a good overall system load regulation.
2) Using an SST to branch from the main feeder the SWER system would reflect a balanced three phase load to the utility, unlike the single phase load reflection in traditional systems.
3) Using a SST system with an available MV DC link, the power could be transmitted in DC. This not only eliminates the charging current and associated losses but also increases the power capability of the line for a certain conductor size and insulation capability.

Protection as part of normal operation the different controllers of the SST measure all the relevant operational parameters, such as the input and output current and voltage. Using this information the controllers have control over parameters such as the output voltage magnitude. Through the implicit control of the SST the concept will bring the following advantages to the distribution protection system:

1) If one of the outputs experience a line to ground short or another fault, the inverter can continue to supply power to the other two phases. The SST can relay information of the fault to the utility should maintenance be necessary. The inverter can also monitor the phase through active impedance measurement techniques to determine if the fault is still present and can reinstate power delivery to the faulty phase should the fault clear.
2) The SST acts as a barrier to fault currents. Even in the event of a full three phase fault on the LV side, the fault will not propagate back to the MV side. The network would not see a short circuit, as the SST simply decreases the output voltage to limit the flow through the SST. The network will however
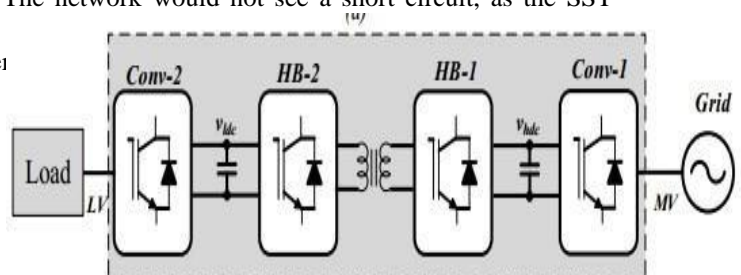


### AC to DC Conversion Stage
The AC-DC conversion stage of the SST has a MV, AC-side and a DC side. There are two options

available for operating at such high voltages are twolevel converters using
cutting-edge high voltage power semiconductors and multilevel converters using mature power semiconductors. The use of high power semiconductor in combination with classic Two-Level Voltage Source Converter (2L-VSC) topologies has the advantage of using well-known circuit structures and control methods. However, the newer power semiconductors are more expensive and their higher power rating introduces other

power-requirements and the need of HV filters. The scalability of 2L- VSCs is also an issue, since the voltage handling capabilities are restricted by the power semiconductor ratings.

Converters require multilevel modulation methods. These methods have received a lot of attention over the last years from researchers. The main reasons for the increased interest are the challenge to apply traditional modulation techniques to multilevel converters. The inherit complexities of multilevel converters due to the increased amount of power semiconductor devices. The possibility to take advantage of the extra degrees of freedom provided by the additional switching states provided by multilevel topologies.

These reasons lead to the development of several modulation methods, each with their own unique features and drawbacks, depending on the application. Depending on the domain in which the modulation technique operates, two categories can be distinguished. These are voltage based

algorithms and space vector based algorithms.

Voltage Level Based Algorithms operate in the time domain. Among the several voltage level based modulation techniques, the PWM methods are the most often used. The reasons for this high adoption are high performance, simplicity, fixed switching frequency and easy digital and analog implementation. Space vector based algorithms are techniques where the reference voltage is represented by a reference vector. Instead of using a phase reference in the time domain, these methods use the reference vector to compute the switching times and states. Space vector algorithms have redundant vectors, which can generate the same phase-to- neutral voltage. This feature can be used to improve inverter properties by using the redundant vector to fulfill other objectives, such as reducing the common-mode DC output voltage, reducing the effect of over modulation of output currents, improving the voltage spectrum, minimizing the switching frequency and controlling the DC-link voltage when floating cells are used. Although several space vector based algorithms are available, they are not the dominant modulation technique used in the industry. The reason for this is that carrier based PWM only requires a reference signal, carrier signals, and a simple comparator to for the gating signals. Space vector based algorithms on the other hand, require at least three stages: a stage to select the vectors for modulation, a stage to compute the duty cycle and a stage where the sequence for the vectors is generated. This means that the space vector algorithms have higher hardware requirements than the PWM techniques.

## DC-DC Conversion Stage

The second stage of the SST is a DC-DC conversion stage. There are 5 main types of dc-dc converters. Buck converters can only reduce voltage, boost converters can only increase voltage, and buck-boost, Cúk, and SEPIC converters can increase or decrease the voltage. Single Ended Primary Inductance Converter is used in this stage. This converter allows a range of dc voltage to be adjusted to maintain a constant voltage output.

## DC – AC conversion Stage

The third stage of the SST is an AC-DC circuit that converts the DC output from the DC- DC stage into an AC voltage. Since this stage is at low voltage, it is more feasible to use a Two-Level Voltage Source Inverter than a multilevel inverter. The reasons for this are the cheaper, simpler circuit and the use of a more mature technology. The DC-AC conversion stage of the SST should be capable of producing a three-phase line-to-line and line-to-neutral voltage. This stage will either be connected to a low-voltage distribution grid on will work in standalone mode. In both cases, it should be capable of handling asymmetrical loads, since distribution grids are inherently asymmetrical . They should also allow bidirectional power flow, to accommodate the integration of distributed generation. . Based on the required functions, the possible DC-AC topologies are three Half-Bridges Converters in parallel, three Full-Bridges Converters in parallel, three Single-Phase Three-Wire Converters in parallel, conventional Three- Phase Converter and three-Phase Four-Leg Converter.

The Continuous Pulse Width Modulation (CPWM) is an adaptation of the CPWM for three-leg inverters. The PWM signals are generated by comparing the phase-voltages and the neutral phase-voltage to a triangular carrier waveform. The simple algorithm of the CPWM allows for easy implementation with very low hardware requirements. However, compared with other modulation methods, CPWM may result in higher switching losses. The implementation of CPWM only requires the conventional abc duty cycle in order to generate the IGBT gate signals.
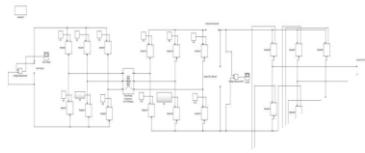
## VII. SIMULATION RESULTS

### Input voltage

The input voltage is a parameter defining the differential DC voltage required between the inputs of an amplifier, especially an operational amplifier , to make the output zero.

### Three phase output voltage and current

Three-phase electric power is a common method of alternating current electric power generation, transmission, and distribution.

Three-phase power supply system, three conductors each carry an alternating current of the same frequency and voltage amplitude relative to a common reference but with a phase difference of one third of a cycle between each. The common reference is usually connected to ground and often to a currentcarrying conductor called the neutral.

Due to the phase difference, the voltage on any conductor reaches its peak at one third of a cycle after one of the other conductors and one third of a cycle before the remaining conductor. This phase delay gives constant powertransfer to a balanced linear load. It also makes it possible toproduce a rotating magnetic field.
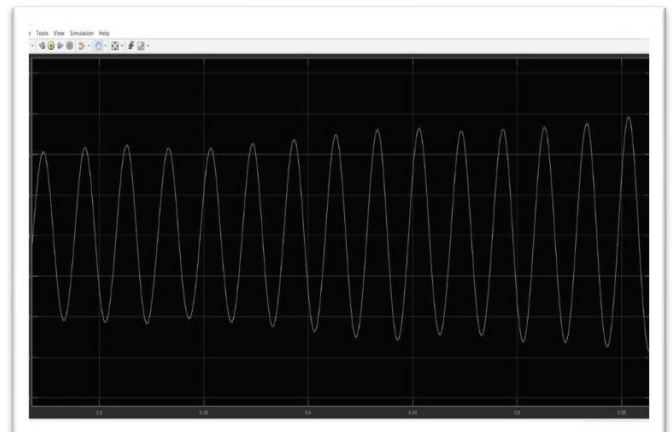
#### OUTPUT VOLTAGE

The output voltage curve shows the final three phase sinusoidal output having amplitude on Y-axis and time on X-axis.
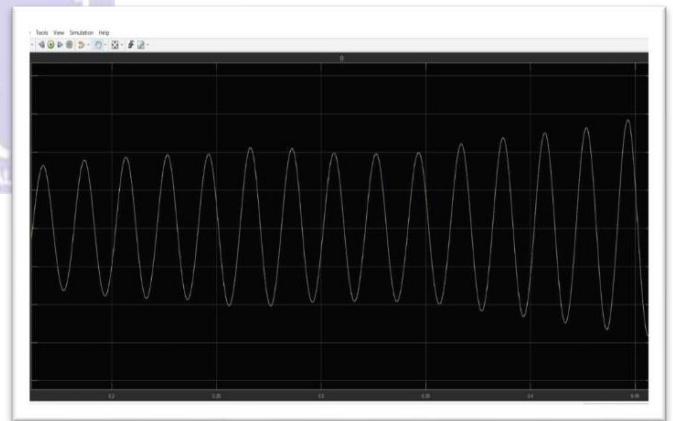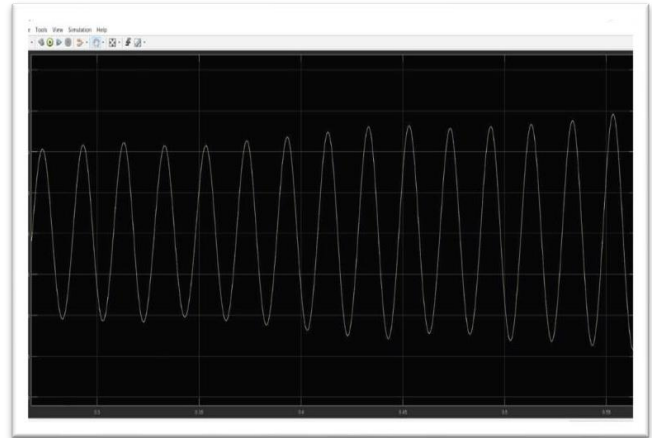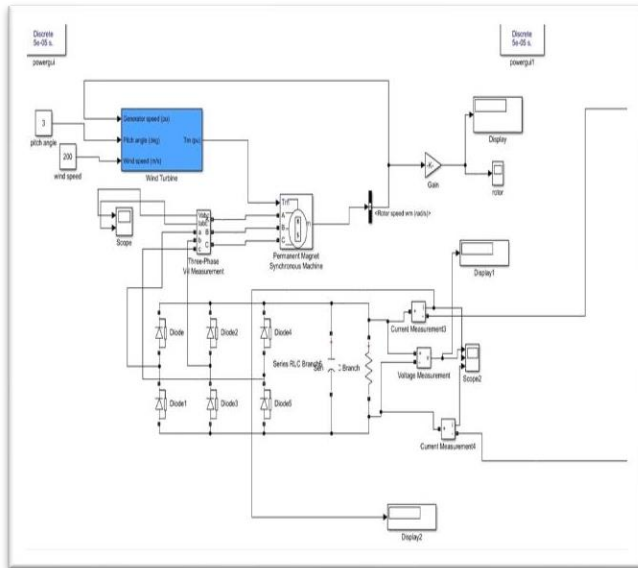




R
B

#### OUTPUT CURRENT

The output current curve shows the

final three phase sinusoidal output current having amplitude on Y-axis andtime on X-axis.



ind Turbine [(using permanent magnet synchronous Generator (PMSG)]

## VIII. CONCLUSION AND FUTURE SCOPE

In this paper, a new wind energy conversion system configuration that combines PMSG and SST operation, has been proposed. This configuration replaces the regular fundamental low frequency transformer with advanced power electronics based Solid State Transformer (SST). The key features of the proposed configuration are outlined below:

- Replacement of regular low frequency transformer with SST leading to smaller size of wind turbine.
- The proposed solid state transformer was simulated using permanent magnet

synchronous generator under grid conditions.

- The SSTs also allows for control of the power flow, which is needed to ensure a stable and secure operation of the grid.
- high controllability of grid side current.
- It is more efficient and reliable

## IX. REFERENCES

[1] S.Bifaretti,P. Zanchetta, A. Watson, L. Tarisciotti, and
J. C. Clare, "Advanced Power Electronic Conversion andControl System for Universal and Flexible PowerManagement," IEEE Trans. Smart Grid, vol. 2, no. 2, pp.231–243, Jun. 2011.

[2] L.Heinemann and G. Mauthe, "The universal power electronics based distribution transformer, an unified approach," 2001 IEEE 32nd Annu. Power Electron. Spec. Conf. (IEEE Cat. No.01CH37230), vol. 2, pp. 504–509.

[3] W.van der Merwe and T. Mouton, "Solid-state transformer topology selection," in IEEE International Conference on Industrial Technology, 2009, pp. 1–6.

[4] S.Bhattacharya, T. Zhao, G. Wang, S. Dutta, S. Baek,
Y. Du, B. Parkhideh, X. Zhou, and A. Q. Huang,"Design and development of Generation-I silicon based Solid State Transformer," in 2010 Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), 2010, pp. 1666–1673.

[5] S.Falcones and R.Ayyanar, "Topology comparison for Solid State Transformer implementation," in IEEE PES General Meeting, 2010, pp. 1–8

[6]G. Pannell, B. Zahawi, D. J. Atkinson and P. Missailidis, "Evaluation of the Performance of a DC-Link Brake Chopper as a DFIG Low-Voltage Fault-Ride-Through Device," inIEEE Trans. Energy Convers., vol. 28, no. 3, pp. 535- 542, Sept. 2013.

[7]G. G. Oggier, G. O. GarcÍa and A. R. Oliva, "Switching Control Strategy to Minimize Dual Active Bridge Converter Losses,"IEEE Trans. Power Electron. ,vol. 24, no. 7, pp. 1826-1838, July 2009.

[8]M. N. Kheraluwala, R. W. Gascoigne, D. M. Divan and E. D. Baumann, "Performance characterization of a high-power dual active bridge DC-to-DC converter," in IEEE Trans. on Ind. App., vol. 28, no. 6, pp. 1294-1301, Nov/Dec 1992.

[9] G.G. Oggier, R. Leidhold, G. O. Garcia, A. R. Oliva, J. C. Balda, F. Barlow"Extending the ZVS Operating Range of Dual Active Bridge High-Power DC-DC Converters," Power Electronics Specialists Conference, 2006. PESC '06. 37th IEEE, Jeju, 2006, pp. 1-7.

[10]J. E. Huber, J. W. Kolar, "Volume/weight/cost comparison of a 1MVA 10 kV/400 V solid-state against a conventional low-frequency distribution transformer," in proc. IEEE Ener. Conv. Cong. and Expo. (ECCE), pp. 4545-4552, Sept. 2014.