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Investigation of PMSG Based Wind Energy System and it's Analytical Approach Using Various Loads and Power Electronics Devices

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ABSTRACT To meet the future energy demand and to provide a quality and pollution free supply to the growing and today's environment conscious pollution the present world attention is to go for natural, clean and renewable energy sources. These energy sources capture their energy from ongoing natural process. There are so many renewable energy sources such as sun, wind, tides etc. Due to the developments in the power electronics area nowadays wind energy becomes one of the most important forms of renewable energy. It also has the following features, it doesn't cause any kind of pollutions, it is easily available and the space requirement for a wind energy conversion system is also less. The main components of a wind energy conversion system include a wind turbine, generator, interconnection apparatus and control system. To interface the generating station and the grid station there are so many converter topologies are used. Due to the advantages like high efficiency and reliability, PMSG is mainly used in a WECS. So a PMSG based WECS is taken in account for the various case studies. In this paper performance and analysis of PMSG based wind energy system, the various conditions have been studies and their MATLAB/**SIMULINK** based prototype simulation and results have been discussed. All the different cases are given as PMSG with various types of 3-phase nonlinear loads and PMSG for DC Loads with various types of Power Electronics Switches. In this paper analysis of all the results and its discussions are given, based on the waveforms of the prototype SIMULINK model of the systems.

INDEX TERMS PMSG Permanent Magnet Synchronous Generator, WECS Wind Energy Conversion System, Resistive R-load, Resistive Inductive RL-load, Resistive Capacitive RC-load, Resistive Inductive Capacitive RCL-load, AC Alternating Current, and GTO Gate Turn off Thyristor, IGBT Insulating Gate Bipolar Junction Transistor, and MOSFET Metal Oxide Semiconductor Field Effect Transistor.

1.0 INTRODUCTION

Today, the world is progressing at quite a fast rate with use of the non conventional sources of energy ,because of environmental pollution and their limited availability motivate towards the non- conventional energy sources which are available in plenty, free of cost and pollution free.

Compared to solar panels, wind turbine release less amount of CO2 to the atmosphere, consume less energy and produces more energy overall. In fact one wind turbine can generate the same amount of electricity per kWh as about 48,704 solar panels.

Frequently load changing conditions and applying variable frequency loads to the wind power system makes the voltage and current fluctuations on generation side of wind turbine.

Linear and nonlinear load switching in power system connected to wind turbine PMSG generation makes active and reactive power variation and voltage unbalance on the generation side of PMSG.

The uses of power semiconductor devices have the different-different switching characteristics. It may cause the noise in the PMSG and reduction in smooth power generation of the PMSG.

Nowadays, PMSGs are most popular for power-generation, as they have high efficiency [1–5]. For instance, the electrical efficiency of PMSGs is higher than the synchronous-generators (SGs) in the moderate-size power marine diesel gen-sets [6]. As PMSG don't comprise excitation control, voltage regulation in island-operation is challenging. The flux-density of permanent magnet (PM) reduces with the rise in temperature, so voltage-control become complicates. Some of the difficulties of PMs are high cost and handling while manufacturing [7]. The variable-speed operation of the WECS is essential for extracting maximum wind power. A modern control based tracking of power or torque helps to achieve best utilization of wind-energy [8, 9]. Control strategies are developed based on wind-velocity to acquire required shaft speed. These schemes involve high cost and reduced reliability for a small scale WECS. The current-vector of an interior type PMSG optimizes the operation at variable wind-velocity, which needs control of six active switches [10]. Switch-mode rectifier is also designed for PMSM

[11]. For standalone operation, load side converter voltage needs to be controlled in terms of amplitude and frequency [12].

This paper is summarized for the performance of the PMSG wind energy system and analyzed under different cases such as Effect of Nonlinear Loads and Power Electronics Devices. It is observed from the different literatures that a practical power system behaves in an unpredicted way.

Now these days the use of the nonlinear loads and switching of the modern devices and equipment as like Electric Cars, Microwaves, Induction Furnaces, Air conditioners, Electric Hammers and many mores, It cause fluctuations and deviations in the voltage and current waveform from its actual shapes. The power semiconductor devices are used to control and utilize the voltage and current waveform in a desired manner. The conversion of AC into DC and its opposite DC to AC happens in power system by the use of the power electronics switches.

These power electronics devices have their different-different on/off characteristics with their switching frequency. It is observed from the literatures that the semiconductor devices distort the voltage and current waveform and it is hard to achieve the desired accuracy as like the natural AC or DC waveform.

It is necessary to find out the impact of nonlinear loads and power electronics switches over the PMSG generation. Because the can not vary as like conventional fuels during the peaks and the undesired frequent maintenance would not be affordable in the case of PMSG wind energy systems.

This paper work discussion is based on the MATLAB/SIMULINK model and its generated output result. The different model for different cases and conditions is simulated and their output result has been analyzed for the PMSG generation side mainly.

2.0 System Model

In a PMSG based WECS the mechanical output of the wind turbine is directly fed into the rotor of the generator. Since it is a direct driven wind turbine system, gear box is not required. The ac output of the generator is given to the grid through a power electronic converter. The main components of the system are wind turbine, drive train, and PMSG.

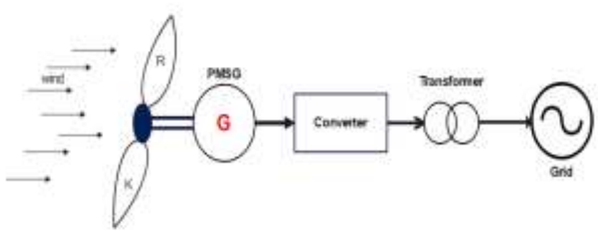

Fig-1 Grid-connected PMSG for direct-drive wind turbine

The captured power of the wind for a wind turbine is given by

$$P = 0.5\, C_P \rho A V^3 \quad (1)$$

The power coefficient C_P is defined as the ratio of actual power to the theoretical power as shown in figure-2. That is:

$$C_p = P_{actual} / P_{theoretical} \quad (2)$$

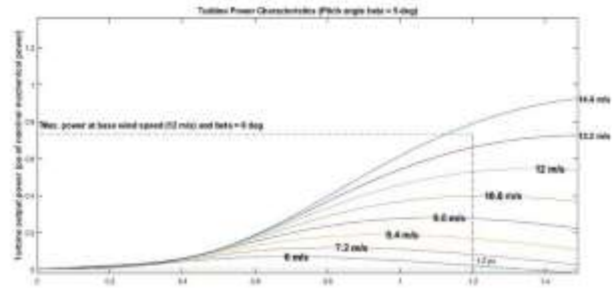

Fig-2 Power Coefficient of the Wind Turbine Model

Due to the permanent excitation a PMSG has no field windings, in which transient currents could be induced or damped respectively. As neither a damper nor field winding exists in a PMSG, so transient or sub-transient reactance can be defined for the PMSG. i.e.

Xd=Xd' =Xd"

Xq=Xq' =Xq"

Where Xd and Xq synchronous reactance, Xd' and Xq' transient reactance, Xd" and Xq" sub-transient reactance.

Numerous power-converter topologies are there for direct-drive PMSG based wind turbines as shown in figure-3.

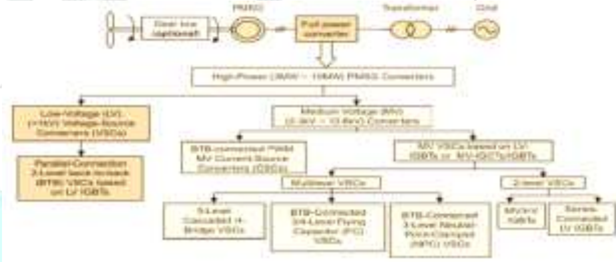

Fig-3 Power Converter Topologies for PMSG

3.0 Case-1: PMSG with Non Linear Loads

Ideally the electrical loads are indentified as like the pure resistive, pure inductive and pure capacitive loads. But in practical / real loads no load can exist in it`s pure form because of the material property. Therefore in this case study, the following type of the load combinations are performed and analyzed with MATLAB / SIMULINK model and it`s waveforms.

[R- load, RL- load, RC- load, RLC- load]

3.1 Block Diagram Model of System

The above types of the 3-phase nonlinear loads are connected through the PMSG one by one and constant wind speed is applied with constant pitch angle to the wind turbine.

All of the investigation of the simulation results is to be performed on the generation side and the generator rotor speed fluctuation has also monitored. A basic block diagram is shown in the figure-4.

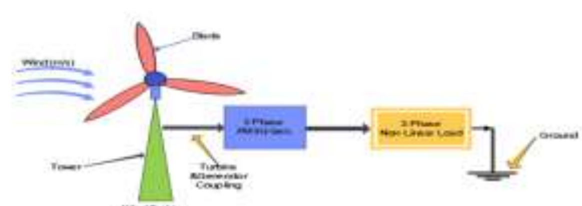

Fig-4 Block diagram of the Testing system

3.2 Simulation Results and Discussion

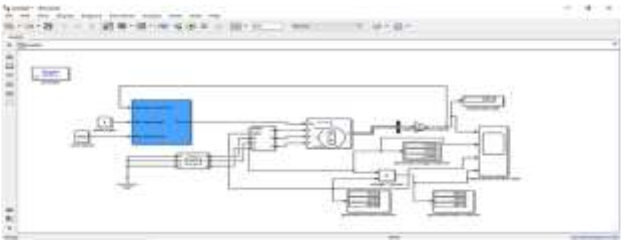

Fig-5 Simulink Model of the System

The Simulink model of the system has designed and tested for each 3-phase nonlinear loads to find out exactly what happens at the PMSG generation of voltage and current. The generator speed fluctuation is also monitored for each nonlinear load. And there simulation results have discussed below.

3.3 Performance of Different Load Condition

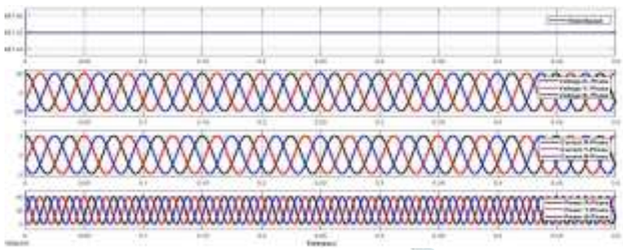

Fig-6 PMSG R-load output characteristics

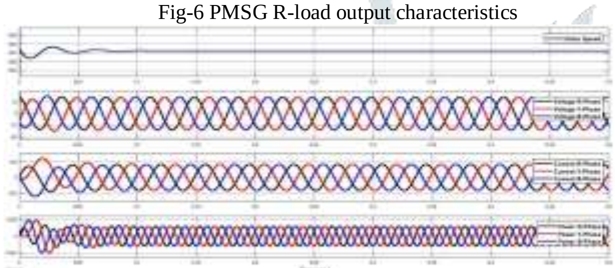

Fig-7 PMSG RL-Load output characteristics

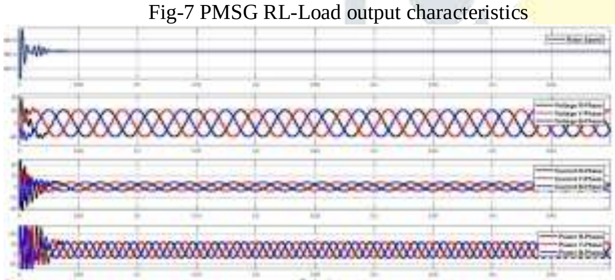

Fig-8 PMSG RC-Load characteristics

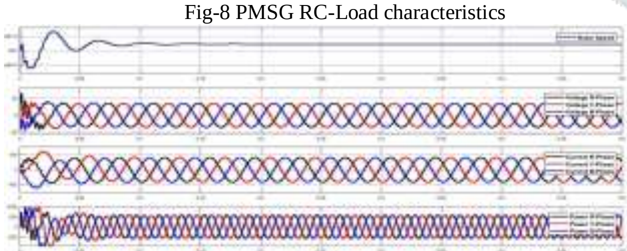

Fig-9 PMSG RLC-Load characteristics

Figure-5 shows the SIMULINK model testing the non linear loads impact on the PMSG generation and it`s rotor speed. As we can see from the SIMULINK results the different load condition as like 3-phase (R-load, RL-load, and RC-load, RLC-load) is tested one by one and its output waveforms are shown in figure-6 to figure-9.

It is clearly visible from the waveform in figure-6 that there is no effect on voltage, current and power generated from PMSG wind energy system. And also the rotor speed is always constant initially and finally. As we know that pure resistive load has a property that its voltage and current always be in the phase of each other.

In figure-7, it is observed that resistive inductive load is deviated the voltage, current and power with the fluctuation in PMSG rotor speed initially and then it is settled shortly. As we know that pure inductive load lags the current behind voltage, it can be seen from figure-7 that the current is reduced and voltage is increased.

From figure-8, it is observed that the resistive capacitive load is deviated the voltage, current, and power which generated from PMSG. It can also be observed from figure-8 that the PMSG rotor speed is fluctuating initially high in a chopping manner and then it is settled. As we know, the pure capacitive load has leading power factor, so it can see from figure-8 that the current is leading to the voltage of the PMSG generation.

From figure-9, it is observed that a practical load always have the different property of the material. So a practical load may have all the electrical property as like resistive, inductive and capacitive. Figure-9 shows a pure practical load effect on the PMSG generation. It is clearly visible from the waveform that the voltage, current and power is deviated from its original state as it is generated in pure resistive load. Rotor speed is also fluctuates in practical loads initially.

Finally, it has observed after investigating the figure-6 to figure-9 that in practical loads the generation of the PMSG voltage and current with rotor speed get affected due to their electrical property.

4.0 Case-2: PMSG for Different DC Loads with various types of Power Electronics Switches

The power electronics switches are playing a wide role in the renewable electricity generation and conversion. The power semiconductor devices have their own limitations and consequences in comparison conventional generation. The switching losses and waveform distortion and harmonics content are the main drawback with power electronics switches. But today`s world is introducing the AC/DC generation and transmission together because of advancement in power electronics switches. The behavior and turn on/off characteristics with their switching frequency are different for different power devices. Here in this case study PMSG wind energy conversion is introduced with AC/DC conversion load side and generation side with different power semiconductor switches.

The following devices are taken one by one in this case study with their MATLAB/SIMULINK model and output waveform, a comparative analysis is to be done with their output waveform.

[Power Diode, GTO, IGBT, MOSFET]

4.1 Block Diagram Model of System

The various power semiconductor switches are used in the power system to utilize the power generated from the wind power plant. Various types of power devices as like converter, inverter and cyclo converter e.t.c. are made from power electronics switches.

These switches have their different- different on/off and tuning characteristics. So if we use these switches, it may cause voltage and current fluctuations on generation side of the wind power plant. It may also cause fluctuations on the generator rotor speed.

So here we will take above power semiconductor switches one by one to make dc-converter for dc-practical loads and results of the simulation model will be analyzed.

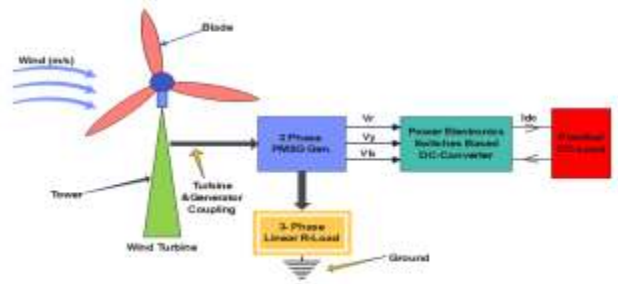

Fig-10 Block Diagram of the Testing System

4.2 Simulation Results and Discussion

4.2.1 Performance of Power Diode Bridge

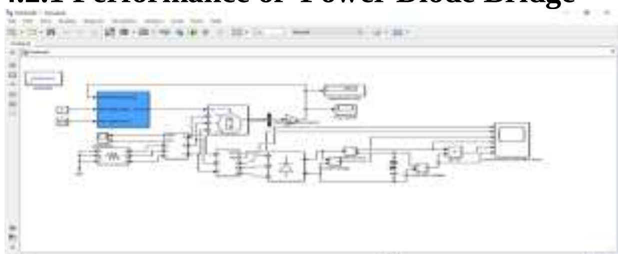

Fig-11 Simulink Model of Power Diode Bridge with different load conditions

The SIMULINK model of the case study-2 is designed taking power Diode Bridge for the conversion of the 3-phase AC voltage and current in to DC voltage and current and different DC nonlinear load in connected through that bridge. A 3-phase R-load is also connected through the PMSG generation side to investigate the impact of the switches over the voltage and current with different non linear DC-loads. There output results have been discussed in the following figures.

4.2.1.1 Resistive-load

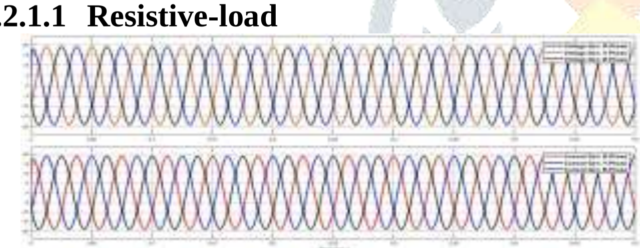

Fig-12 PMSG generation side output characteristics under dc R-load connected to Diode Bridge

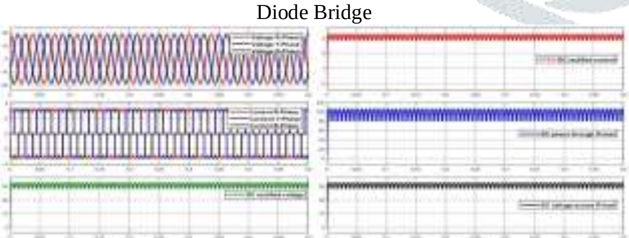

Fig-13 Diode Bridge rectifier connected R-load DC output characteristics

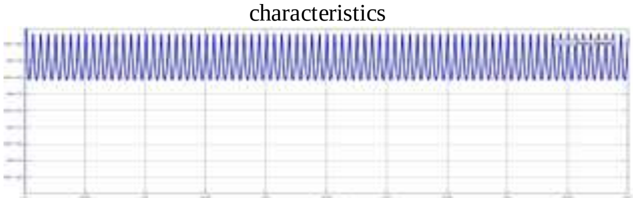

Fig-14 PMSG Rotor Speed Characteristics

Figure-11 shows the SIMULINK model of the system in which the Power electronics switch Power Diode is taken in account first. In figure-12 to figure-14, it is given the simulation result of the system with R-load.

As we know that pure resistive load has no impact upon the voltage and current of the PMSG generation as we discussed earlier and also we know that Power diode switch is an uncontrolled device. So it makes the natural switching and does not affect the voltage and current of the PMSG generation. It is clearly visible from figure-12 that there is no effect on voltage and current of the PMSG.

From figure -13 it is observed that the PMSG voltage and current at the injection side of the Power Diode Bridge is distorted. Figure-14 is just showing the effect of Power Diode Bridge over the PMSG rotor speed fluctuation.

4.2.1.2 Resistive-Inductive-load

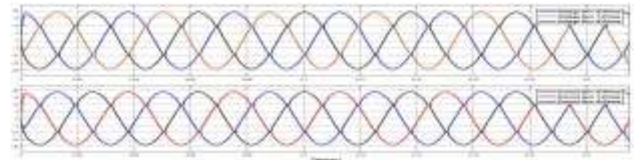

Fig-15 PMSG generation side output characteristics under dc RL-load connected to Diode Bridge

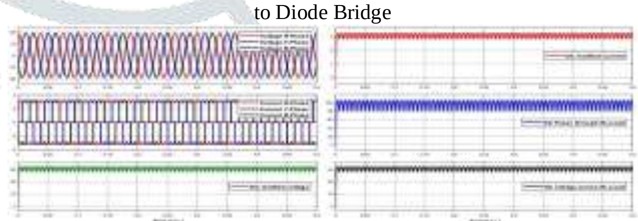

Fig-16 Diode Bridge rectifier connected RL-load DC output characteristics

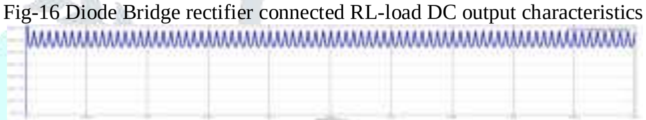

Fig-17 PMSG Rotor Speed Characteristics

From figure-15 to figure-17, it is the simulation results of the DC resistive inductive load connected to the Power Diode Bridge. It can be observed from the figure-15 that there is no impact of the RL-load over the generation of the voltage and current of the PMSG. From figure-16 it is clearly visible that the PMSG voltage and current injection at the power diode bridge is distorted more than DC-load. From figure -17, it is clearly visible that the PMSG rotor speed in fluctuating as like the DC R-load rotor speed fluctuation.

4.2.1.3 Resistive-Capacitive-load

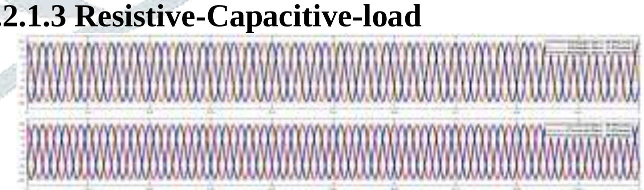

Fig-18 PMSG generation side output characteristics under dc RC-load connected to Diode Bridge

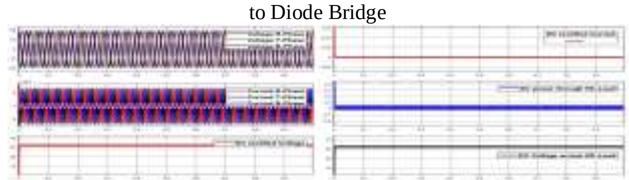

Fig-19 Diode Bridge rectifier connected RC-load DC output characteristics

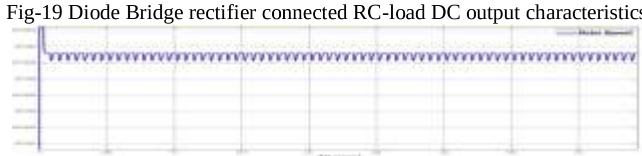

Fig-20 PMSG Rotor Speed Characteristics

From figure-18 to figure-20, these are the simulation results of the resistive capacitive load connected to the power diode bridge.

In figure-18, it is observed that there is a minor fluctuation in voltage and current. Figure-19 is showing the PMSG voltage and current distortion at the injection side of the power diode bridge. It is clearly visible in figure-20 that PMSG rotor speed fluctuates more that the R and RL-load as shown in previous discussions.

4.2.1.4 Resistive-Inductive-Capacitive-load

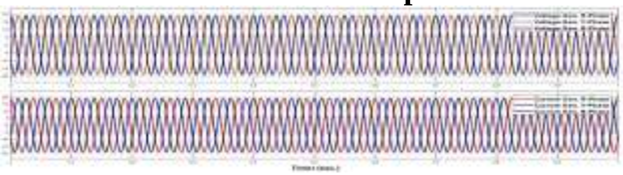

Fig-21 PMSG generation side output characteristics under dc RLC-load connected to Diode Bridge

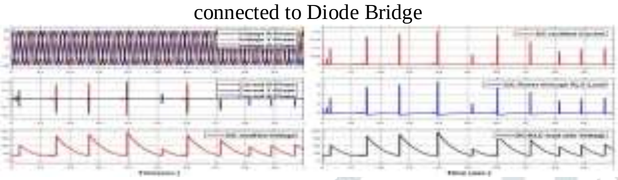

Fig-22 Diode Bridge rectifier connected RLC-load DC output characteristics

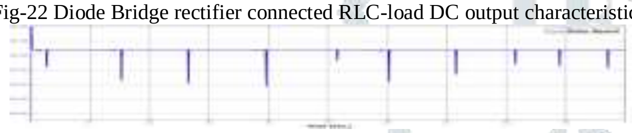

Fig-23 PMSG Rotor Speed Characteristics

From figure-21 to figure-23, these are the simulation results of DC RLC-load connected to power Diode Bridge. From Figure-21, it is observed that there is a minor fluctuation in voltage and current. Figure-22 is showing the PMSG voltage and current distortion at the injection side of Power Diode Bridge. It is investigated that the injection current is totally deformed from the PMSG actual current generation.

Although it is clearly visible from figure-23 that rotor speed fluctuation of the PMSG during practical load is in a chopping way on a particular period and then there is no fluctuation. The sequence is repeating for the rotor speed fluctuation.

4.2.2 Performance of Power GTO Bridge

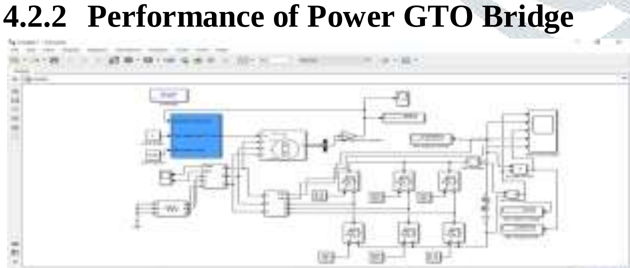

Fig-24 Simulink model of GTO Bridge with different load conditions

After investigating the power Diode Bridge and power Thyristor Bridge, The SIMULINK model of the case study-2 is designed taking power GTO Bridge for the conversion of the 3-phase AC voltage and current in to DC voltage and current and different DC nonlinear load in connected through that bridge.

A 3-phase R-load is also connected through the PMSG generation side to investigate the impact of the switches over the voltage and current with different non linear DC-loads. There output results have been discussed in the following figures.

4.2.2.1 Resistive-load

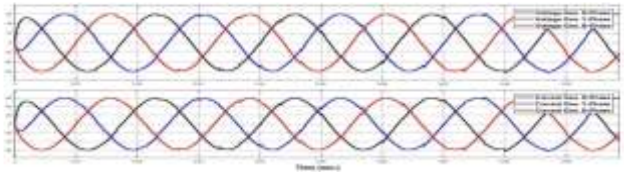

Fig-25 PMSG generation side output characteristics under dc R-load connected to GTO Bridge

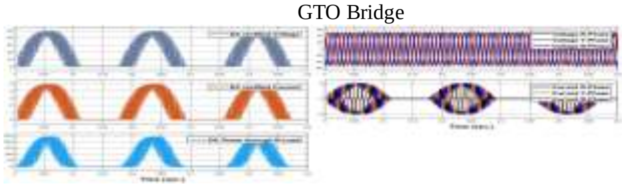

Fig-26 GTO Bridge rectifier connected R-load DC output characteristics

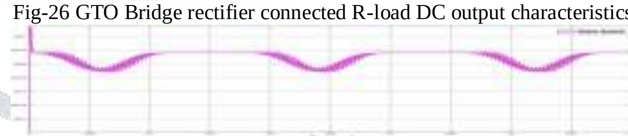

Fig-27 PMSG Rotor Speed Characteristics

The simulation model shown in figure-24 is the PMSG connected GTO Bridge. To find out the effect and impact of GTO Bridge on the PMSG voltage and current generation. The figure-25 to figure-27, these are the simulation results of DC resistive load connected to power GTO Bridge. From figure-25, it is observed that the PMSG voltage and current is distorted in a notching form the complete simulation period. In figure-26, it is clearly visible that the PMSG voltage and current is completely distorted from its original shapes at the injection side of the GTO Bridge. From figure-27, it can be said that the PMSG rotor speed is fluctuating, rising and falling variation from its nominal rotor speed.

4.2.2.2 Resistive-Inductive-load

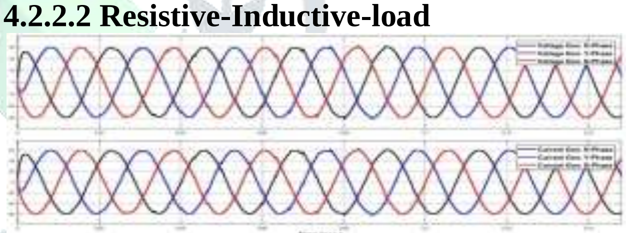

Fig-28 PMSG generation side output characteristics under dc RL-load connected to GTO Bridge

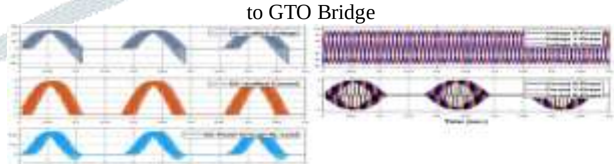

Fig-29 GTO Bridge rectifier connected RL-load DC output characteristics

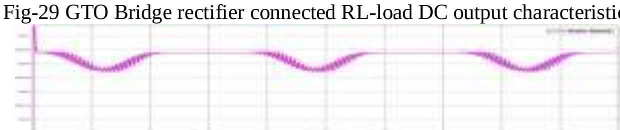

Fig-30 PMSG Rotor Speed Characteristics

Figure-28 to figure-30, these are the simulation results of DC resistive inductive load connected to power GTO Bridge. From figure-28, it is observed that the PMSG voltage and current is distorted in a periodic form. From figure-29, it can be said that the PMSG voltage and current is distorted as similar in figure-26 at the injection side of GTO Bridge. But the DC rectified voltage and power through resistive inductive load is deviated down side from its nominal shapes. From figure-30, it is observed that the PMSG rotor speed fluctuates and vary down side more than the rotor speed fluctuation shown in figure-27.

4.2.2.3 Resistive-Capacitive-load

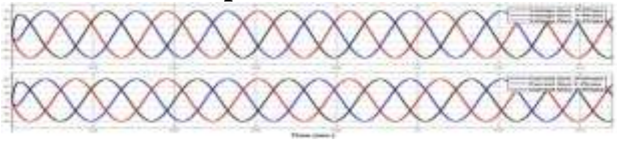

Fig-31 PMSG generation side output characteristics under dc RC-load connected to GTO Bridge

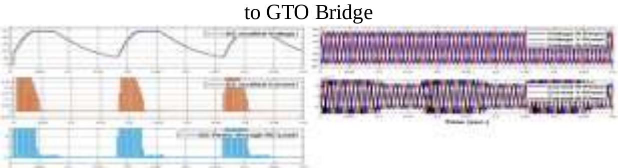

Fig-32 GTO Bridge rectifier connected RC-load DC output characteristics

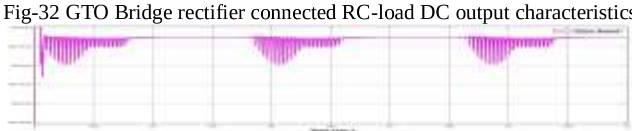

Fig-33 PMSG Rotor Speed Characteristics

Figure-31 to figure-33, these are the simulation results of the DC resistive capacitive load. From figure-31, it is observed that there is no distortion in PMSG voltage and current for complete simulation period. From figure-32, it is observed that the distortion in PMSG voltage and current at the injection side of GTO Bridge is more than resistive and resistive inductive load. DC rectified current and power has capacitor switching voltage effect. From figure-33, it is clearly visible that the PMSG rotor speed has the fluctuation in a form of capacitor switching. The notching in waveform can be seen easily.

4.2.2.4 Resistive-Inductive-Capacitive-load

Fig-34 PMSG generation side output characteristics under dc RLC-load connected to GTO Bridge

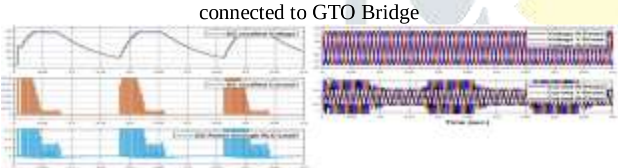

Fig-35 GTO Bridge rectifier connected RLC-load DC output characteristics

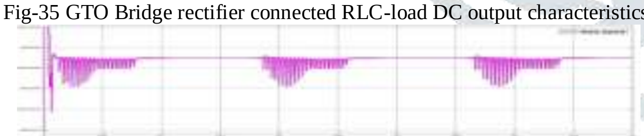

Fig-36 PMSG Rotor Speed Characteristics

Figure-34 to figure-36, these are the simulation results of the resistive inductive capacitive load. From figure-34, it is observed that the PMSG voltage and current is not distorted. From figure-35, it is observed that that the PMSG voltage and current distortion is similar to resistive capacitive load. The DC rectified current and power shown in figure-35 is different from figure-32. From figure-36, it can be said that the PMSG rotor speed fluctuation is similar as like rotor speed fluctuation is shown in figure-33.

4.2.3 Performance of Power IGBT Bridge

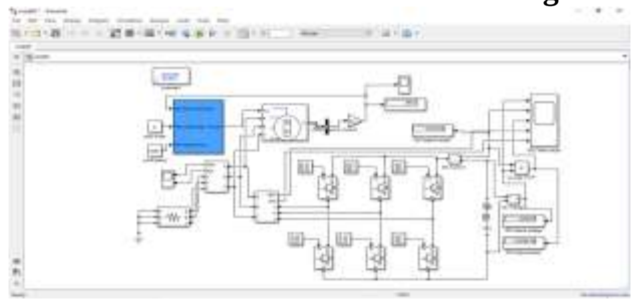

Fig-37 Simulink model of IGBT Bridge with different load conditions

Now after investigating the power Diode Bridge, power Thyristor Bridge and power GTO Bridge, The SIMULINK model of the case study-2 is designed taking power IGBT Bridge for the conversion of the 3-phase AC voltage and current in to DC voltage and current and different DC nonlinear load in connected through that bridge. A 3-phase R-load is also connected through the PMSG generation side to investigate the impact of the switches over the voltage and current with different non linear DC-loads. There output results have been discussed in the following figures.

4.2.3.1 Resistive-load

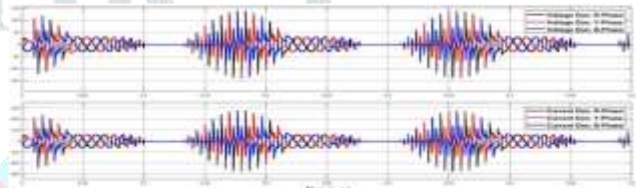

Fig-38 PMSG generation side output characteristics under dc R-load connected to IGBT Bridge

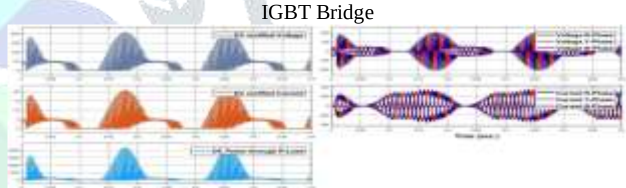

Fig-39 IGBT Bridge rectifier connected R-load DC output characteristics

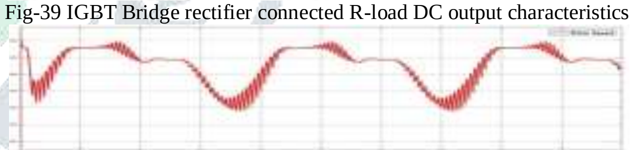

Fig-40 PMSG Rotor Speed Characteristics

Figure-37 shows the simulation model of the PMSG wind energy system connected to Power IGBT Bridge. Figure-38 to figure-40, these are the simulation results of DC R-load connected to Power IGTB Bridge. From figure-38, it is observed that the PMSG voltage and current distorted more than the Power Diode, Power Thyristor and Power GTO Bridge.

From figure-39, it is observed that the PMSG voltage and current is distorted at the injection side of IGBT Bridge.

From figure-40, it is clearly visible that the rotor speed fluctuation is more than the previous studies.

4.2.3.2 Resistive-Inductive-load

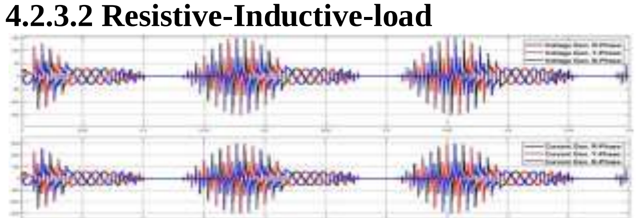

Fig-41 PMSG generation side output characteristics under dc RL-load connected to IGBT Bridge

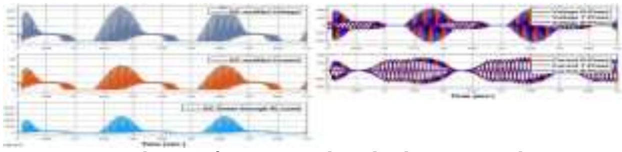

Fig-42 IGBT Bridge rectifier connected RL-load DC output characteristics

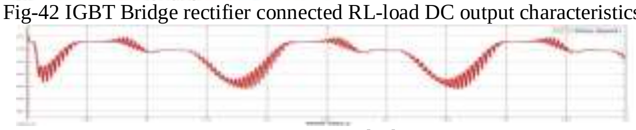

Fig-43 PMSG Rotor Speed Characteristics

Figure-41 to figure-43, these are the simulation results of DC resistive inductive load connected to IGBT Bridge. It can be observed that the distortion in PMSG voltage and current in figure-38. From figure-42, it is clearly visible that the fluctuation in PMSG voltage and current at the injection side of IGBT Bridge is similar as shown in figure-39. From figure-43, it is observed that the PMSG rotor speed fluctuation is similar as shown in figure-40.

4.2.3.3 Resistive-Capacitive-load

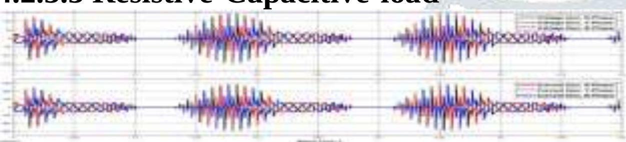

Fig-44 PMSG generation side output characteristics under dc RC-load connected to IGBT Bridge

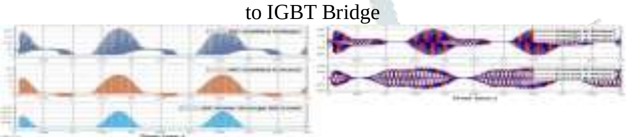

Fig-45 IGBT Bridge rectifier connected RC-load DC output characteristics

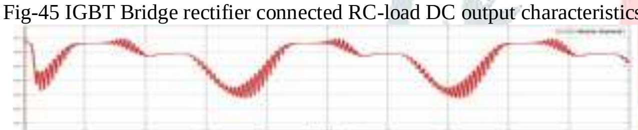

Fig-46 PMSG Rotor Speed Characteristics

Figure-44 to figure-46 shows the simulation results of DC resistive capacitive load connected to power IGBT Bridge. From figure-44 and figure-46, it is observed that PMSG voltage and current, rotor speed fluctuation is similar as shown in R-load and RL-load.

But in figure-45, it is observed that the DC rectified current and power is different from R and RL-load. The current is deviated down side from its nominal shapes. The DC power shown in figure is constant and not deviated from its nominal shapes.

4.2.3.4 Resistive-Inductive-Capacitive-load

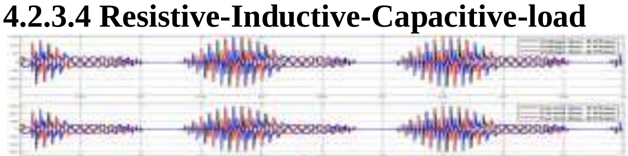

Fig-47 PMSG generation side output characteristics under dc RLC-load connected to IGBT Bridge

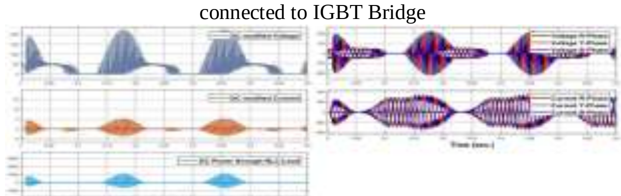

Fig-48 IGBT Bridge rectifier connected RLC-load DC output characteristics

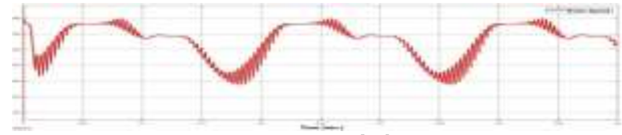

Fig-49 PMSG Rotor Speed Characteristics

Figure-47 to figure-49, these are the simulation results of DC resistive inductive capacitive load connected to IGBT Bridge. From figure-47 and figure-49, it is observed that the PMSG rotor speed, voltage and current is distorted as like shown in figure-44 and figure-46. From figure-48, it is observed that the DC rectified current and power is distorted differently as shown in figure-42 and figure-45.

4.2.4 Performance of Power MOSFET Bridge

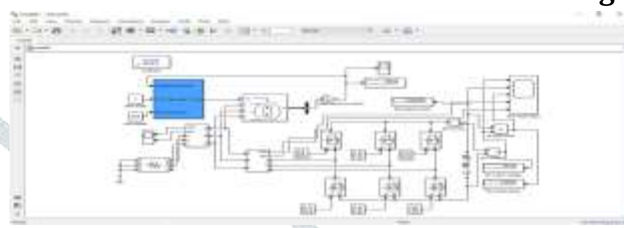

Fig-50 Simulink model of MOSFET Bridge with different load conditions

Finally after investigating the power Diode Bridge, power Thyristor Bridge, power GTO Bridge and power IGBT Bridge, The SIMULINK model of the case study-2 is designed taking power MOSFET Bridge for the conversion of the 3-phase AC voltage and current in to DC voltage and current and different DC nonlinear load in connected through that bridge. A 3-phase R-load is also connected through the PMSG generation side to investigate the impact of the switches over the voltage and current with different non linear DC-loads. There output results have been discussed in the following figures.

4.2.4.1 Resistive-load

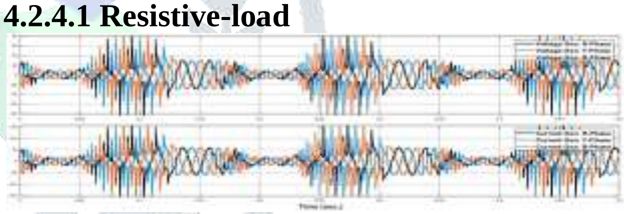

Fig-51 PMSG generation side output characteristics under dc R-load connected to MOSFET Bridge

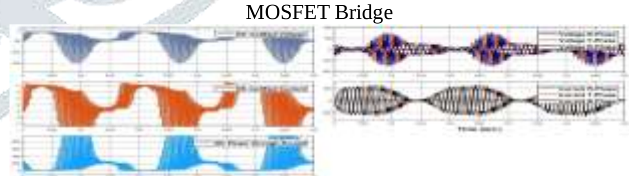

Fig-52 MOSFET Bridge rectifier connected R-load DC output characteristics

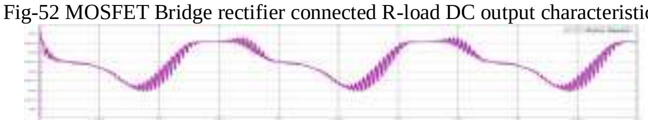

Fig-53 PMSG Rotor Speed Characteristics

Figure-50 shows the SIMULINK model of the PMSG wind energy system connected to power MOSFET Bridge.

Figure-51 to figure-53, these are the simulation results of the DC R-load connected to power MOSFET Bridge. From figure-51, it is observed that the voltage and current distortion and fluctuation in PMSG generation is more than power IGBT Bridge. From figure-52, it is also clear that the PMSG voltage and current at the injection side of MOSFET is more than previous discussion. Figure-53 shows the PMSG rotor speed fluctuation in intermittent and frequent in nature.

4.2.4.2 Resistive-Inductive-load

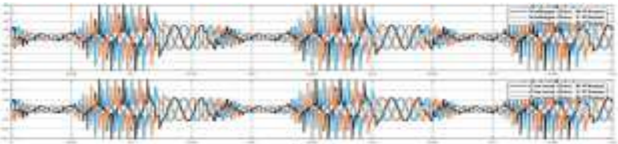

Fig-54 PMSG generation side output characteristics under dc RL-load connected to MOSFET Bridge

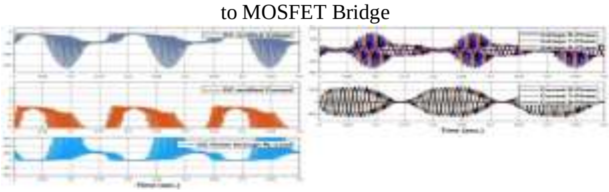

Fig-55 MOSFET Bridge rectifier connected RL-load DC output characteristics

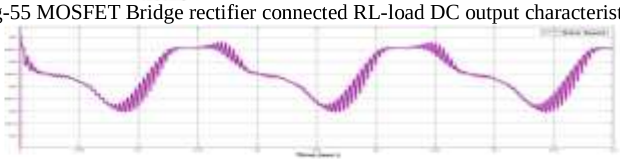

Fig-56 PMSG Rotor Speed Characteristics

Figure-54 to figure-56, these are the simulation results of DC resistive inductive load connected to power MOSFET Bridge. From figure-54, it is observed that PMSG voltage and current fluctuation is similar as shown in figure-51.

From figure-55, it is observed that the PMSG voltage and current distortion is almost similar at the injection side of MOSFET Bridge as shown in figure-55. From figure-56, it is clearly visible that rotor speed fluctuation is frequent and intermittent in nature.

4.2.4.3 Resistive-Capacitive-load

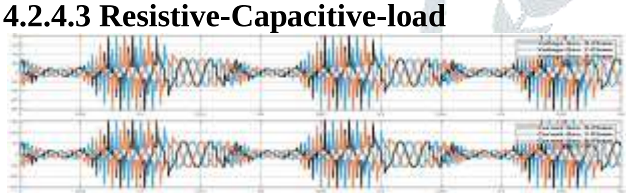

Fig-57 PMSG generation side output characteristics under dc RC-load connected to MOSFET Bridge

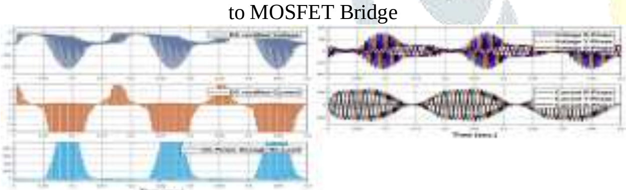

Fig-58 MOSFET Bridge rectifier connected RC-load DC output characteristics

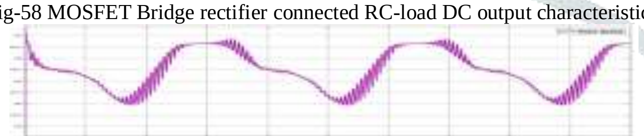

Fig-59 PMSG Rotor Speed Characteristics

Figure-57 to figure-59, these are the simulation results of DC resistive capacitive load connected to power MOSFET Bridge. From figure-57 and figure-59, it is clearly visible that rotor speed fluctuation and PMSG voltage, current distortion is almost similar as shown in resistive and resistive inductive load. From figure-58, it is observed that the DC rectified current and DC power discussed is deviated from its nominal shape as discussed in resistive and resistive inductive load.

4.2.4.4 Resistive-Inductive-Capacitive-load

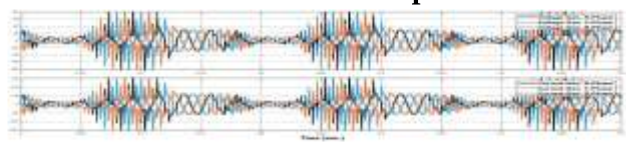

Fig-60 PMSG generation side output characteristics under dc RLC-load connected to MOSFET Bridge

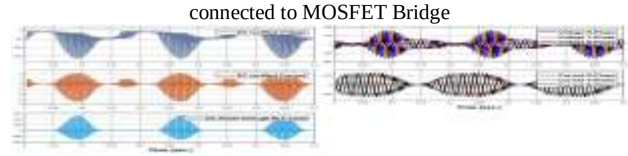

Fig-61 MOSFET Bridge rectifier connected RLC-load DC output characteristics

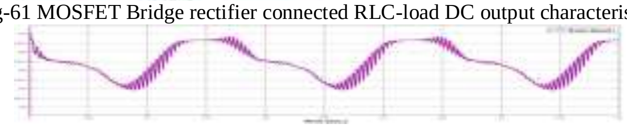

Fig-62 PMSG Rotor Speed Characteristics

Figure-60 to figure-62, these are the simulation results of DC resistive inductive capacitive load connected to power MOSFET Bridge. From figure-60 and figure-62, it is observed that the PMSG rotor speed and voltage, current fluctuation is almost similar. In figure-61, it is observed that DC rectified current and power is distorted and deviated from its nominal shapes as shown in resistive and resistive inductive load.

5 CONCLUSION

The simulation model and its output waveforms results are discussed in case study-1 and case study-2. Case-1 was effect of 3-phase nonlinear load on voltage, current and the rotor speed of the PMSG wind energy system. Case-2 was the effect of the power electronics switches on voltage, current and the rotor speed of the PMSG wind energy system.

From case study-1, it is discussed that the nonlinear load switching in PMSG wind energy system causes voltage and current fluctuation with its rotor speed fluctuation. It is observed that the switching of purely resistive load does not result any fluctuation and distortion in PMSG voltage, current with its rotor speed. But in case of resistive-inductive, resistive-capacitive and resistive-inductive-capacitive loads, it is observed that fluctuation and distortion in PMSG voltage, current and its rotor speed happens and results accordingly their electrical property.

From case study-2, it is discussed that the power electronics switches as like Power Diode, Power GTO, IGBT and Power MOSFET have the different-different on/off characteristics and switching frequency, switching losses in electrical circuit. The uses of these devices are also different for different application. It has been discussed in case study-2 that the Power Diode has very results very less fluctuation and distortion in PMSG voltage, current and its rotor speed. We know that Power Diode is a unidirectional, uncontrolled and natural commutated device. While in case of Power Thyristor Bridge, it is discussed that the PMSG voltage, current and rotor speed fluctuate and distort more in comparison to Power Diode Bridge. We know that Power Thyristor is a semi controlled device. Power MOSFET result much fluctuation and distortion in PMSG voltage, current and its rotor speed than the Power Thyristor, Power GTO and Power IGBT devices, because its switching frequency and losses are higher in comparison to the other devices. The PMSG rotor speed, voltage and current fluctuation and distortion are comparable to each other of the different power semiconductor devices discussed over. Power Thyristor Bridge is also tested but in this paper the result discussion of it’s not given.

From above discussion, it can be said that the effect on PMSG voltage and current with its rotor speed results because of uneven loading of the non linear loads and switching of different power electronics devices in PMSG wind energy system. Mostly it can be said that a power system always has a practical nonlinear load and different power electronics switches. So it makes fluctuation and distortion in voltage, current and rotor speed of PMSG wind energy system.

REFERENCES

[1] Sindhya, K., Manninen, A., Miettinen, K., and Pippuri, J. (2017). Design of a Permanent Magnet Synchronous Generator Using Interactive Multiobjective Optimization. IEEE Transactions on Industrial Electronics, 64(12), 9776–9783.

[2] Dehghan, S. M., Mohamadian, M., and Varjani, A. Y. (2009). A new variable-speed wind energy conversion system using permanent-magnet synchronous generator and Z-source inverter. IEEE Transactions on Energy Conversion, 24(3), 714–724.

[3] Nakano, M., Kometani, H., and Kawamura, M. (2006). A study on eddy-current losses in rotors of surface permanent-magnet synchronous machines. IEEE Transactions on Industry Applications, 42(2), 429–435.

[4] Qiao, W., Qu, L., and Harley, R. G. (2009). Control of IPM synchronous generator for maximum wind power generation considering magnetic saturation. IEEE Transactions on industry applications, 45(3), 1095–1105.

[5] Semken, R. S., et al., (2012). Direct-drive permanent magnet generators for high-power wind turbines: Benefits and limiting factors. IET Renewable Power Generation, 6(1), 1–8.

[6] Bernardes, T., Montagner, V. F., Gründling, H. A., and Pinheiro, H. (2014). Discrete-time sliding mode observer for sensorless vector control of permanent magnet synchronous machine. IEEE Transactions on industrial electronics, 61(4), 1679–1691.

[7] Po-Yen Chen, Kai-Wei Hu, Yi-Guang Lin, Chang-Ming Liaw, "Development of a Prime Mover Emulator using Permanent-Magnet Synchronous Motor Drive", IEEE Transactions on Power Electronics, 2017, IEEE Early Access Articles, 99.

[8] Tan, K., and Islam, S. (2004). Optimum control strategies in energy conversion of PMSG wind turbine system without mechanical sensors. IEEE transactions on energy conversion, 19(2), 392–399.

[9] Chinchilla, M., Arnaltes, S., and Burgos, J. C. (2006). Control of permanent-magnet generators applied to variable-speed wind-energy systems connected to the grid. IEEE Transactions on energy conversion, 21(1), 130–135.

[10] Morimoto, S., Nakayama, H., Sanada, M., and Takeda, Y. (2005). "Sensorless output maximization control for variable-speed wind generation system using IPMSG", IEEE Transactions on Industry Applications, 41(1), 60–67

[11] Soong, W. L., and Ertugrul, N. (2004). Inverterless high-power interior permanent-magnet automotive alternator.IEEE Transactions on Industry Applications, 40(4), 1083–1091.

[12] Bhende, C. N., Mishra, S., and Malla, S. G. (2011). Permanent magnet synchronous generator-based standalone wind energy supply system. IEEE Transactions on Sustainable Energy, 2(4), 361–373.

[13] www.Wikipedia.com

[14] www.Researchgate.com

[15] www.Google.com

[16] www.Sciencedirectia.com

[17] www.seciencedirectia.com