International Journal of Electrical Engineering & Emerging Technology, Vol. 05, No. 02, DEC 2022, pp 6-10

Design of PI Controller for Wind Energy Conversion System Using MATLAB/Simulink

[1] Ghulam Murtaza*, [2]Javed Jamshed Korai
[1]Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah, Pakistan
[2]Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan
Corresponding author e-mail: (murtazasahito63@gmail.com[1], javedjamshed28@gmail.com[2])

[Received on: 24/08/2022 **Accepted on:** 05/10/2022 **Published on:** 11/12/22**]**

Abstract—**The purpose of this paper is to design a controller for back-to-back converter that will guarantee steady functioning of a wind turbine under fluctuating wind speed. Two stages of this process are carried out by several subsystems. The initial phase is performed by the mechanical component that transfers the wind's energy to a rotational mass then, it is expelled in the form of electrical energy in the second stage by the electrical subsystem. This study focuses on wind turbines with fully rated back-to-back converters are operated by Permanent Magnet Synchronous Generators (PMSG).This converter is divided in two sides: This converter has a Grid Side Converter (GSC) that interacts with the network and a Machine Side Converter (MSC) that manages the generator. The electrical grid is integrating numerous types of distributed energy resources, interest in the control system of power converters is growing. Hence, a variety of control strategies have been examined; however, in the present work, the converter control system is based on conventional PI controllers. The acquired results have verified how the controller in the model operates. The complexity inherent in existing control systems has been reduced in the presented controller, which may also be constructed practically at a significant cost savings."**

***Index Terms*—PMSG, GSC, MSC back-to-back converter**

I. INTRODUCTION

THE energy demands have increased rapidly as a result of growing industry and an increasing worldwide population, negative trend, and the quick depletion of conventional energy supplies. The growth in acid rain, greenhouse gases, and deteriorating public health are linked to massive use of fossil fuels that causes pollution burning every day throughout the world. A solution for this by using renewable energy, an issue can be solved. Resources like wind energy by offering extremely effective energy conversion devices called power converters reduce costs and simple to use control mechanisms [1-2].

The Systems for converting wind energy turn the kinetic energy brought on by wind speed into electrical energy for grid feeding. The blades of wind turbines, Its rotor is attached to the shaft of the generator, catch the energy. Two stages of this process are carried out by several subsystems.

Subsystem transforms it into electrical energy in the second stage. The blades are responsible for capturing the wind's energy. In this paper, PMSG - integrated WECSs are used. In comparison to other generating technologies, PMSG are further capable, have a better Weight/power ratio, and do not require electrical excitation [3]. Due to these characteristics, many writers have thought about using the PMSG in a variety of applications, including gas turbines, hydropower, diesel generators, and wind power systems among others [4-7].

The PMSG is connected to a fully rated power converter via its stator, which serves as a conduit b/w the generator & the grid. The generator's magnets produce a steady magnetic field, without the need for further electrical excitation. Because it offers a strong power-to-weight ratio, this kind of generator is an appropriate option for the new generation of offshore wind turbines. Due to this, power converters have become increasingly prevalent in the power grid [8]. Their adaptability in managing energy flow enables the connecting of various power sources or energy storage systems with the AC grid [9-11].

Higher voltage levels in semiconductors have been acquired over the decade, and costs have decreased [12]. Power electronic devices have been widely implemented as a result of this progress, particularly as a means of integrating renewable energy sources into the AC grid [13-14]. For these applications, a back-to-back converter is typically employed; this topology involves connecting the DC sides of two AC/DC converters. Each AC side of a two-level converter contains three high-frequency switch branches, three of which are connected to different phases of a 3-Φ electrical system. There are additional topologies, such as MLI, however they are outside the purview of this Paper even though they represent interesting structures.

There are various semiconductor types as well, but IGBTs are currently the most popular due to their high commutation frequency and ampere carrying capacity. A capacitor bank separates the electrical frequency from both the AC sides and acts as a DC link between the two AC sides. A conventional Proportional Integral controller (PI) is then used to control the converters and control the voltage (V) of the dc link. The regions where wind turbines are operated determine the definition of control objectives. These are closely related to the wind speed and one can identify three operation regions according to the wind speed. they are related to several potential technical solutions for WECS.

II. RESEARCH METHODOLOGY

Three main components of WECS are the wind turbine, the electrical generator, and the power-electronic converter The PMSG or Doubly-Fed Induction Generator are the two types of electrical generators that are most frequently employed. The direct driven PMSG is the most prevalent machine type in literature, accounting for 42% of all other types, and has been shown to be an excellent choice for WECS. It has a wide range of speed control and a number of benefits, including a higher system efficiency and reduced maintenance due to the lack of a gearbox and field excitation. A bidirectional power converter allows the PMSG to be connected to the grid through a back-to-back converter with two PWM voltage source converters, a machine side converter, and a grid side converter.

A. Wind Turbine

Horizontal Axis Wind Turbine (HAWT):
One of the well-known types of wind turbines is the HAWT. A HAWT's primary shaft is fixed to the ground in a horizontal orientation, making it N/60. As a result, the frequency(f) of the generated emf will be specified differently from a wind turbine with a vertical axis. In simpler terms, a horizontal axis wind turbines rotating axis is positioned horizontal to the ground. The majority of the world's wind energy is now generated by massive 3-bladehorizontal axis wind turbines when the blades are positioned around the tower. A generator and rotor shaft on these turbine towers need to face the wind. The sizes of the horizontal axis wind turbines range from 100W to 100KW.In order to capture the most wind power, these HAWTs are typically used in streamlined air conditions with steady airflow and direction.
Simulink Model for Wind Turbine is shown in Fig: 1

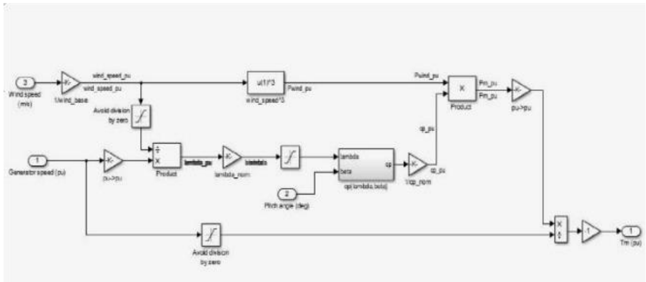

Fig: 1 Simulink Model for Wind Turbine

B. Permanent Magnet Synchronous Generator

DC current excitation in the rotor winding is needed for wound-field synchronous machines. On the generator shaft, slip rings and brushes are used to achieve this excitation. However, there are a number of drawbacks, including the need for routine maintenance and removal of the carbon dust. A different strategy is brushless excitation, which substitutes permanent magnets for electromagnets.

The rotor's permanent magnets are used to generate the excitation field. The rotor surface, the interior of the rotor, or all three can be secured by permanent magnets. Reduced air gap between the stator and rotor to increase performance and lower the need for rare earth magnets.

The rotor's rotational velocity, or more specifically, its "angular velocity," determines the frequency of the output voltage as well as the synchronous machine contains two magnetic poles on the rotor, one each for the N Pole and the S Pole. That is to say, the gadget has two independent poles or one pair of poles that are oriented north to south and are referred to as pole pairs. One cycle of induced emf is produced every entire rotation of the rotor, or 360 degrees, A cycle will therefore repeat every 360 degrees at this frequency. When we increase the number of magnetic poles to four (two pairs of poles), two cycles of induced emf will be produced for every rotation of the rotor. Since one cycle of induced emf is produced by each pair of poles, Therefore, the number of pole pairs, P, will equal the number of emf cycles generated in a single rotor rotation. As a result, if P/2 is used to denote the number of cycles per rotation in proportion to the number of poles and rotors.

$$Frequency(f) = \frac{P}{2} * \frac{N}{60} = \frac{PN}{120} Hz \tag{1}$$

The frequency of the supply voltage controls the angular velocity of synchronous motors, hence N is called the synchronous speed. In order to generate the required frequency output, either 50Hz or 60Hz of induced, a "P"-pole synchronous generator's prime mover (turbine blades) must rotate at a high rate. Fig.2 displays a model of a permanent magnet synchronous generator.

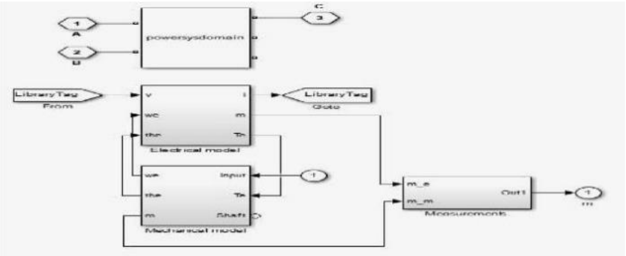

Fig: 2 Simulink Model for Permanent Magnet Synchronous Generator

C. Power Electronic Converter

“Wind power begins to have substantial effects on the electrical grid system as the penetration of the grid and wind turbine power levels rise. Therefore, in order to be more suitable for integration into the power grid, the features of the wind power plant must be enhanced. To do so, more sophisticated generators, power electronic systems, and control strategies must be introduced. One of the more appealing solutions is a PMG with a full-scale back-to-back converter. Back-to-back converters had a significant impact on the world of power systems, improving system dependability and providing a means of synchronizing renewable energy sources with the grid. Voltage source converters and current source converters are two broad categories for the design of back-to-back converters. The current source converters &

voltage source converters both have a common dc link with a capacitor and an inductor, respectively. The grid-side output filter, step-up transformer, and inverter are used to join the DC link to the power grid.”

D. Back-to-Back Converter

“The following characteristics of the BTB converter are advised for this application: a) voltage regulation in the DC connection; b) the capacity to modify active power; and c) the ability to regulate reactive power. It is customary for one VSC to regulate the voltage level in the DC-link and the other to regulate the active power flow in order to simplify the control law. Any of the two tasks can be developed by either converter. VSC1 and VSC2 regulate DC-link voltages and active power flows, respectively, in this case. Reactive power is controlled for the associated VSC. Each VSC has similar control architecture, with outer loops controlling DC-link voltage and active/reactive power and inner loops controlling current. The DC-link voltage will be indirectly driven to the desired setting by the BTB converter as it regulates the d component to the desired operating point. The system parameters must be used to precalculated the d references (d*). PI controllers coupled with inner loops calculate this reference.”

E. PI Controller

“Since a constant voltage is a crucial need for the power converter, DC-link voltage regulation is crucial and suitable for the majority of BTB structure applications. Industrial operations still favor the PI controller after the DC-link voltage has reached a certain working point and stabilized, despite the introduction of highly developed control concepts in recent years. Control-block for VSC1 is used to demonstrate the control strategy for 1-ϕ and 3-ϕ BTB converters (VSC2 has a similar control configuration). The outer and inner loops, which are coupled in a cascade, are the primary building elements of the control block. Since it determines the amplitude of the input current, the inner loop ensures asymptotic tracking, while the outer loop controls the reactive power and DC-link voltage, maintaining a steady DC-link voltage requires power from the outer voltage loop. In order to achieve voltage regulation, the device must be carefully constructed. Parameters for PI Controller are shown in Table 1.”

TABLE I: Parameters for PI Controller.

Controller	K_p	K_i
MSC I	0.65	2.27
MSC II	0.94	2.27
MSC I	0.63	2.36
MSC II	0.98	2.36

F. Machine Side Converter

“In the generator side converter's control objectives in the turbine's control system, active power control as well as pursuing its maximum achievable value are considered. An illustration of the MSC control loop. The other control objectives are handled by the d axis loop, While the q axis loop controls the generator's speed and torque. The reference voltage signal of the d axis (Vsd′) is produced by the PI controller by comparing and subtracting the d axis current of the generator (isd) and the reference current (isd) as shown in the d axis loop.”

When a power is stabilized, w_m and i_q are correlated, and any change in w_m will change i_q.In order to provide the q axis reference current (i_{sq}*)), a PI controller compares the nominal rotational speed of the generator with its instantaneous rotational speed (w_m). When the PI controller is used to determine the reference voltage of the q axis, the generator stator's q axis current is compared to its reference value ($V_{sq'}$).

Finally, the decoupled voltages,* and V_{sq}*

$$V_{sd}^* = V_{sd}' - W_e L_q i_{sq} \qquad (2)$$

$$V_{sq}^* = V_{sq}' - W_e L_q i_{sd} + W_e \psi_f \qquad (3)$$

G. Grid Side Converter

“Managing the grid-side converter The DC link voltage must be kept at a predetermined reference level as one of this converter's control objectives. To regulate the amount of reactive power that is injected into the grid at a specific reference point. The DC link voltage is controlled by the d axis loop, while the reactive power injection is managed by the q axis loop. The GSC must be able to keep the DC link voltage within the converter's authorized operating range. In addition, considering that the grid side converter's d axis current, active power, and DC link voltage are all directly related, A PI controller can be used to control the d axis current using the output of the DC link voltage controller. Using a PI controller and a comparison of the d axis current with its reference signal.”

$$V_{dI}^* = V_d' - W_s L_f i_q + V_d (4)$$

$$V_{qI}^* = V_q' - W_s L_f i_d \qquad (5)$$

The d axis reference voltage signal ($V_{d'}$) is derived the q axis control loop controls the reactive power of the inverter. Therefore, The GSC converter must inject an appropriately equivalent reactive power to correct changes in the voltage at PCC Voltages decrease whenever transient failures occur on the grid side or whenever overvoltages are detected there. Accordingly, the transformed reactive power (Q) is compared to a reference value (Qref), and a PI controller is used for the axis current reference.

III. SIMULATION AND RESULTS

“The model for the PI Controller for Wind Energy Conversion system is made using Simulink.". The Simulink model is made up of a PI controller, a PMSG, a direct-drive wind turbine, and a back-to-back converter. A variety of blocks from the Simulink library are used to make a complete model. In the research methodology, the parameters of the wind turbine, PMSG, and back-to-back converter are already described. Trial and error is used to determine the K_i and K_P coefficients of the PI Controllers."

A. Simulink Model of PI Controller for WECS

In this study, a technique for the design and control of variable speed wind turbine generators employing direct drive synchronous generator coupled to the grid through Back-to-Back converter is presented. After accurately modelling the mechanical and electrical system components, the Back-to-Back converter and DC link are sized. The converter controllers were then designed and the parameters were determined through a process of trial and error tweaking. Finally, the wind turbine generator's capabilities with the destined converter at variable speed are assessed. Simulink Model of PI Controller for WECS is shown in Fig: 3N

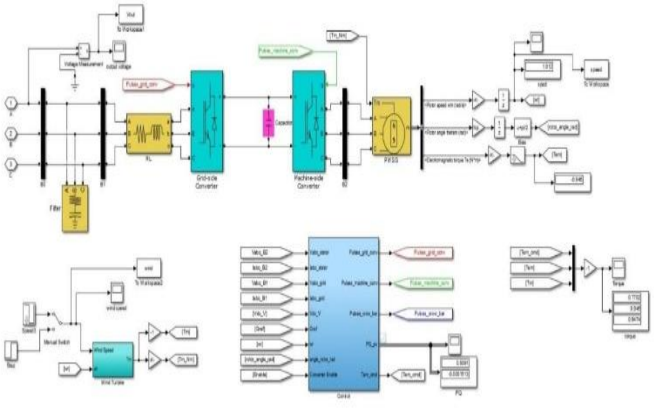

Fig: 3 Simulink Model of PI Controller for WECS

CASE STUDY:

In this case study wind speed is varied from 12m/sec to 8m/sec and parameters of PI controller KP and Ki are tuned for machine side and grid side converters such that output should be stable at varying wind speed, the following figures shows wind speed, rotor speed, Torque (Mechanical, Electromagnetic, Controlled), Output Voltage, Voltage across Capacitor, Active and Reactive Power respectively.

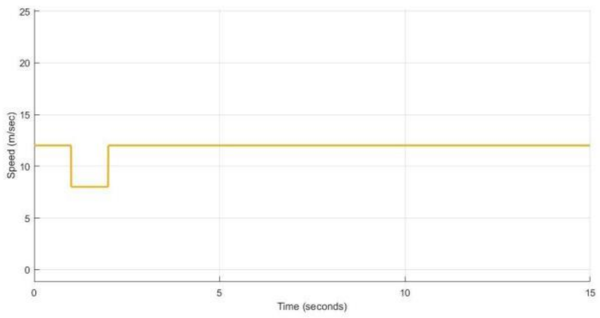

Fig: 4 Wind Speed

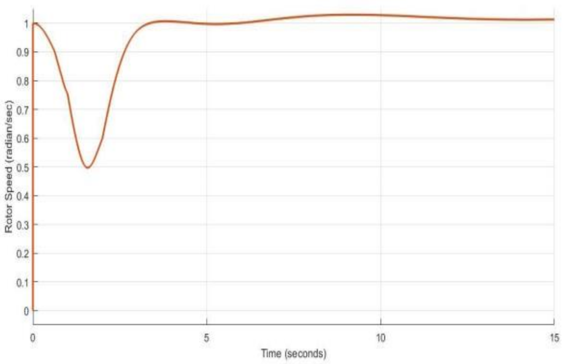

Fig: 5Rotor Speed

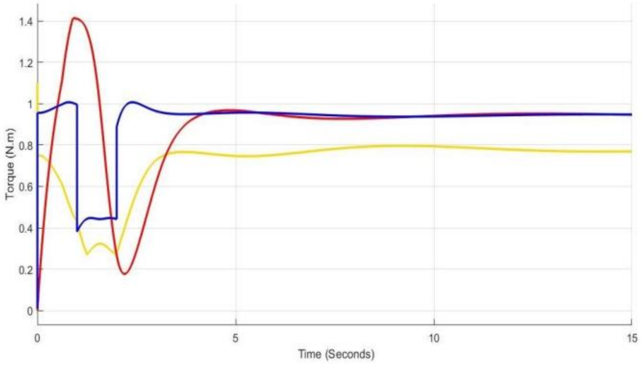

Fig: 6 Torque (Mechanical, Electromagnetic, Controlled)

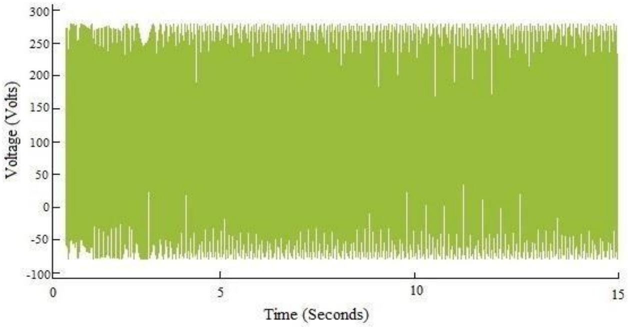

Fig: 7 Output Voltage

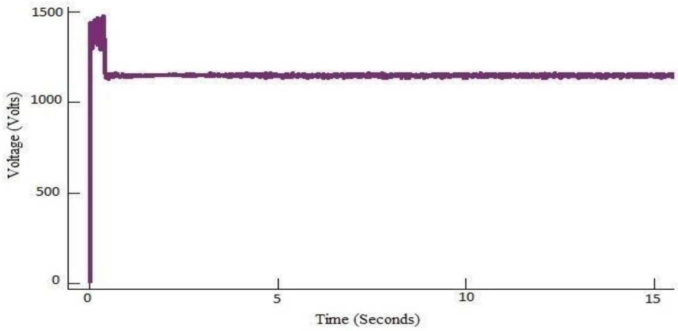

Fig: 8 Voltage Across Capacitor

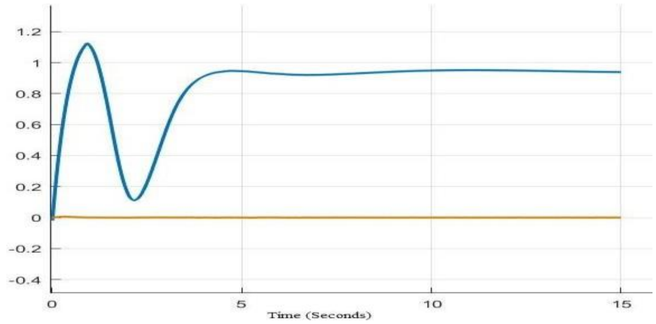

Fig: 9 Active and Reactive Power

IV. CONCLUSION

“A PI controller for the Back-to-Back converter in the Wind Energy Conversion System is presented in this research article. A simple PI control strategy for a variable speed Direct Drive PMSG wind turbine is presented in this paper. In this control scheme, the DC link voltage is regulated by controlling the generator side converter, and Variable speed wind turbines can be controlled to maintain a constant DC link voltage under fluctuating winds with the proposed controllers. Power injection into the grid is managed by the GSC.The proposed control strategy was successful in transferring electricity from the generator side to the grid. The results obtained have confirmed the stability of the operation under changing wind speeds. The complexity inherent in other control schemes has been removed by the presented controller, which can be constructed practically with a significant cost and processing amount reduction.”

REFERENCES

[1] lasnovic Z, Margeta J. Renew Sust Energy Review vol. 1, "Vision of 100% renewable electricity future". 15, n°. 4, pp.1873–1884, 2011.

[2] Chowdhury SP, Chowdhury S, Crossley PA. UK. “scenario for the regional business of Active Distribution Networks S.Z.. networks with renewable distributed generators”. International Journal of Electrical Power & Energy Systems, volume 33, number 7, 2011; pages 1251–1255[3] Z. Chen and H. Li. overview and comparison of several wind generator systems. Rene

[3] H. Li and Z. Chen. a description of the different types of wind generators and a comparison of each.. Renewable Power Generation, IET, 2(2):123 –138, June 2008. 1

[4] S.Z. Vijlee, A. Ouroua, L.N. Domaschk, and J.H. Beno. Generator Sets with Direct Coupled Gas Turbine Permanent Magnets for Primary Power Generation on Electric Ships. In Electric Ship Technologies Symposium. (ESTS ‘07). IEEE, pages 340 –347, May 2007. 1

[5] A. Binder and T. Schneider. A study of permanent magnet synchronous generators for converting waste energy into usable energy 2005, page 10 of the European Conference on Power Electronics and Applications. 1 \s[6] A.M. Osheiba, E.S. Abdin, T.S. Radwan, and M.A. Rahman. An isolated diesel engine permanent magnet synchronous generator's modelling and controller design

[6] M.A. Rahman, A.M. Osheiba, T.S. Radwan, and E.S. Abdin. modelling and controller design for a standalone permanent magnet synchronous generator powered by a diesel engine. IEEE Transactions on Energy Conversion, 11(2):324 –330, June 1996. 1.

[7] I. Schiemenz and M. Stiebler. modelling and controller design for a standalone permanent magnet synchronous generator powered by a diesel engine. In Electric Machines and Drives Conference (IEMDC 2001). IEEE International, pages 872 –877, 2001. 1

[8] B. Singh, B.N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D.P. Kothari. An analysis of AC-DC converters with three-phase increased power quality. IEEE Transactions on Industrial Electronics, 51(3):641 – 660, June 2004. 2

[9] J.M. Carrasco, L.G. Franquelo, J.T. Bialasiewicz, E. Galvan, R.C.P. Guisado, Ma.A.M. Prats, J.I. Leon, and N. Moreno- A Survey of Power Electronic Systems for Renewable Energy Sources Integration into the Grid, Alfonso. IEEE Transactions on Industrial Electronics, 53(4):1002 –1016, June 2006. 2

[10] Jos´e Luis Dom´ınguez-Garc´ıa, Oriol Gomis-Bellmunt, Llu´ıs TrillaRomero, and Adri`a Junyent-Ferr´e. induction generator generator wind turbine indirect vector control. Computers & Mathematics with Applications, 64(2):102 – 114, 2012. 2

[11] M. Liserre, T. Sauter, and J.Y. Hung. Future Energy Systems: Using industrial electronics, integrating renewable energy sources into the smart power grid. IEEE Industrial Electronics Magazine, 4(1):18 –37, March 2010.

[12] Power Electronics and Motor Drives: Recent Development and Future Perspective, B.K. Bose. In February 2009, IEEE Transactions on Industrial Electronics, 56(2):581-588.

[13] A.V. Timbus, M. Liserre, R. Teodorescu, and F. Blaabjerg. Overview of Distributed Power Generation System Control and Grid Synchronization. IEEE Transactions on Industrial Electronics, Oct. 2006, 53(5):1398–1409.

[14] Andreas Sumper, Jos'e Luis Dom'nguez-Garc'a, Oriol Gomis-Bellmunt, and Fernando D. Bianchi. A review of power oscillation damping supported by wind power. Reviews of Renewable and Sustainable Energy, 16(7):4994–5006

[15] J.J. Korai, M.A. Mahar, A.S. Larik, F.U.R. Soomro, I. Ali, and M.S. Awan, 2020. Cascaded H-Bridge Sub-Multilevel Inverter Design Level Shifted Multicarrier Techniques. ICT Design Engineering Technological Science Journal, pp. 23–28.