5

POWER CONVERTER TOPOLOGY OF SEPIC-FED BRUSHLESS DC MOTOR DRIVE FOR IMPROVEMENT OF POWER QUALITY

Mr. Devang Parmar, Dr.Alpesh Adesara & Mr Harshit Palan

ABSTRACT: The article presents an overview of various control schemes and Power Factor Correction techniques used for Brushless DC (BLDC) motor drives. It aims to provide a basis for choosing the appropriate Power Factor Correction topology for a specific application. The study compares the performance of different AC-DC converter-based Power Factor Correction techniques, such as Buck, Boost, Cuk, and SEPIC convertor fed through BLDC drive. A bridgeless SEPIC converter is used as the front-end for DC link voltage control and PFC operation, operating in discontinuous inductor current mode for a simple control scheme. The BLDC motor uses electronic commutation for low-frequency operation and reduced switching losses in the voltage source inverter (VSI). The bridgeless topology also reduces conduction losses and increases efficiency. The study also considers bi-directional extension converter and unipolar inverter topologies. The proposed Power Factor Correction Converter techniques show improvement in worldwide power quality measures, such as reduced AC mains current harmonics, close unity power factor, and reduced speed and torque fluctuations. PSIM Version 9.0.3 software has been used for simulation purpose.

KEYWORDS

Brushless Direct Current, Voltage Source Inverter, Total Harmonic Distortion, Power Factor Correction Permanent magnet brushless DC motor, SEPIC.

Introduction

The Brushless Direct Current Motor (BLDC) is rapidly gaining popularity and is being used in various industries such as electrical devices, manufacturing automation equipment, automotive, aerospace, medical devices, and instrumentation. BLDC motors are electronically commutated, eliminating the need for brushes. In comparison to brushed DC motors and induction motors, BLDC motors offer several benefits, including higher speed and torque, better dynamic response, high efficiency, silent and smooth operation, low maintenance costs, and a longer operating life. BLDC motors can be controlled with high-speed ranges and closed-loop speed control, making them highly reliable and energy efficient. BLDC motors come in a range of ratings, from fractional horsepower to several horsepower, and are used in a variety of applications, including automobiles, washing machines, computer drives, and toys.

Permanent magnet materials used in PMBLDC Motors come in three types: Alnicos, Ferrites, and rare earth magnets. Alnicos are suitable for applications with low current and high voltage, due to their low coercive magnetizing intensity and high residual flux density. Cost-sensitive applications, such as air conditioners, refrigerators, and compressors, make use of Ferrites. Rare earth magnets, made of samarium-cobalt and neodymium-ion-boron, are favored for their high residual flux and high coercive magnetizing intensity. (Singh &Singh, 2010)

CONSTRUCTION OF BRUSHLESS DC MOTOR

A Permanent Magnet Brushless DC Motor (PMBLDC) is a type of DC motor that employs permanent magnets in its rotor, while the stator acts as the magnetic field's return path. The magnets are devoted to the internal surface of the cylindrical steel stator. The rotor, on the other hand, is composed of multiple commutator segments and brushes.

BLDC motors are commonly controlled using a three-phase power electronics device and are commutated based on the rotor position having an interval of 60º. Unlike brushed motors, which utilize brushes to commutate the armature current, PMBLDC motors eliminate the problems of

commutator segment sparking and brush wear, making them a more efficient option.

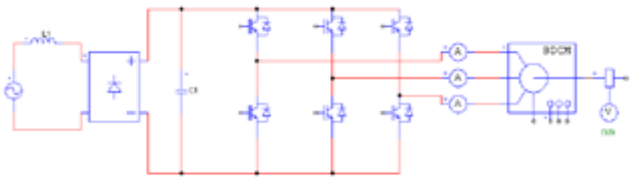


FIGURE1: Block Diagram of Single-Phase Diode Bridge Rectifier fed Voltage Source Inverter based BLDC Motor drive [2]

The speed and torque of a BLDC motor can be controlled by armature voltage control, armature rheostat control, and chopper control. However, it's not possible to control its speed by the flux control method since the flux remains constant. These control methods have uses in certain applications where a reduced base speed is necessary, but the motor cannot function beyond this base speed.

A. BLDC motor modeling

To control the speed of a BLDC motor, modeling is necessary and different power electronics-based modeling is essential. Mathematical equations can be used to model each component of the BLDC drive, and their combination characterizes the complete BLDC drive. The modeling of the speed controller is critical as the performance of the system depends on it. The speed error can be calculated as the difference between the reference speed ($\omega r^*(k)$) and the actual rotor speed ($\omega r(k)$) at the kth instant of the period interval. The formula for the speed error is,

$$\omega_e(k) = \omega_r^*(k) - \omega_r(k) \; .... (1)$$

This speed error is processed through a speed controller to take desired control signal.

B. Speed controller

There are several categories of speed controllers, such as PI, sliding mode, fuzzy pre-compensated PI, hybrid fuzzy PI, NN-based, and Neuro-fuzzy. The most used controller is the PI controller. The output of a PI controller at a given time interval is determined by controlling the drive.

$$T(k) = T(k-1) + K_P\{\omega_e(k) - \omega_e(k-1)\} + K_I\omega_e(k) .... (2)$$

The output of a PI controller at the kth instant, T(k), is given by the equation, where K_P and K_I are the proportional and integral gains of the controller, respectively.

Let $I^* = T(k)/K_b$, where K_b is the back-EMF constant of the Motor.

C. Reference current generation

The reference three phase currents of the motor winding are denoted by i_a, i_b, i_c for phases a, b, c, respectively. For duration of 0 to 60 degrees, the reference currents can be given as,

$$i_a^* = I^*,\; i_b^* = -I^*,\; i_c^* = 0 ... (3)$$

Correspondingly, the reference currents through other periods can be generated, which follows the trapezoidal voltage of respective phases. These reference currents are associated with sensed phase currents to generate the current errors as,

$$\Delta I_a = (i_a^* - i_a),\; \Delta I_b = (i_b^* - i_b),\; \Delta I_c = (i_c^* - i_c) ... (4)$$

D. Current Controller

The current controller generates a switching sequence for the Voltage Source Inverter by connecting the current error of each phase with a carrier waveform of a fixed frequency. The current errors ΔIa, ΔIb, ΔIc are amplified by a gain k1 before being associated with the carrier waveform g(t). The switching sequence is determined based on the logic applied to phase as give below equations.

Condition-1 $k_1\, \Delta i_a > g(t)$ then $T_a = 1$

Condition-2 $k_1\, \Delta i_a \leq g(t)$ then $T_a = 0$

CONTROL STRATEGIES OF SINGLE PHASE DBR FED VSI BASED BLDC MOTOR

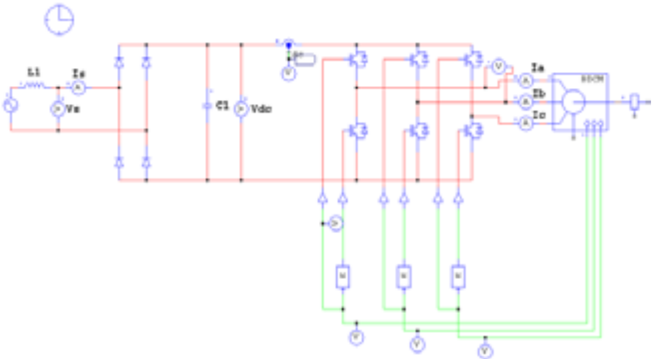


FIGURE 2: PSIM Simulation of BLDC Motor Single Phase Diode Bridge Rectifier fed Voltage Source Inverter

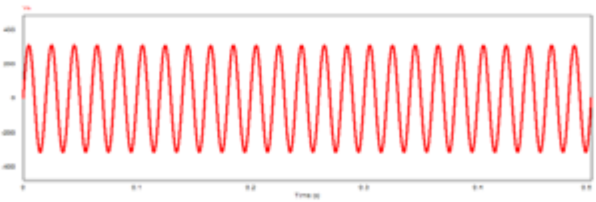


FIGURE 3: Source Voltage of BLDC Motor.

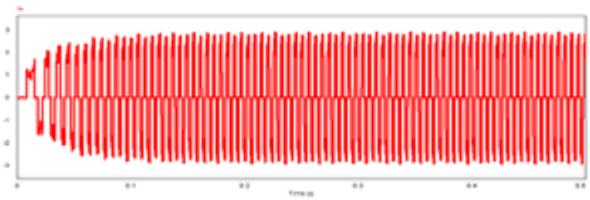


FIGURE 4: Current Waveform of Phase A(Ia)

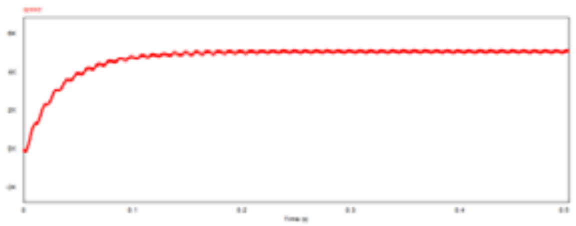


FIGURE 5: Speed waveform of BLDC motor

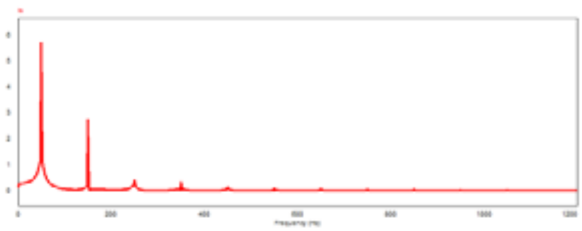


FIGURE 6: FFT Analysis of Supply current (Is)

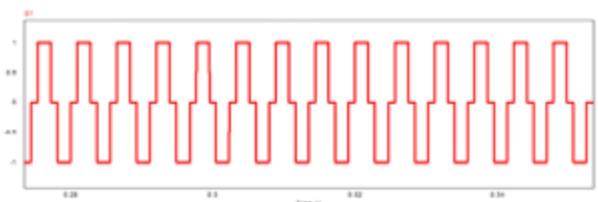


FIGURE 7: Getting pulse g(t)

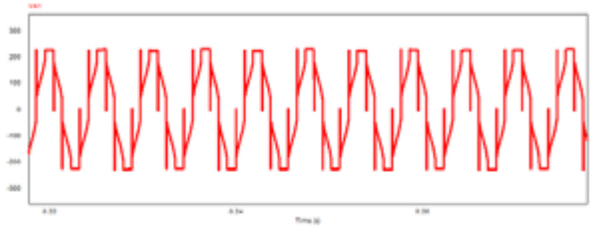


FIGURE 8: Output voltage of BLDC Motor

By simulation result analysis of single-phase, diode bridge rectifier fed VSI based BLDC Motor is Input Source Voltage 230V & Input Source Current (Is) 3.74 A. The Fundamental frequency is 50 Hz. Total Harmonic Distortion of (Is) 62.53% Power Factor is 0.84.

BUCK CONVERTER CONTROL STRATEGIES OF VSI BASED BLDC MOTOR

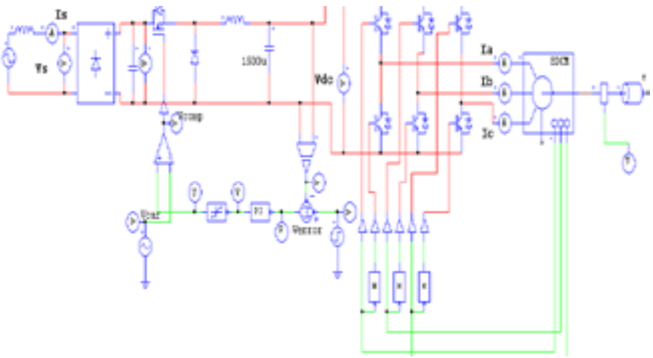


FIGURE 9: PSIM Simulation of BLDC Motor Drive with Buck converters.

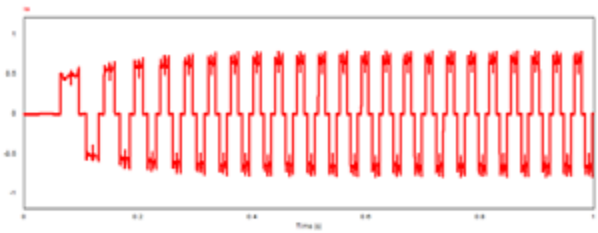


FIGURE 10: Current Waveform of Phase A(Ia)

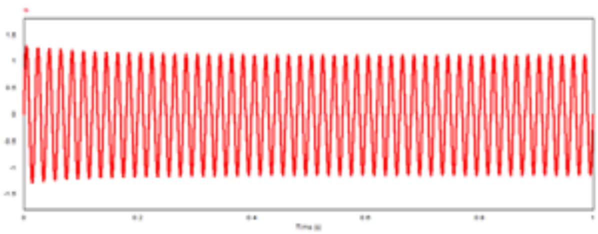


FIGURE 11: Input Source Current

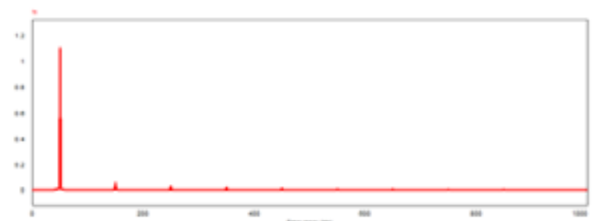


FIGURE 12: FFT Analysis of Source Current

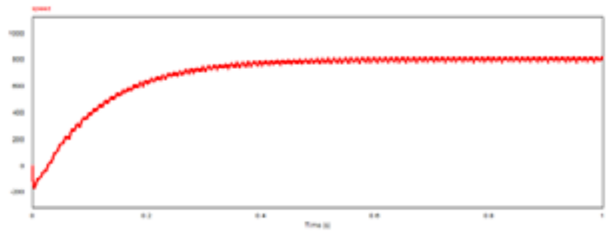


FIGURE 13: Speed Waveform of BLDC Motor

By Simulation Result analysis of BLDC Motor Drive Buck Converter is Source Voltage (Vs) 230V Source Current (Is) 0.8A.The Fundamental frequency is 50 Hz. Total Harmonic Distortion of (Is) 8.39%, Power Factor is 0.9963.

Load (%)	THD(I) (%)	PF
10	11.93	0.9924
20	11.58	0.9929
30	11.18	0.9934
40	10.77	0.9939
50	10.37	0.9943
60	9.97	0.9948
70	9.58	0.9952
80	9.18	0.9956
90	8.78	0.9959
100	8.39	0.9963

TABLE 1: Power Quality Parameters at Different Load Condition for Buck Converter fed VSI Based BLDC Motor.

Vs	THD(I) (%)	PF
170	7.2	0.9973
180	7.5	0.9970
190	7.7	0.9968
200	8.0	0.9966
210	8.2	0.9964
220	8.3	0.9963
230	8.5	0.9961
240	8.7	0.9960

Table 2: Power Quality Parameter with Input AC Voltage Variation for Buck Converter fed VSI based BLDC Motor

BOOST CONVERTER CONTROL STRATEGIES OF VSI BASED BLDC MOTOR

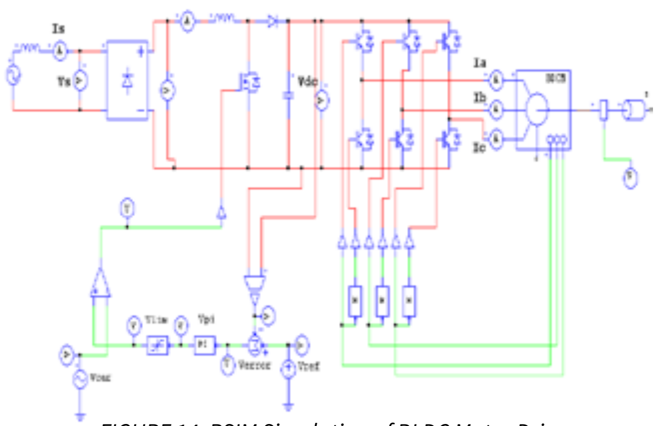


FIGURE 14: PSIM Simulation of BLDC Motor Drive Boost converter

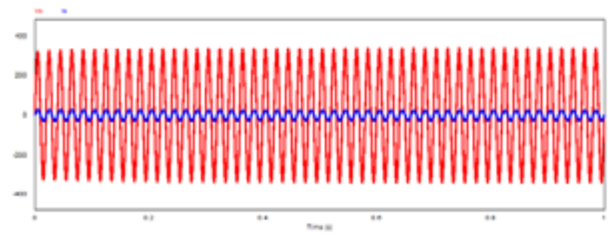


FIGURE 15: Supply current and voltage waveform.

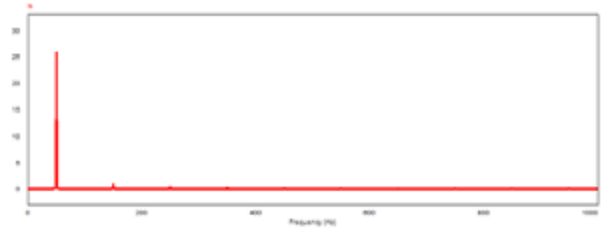


FIGURE 16: FFT Analysis of Source Current

The PSIM Simulation Result demonstrations that using Boost Converter the THD of Source current is decreased to 4.8% and Power Factor is 0.98.

Load(%)	THD(I) (%)	PF
10	5.09	0.99
20	5.07	0.99
30	5.01	0.99
40	4.96	0.99
50	4.95	0.99
60	4.90	0.99
70	4.86	0.99
80	4.84	0.99
90	4.81	0.99
100	4.77	0.99

Table 3: Power Quality Parameters at Different Load Condition for Boost Converter fed VSI Based BLDC Motor.

Vs	THD(I) (%)	PF
170	4.67	0.99
180	4.77	0.99
190	4.81	0.99
200	4.86	0.99
210	4.86	0.99
220	4.87	0.99
230	4.89	0.99
240	4.90	0.99

Table 4: Power Quality Parameter with Input AC Voltage Variation for Boost Converter fed VSI based BLDC Motor

SIMULATION ANALYSIS FOR CUK CONVERTER FED BLDC MOTOR

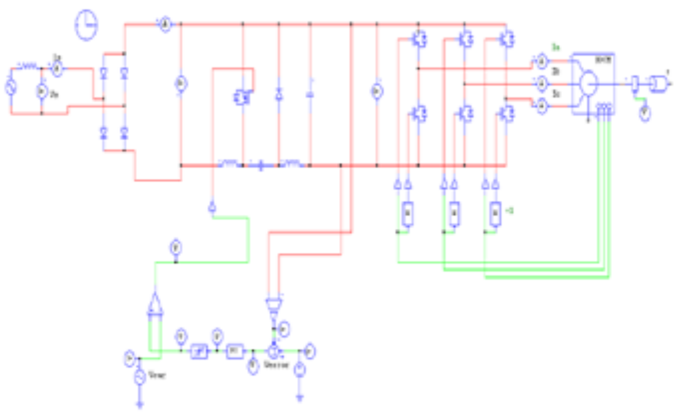


FIGURE 17: PSIM Simulation of BLDC Motor Drive Cuk converters

Load (%)	THD(I) (%)	PF
10	6.11	0.99
20	5.73	0.99
30	5.63	0.99
40	5.63	0.99
50	5.22	0.99
60	4.88	0.99
70	4.55	0.99
80	4.54	0.99
90	4.26	0.99
100	3.98	0.99

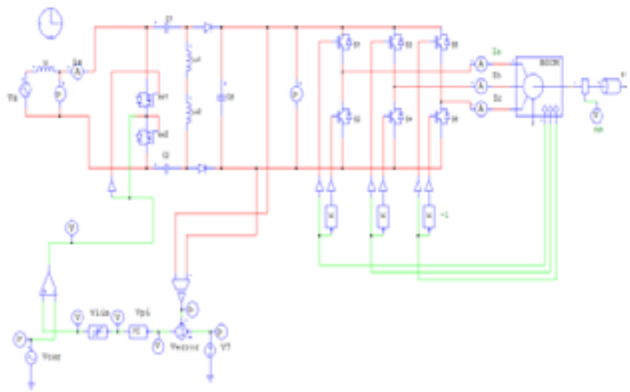
Table 5: Power Quality Parameters at Different Load Condition for Cuk Converter fed VSI Based BLDC Motor.

Vs	THD (I) (%)	PF
170	3.52	0.99
180	3.54	0.99
190	3.67	0.99
200	3.83	0.99
210	3.94	0.99
220	3.98	0.99
230	4.23	0.99
240	4.27	0.99

Table 6: Power Quality Parameters at Different Load Condition for Cuk Converter fed VSI Based BLDC Motor.

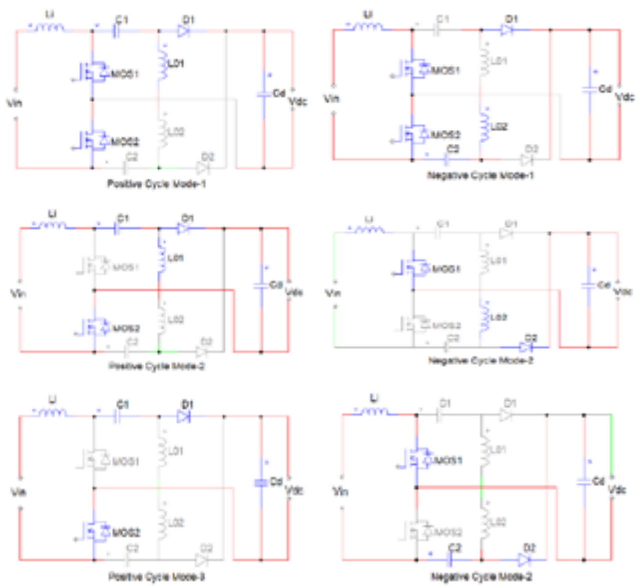
The PSIM Simulation outcome is demonstrations that Cuk converter fed VSI based BLDC Motor is Source Voltage (Vs) 230V Source Current (Is) 30. 47A.The Fundamental frequency is 50 Hz. Total Harmonic Distortion of source current is 3.98% and Power Factor is 0.99.

SIMULATION ANALYSIS FOR SEPIC-Fed CONVERTER FED BLDC MOTOR



Power Rating (P)	690 Watt
DC Link Voltage Rating	310V
Current Rating	5 Amp
Stator Resistance(R)	5.5 Ω
Self-Inductance of Stator winding (L)	15.41mH
Rated Torque	2.2
Number of Machine Pole(P)	4
Moment of Inertia	0.18
Back EMF Constant	78

Table 7 shows specification of BLDC MOTOR used in the design of bridgeless SEPIC-fed BLDC Motor drive.



The input side circuitry is completed during the positive half cycle of the supply voltage by the anti-parallel diode of switch Sw1, when switch Sw1 conducts, and by the anti-parallel diode of switch Sw2 during the negative half cycle when switch Sw2 conducts, as shown in Figure 17(a-c) and (d-f), respectively.

The operation of the converter during both positive and negative half cycles of the supply voltage is conducted by intermediate capacitors C1 and C2, output inductors Lo1 and Lo2, and diodes D1 and D2. Input inductor Li is always conducting throughout the supply voltage cycle to maintain a desired DC link voltage (Vdc) across capacitor Cd.

In the Positive cycle mode-I, when switch Sw1 is turned on, Li starts charging, and C1 begins discharging to charge Lo1. D1 remains non-conducting, and the energy required by the load is supplied by the DC link capacitor.

In the Positive cycle mode-II, Li and Lo1 start discharge, and C1 and Cd start charging when switch Sw1 is turned off. Li has a much higher value than Lo1 or Lo2 due to its continuous conduction mode, making the rate of decrease in iLi slower compared to the rate of decrease in iLo1 or iLo2.

In the Positive cycle mode-III, Lo1 is completely discharged to enter the discontinuous inductor current mode (DICM) of operation, and C1 continues to receive energy from Li, causing the VC1 voltage to increase, as shown in the figure 17.

The operation of the bridgeless SEPIC during the negative half cycle of the supply voltage is also divided into three different modes, which are depicted in Figure 17(d-f). (Singh &Singh, 2010)

Vdc(v)	Speed(rpm)	THD Is (%)	DPF	PF	Is(A)
150	1165	2.92	0.9987	0.9983	1.976
170	1360	2.76	0.9991	0.9987	2.238
190	1555	2.53	0.9995	0.9992	2.504
210	1750	2.41	0.9997	0.9994	2.77
230	1940	2.27	0.9998	0.9995	3.04
250	2130	2.19	0.9999	0.9997	3.314
270	2320	2.09	1	0.9998	3.589
290	2500	1.99	1	0.9998	3.868

Table 7: Performance of bridgeless SEPIC-fed BLDC motor drive under speed control.

Vs(v)	THD Is (%)	DPF	PF	Is(A)	CF
170	1.52	0.9993	0.9992	5.31	1.412
180	1.58	0.9996	0.9995	5.028	1.412
190	1.7	0.9998	0.9997	4.776	1.412
200	1.77	0.9999	0.9992	4.574	1.412
210	1.85	1	0.9992	4.336	1.412
220	1.96	1	0.9992	4.157	1.412
230	2.02	1	0.9992	3.999	1.412
240	2.12	0.9999	0.9992	3.818	1.412
250	2.17	0.9999	0.9992	3.675	1.412
260	2.28	0.9998	0.9992	3.54	1.412
270	2.39	0.9997	0.9992	3.415	1.412

Table 8: Performance of bridgeless SEPIC-fed BLDC motor drive under varying input voltage.

APPENDIX

Design data of Cuk Converter	
Inductor L_1	1.1mH
Inductor L_2	0.5mH,
Inductor L_s	0.3mH,
Capacitor C_1	0.2μF
Capacitor C_2	1590μF
Switching Frequency	20 kHz
PI Voltage Controller Gain (Kpdc, Kidc)	0.05, 4.5
Design data of Buck Converter	
Inductor L_o	0.1mH
DC link Capacitor C_o	1500uF
Filter Capacitor C_f	7uF
PI Voltage Controller Gain (K_p, K_i)	0.01, 4.5
PI Speed Controller Gain (Kp, Ki)	0.004, 0.45
Switching Frequency	20 kHz
Design data of Boost Converter	
Inductor L_o	5mH
DC link Capacitor C_o	1500uF
PI Voltage Controller Gain ($K_p$dc, $K_i$dc)	0.05, 1.5
PI Speed Controller Gain (K_p, K_i)	0.01, 0.1
Switching Frequency	20 kHz
Design data of Sepic Converter	
Inductor Li,Lo1,Lo2	6mH,50 uH
C1,C2	1.6 uH
DC link Capacitor Cd	4000uF
PI Voltage Controller Gain ($K_p$dc, $K_i$dc)	0.05, 1.5
PI Speed Controller Gain (K_p, K_i)	0.01, 0.1
Switching Frequency	20 kHz
Design data BLDC Motor. (For Buck, Boost, Cuk Application)	
Power Rating (P)	1500 Watt
Voltage Rating	300V
Current Rating	5 Amp
Stator Resistance(R)	11.9 Ω
Self-Inductance of Stator winding (L)	0.00207 H
Mutual Inductance of Stator winding (M)	-0.00069 H
Peak Voltage of BLDC Machine	32.3
Peak RMS Voltage of BLDC Machine	22.9
Number of Machine Pole(P)	4
Moment of Inertia	7e-006
Mech. Time Constant	0.006

Conclusions

In this Paper Different comparison of Power Converter topologies of BLDC has been simulated. The simulation results, obtained using PSIM and optimized design of power converters, showed improvement in power quality at the AC mains for a wide range of speeds and source AC voltages. The study proposed a bridgeless SEPIC-fed VSI-based BLDC motor drive for improved speed control, which reduces conduction losses and increases overall efficiency. The proposed drive showed improved power quality, with power-quality indices such as THD of supply current, DPF, and PF within recommended standards. The drive's performance under practical conditions was also satisfactory, with good results for supply voltage variation. The study concluded that the proposed SEPIC-fed BLDC drive is a suitable technique for speed control of BLDC motors with improved power quality at the AC mains.

References

Biswajit S & Bhim S & Aryadip S.(2023) SMO Based Position Sensorless BLDC Motor Drive Employing Canonical Switching Cell Converter For Light Electric Vehicle, IEEE Transactions on Industry Applications Page 1-11.

Bist., V & Singh, B. (2014). PFC Cuk Converter Fed BLDC Motor Drive. IEEE Transactions on Power Electronics, 30 1-17

Catherine.P & Murugan. R.(2015) Simulation Analysis of Power Quality Improvement in BLDC Motor Drive Using Type III CUK Derived Converter. International Conference Electronics and Communication Systems 1506-1510

Karthikeyan., J. & Dhana Sekaran, R. (2011).DC-DC Converter CSI fed BLDC Motor for Defence Applications. International Conference on Recent Advancements in Electrical, Electronics and Control Engineering,68-72.

Manglik., S., Sundeep, B., & Singh, B. (2016) Brushless DC motor-based ceiling fan using a buck-boost converter. IEEE Power India International Conference (PIICON), 978-983

Pireethi,R. Balamurugan (2016) Power Factor Correction in BLDC motor Drives Using DC-DC Converters. International Conference on Computer Communication and Informatics 1-5,

Singh, B & Singh, S (2010). Single-phase power factor controller topologies for permanent magnet brushless DC motor drives. IET Power Electronics, 3, 147-175.

Singh., S & Singh, B. (2012). A Voltage Controlled PFC Cuk Converter Based PMBLDCM Drive for Air-Conditioners' Transactions on Industry Applications 48, 832-838

4

INTENTION TO PURCHASE E-VEHICLES: THE MEDIATION ROLE OF CONSUMPTION VALUES

Dr. Vipul Patel

ABSTRACT: The automotive industry has witnessed a growing trend of electric vehicle (EV) adoption in recent times, with developed and developing nations alike embracing this new technology. Scholars and academicians are progressively investigating the factors that impact the acceptance of electric vehicles. Owning and driving an electric vehicle (EV) can be considered a pro-environmental behaviour because EVs produce significantly less air pollution and greenhouse gas emissions than traditional gasoline-powered vehicles. Individuals who are environmentally conscious are more likely to recognize the negative impacts of environmental pollution and take steps to address it. Additionally, the perceived value of consumption has been found to be an essential determinant of electric vehicle purchase intention. The objective of this research is to analyze how the purchase intention of electric vehicles is affected by pro-environmental behaviour and perceived consumption value, which acts as a mediator variable. The study surveyed 372 customers across three cities in Gujarat using a questionnaire-based survey and analyzed the data using structural equation modeling. The outcomes of the research will be valuable for electric car producers and executives as they endeavor to enhance consumer knowledge of environmental concerns and effectively advertise electric cars.

KEYWORDS

e-vehicles, pro-environmental behaviour, perceived value, purchase intention

Introduction

The automotive industry has witnessed a growing trend of electric vehicle (EV) adoption in recent times, with developed and developing nations alike embracing this new technology. India has set ambitious targets for EV uptake, aiming to have 30% of privately owned cars, 70% of commercial vehicles, and 80% of two and three-wheelers to be EVs by 2030 (Mint, 2022). Consequently, the electric vehicle market in India is expected to grow significantly, with an estimated compounded annual growth rate of 94.4% between 2021 and 2030 and a projected value of $152.2 billion by 2030 (Malik, 2021). As a result, there has been an increase in research aimed at identifying the factors that influence individuals' intention to purchase EVs.

This study employs the theory of perceived value to explore the factors that influence the purchasing behavior of electric vehicles (EVs). The theory of perceived value posits that an individual's decision to purchase a product or service is influenced by their perception of the benefits and drawbacks of the product or service in comparison to available alternatives. In the context of EVs, this study aims to identify the factors that shape a person's perceived value of purchasing an EV and how these factors influence their intention to buy one. Such factors may include the vehicle's performance, fuel efficiency, and environmental impact, price relative to conventional gasoline vehicles, range, charging infrastructure availability, and government incentives or regulations. Additionally, intangible benefits, such as social status or prestige associated with owning an EV, and personal values and beliefs about the benefits of EVs, such as reducing carbon emissions or supporting sustainable transportation, may also shape an individual's perceived value of buying an EV.

The current study aims to fill a gap in the literature by examining the influence of perceived consumption value on the intention to purchase electric vehicles in the state of Gujarat, India. Although previous studies have examined various aspects of EV purchasing behavior, the connection between perceived consumption value and purchase intention has not been thoroughly investigated. By examining this relationship, the study aims to provide a more comprehensive understanding of EV purchasing behavior in an area that has not been previously explored.

The paper is organized in the following manner: The second section delves into the theoretical foundation and research design, and includes the formation of hypotheses. The third section describes the methodologies applied in the study. The fourth section presents and evaluates the findings. The final section summarizes the research, and offers perspective on its limitations, implications, and opportunities for future studies.

Conceptual framework and research hypotheses

Consumption Value Theory

The theory of Consumption Value (CVT) was adopted as the primary theoretical framework for understanding consumer attitudes and behaviors towards e-vehicles. The concept of perceived value, a well-researched topic in the field of marketing, has been demonstrated to be a crucial predictor of consumer attitudes and behaviors (Baek & Oh, 2021; Kotler & Armstrong, 2021). It posits that customers tend to purchase products that they perceive to have the greatest value (Sheth, Newman, & Gross, 1991).

Perceived value is a complex and multifaceted concept that can mean different things to different individuals (Zeithaml, 1988). Zeithaml (1988) defines perceived value as a consumer's assessment of the benefits and drawbacks of a product or service relative to its cost. This concept relates to a customer's assessment of what is reasonable, proper, or warranted in relation to the perceived cost of an offering (Bolton & Lemon, 1999). Perceived value is the equilibrium between the benefits or advantages that a consumer receives from a product and the perceived costs, which include not only monetary expenses but also non-monetary expenses such as effort, time, and emotional stress that customers may incur during the process of evaluating, obtaining, and utilizing a product (Komulainen, Mainela, & Tähtinen, 2013; Kotler & Armstrong, 2021; Oliver & DeSarbo, 1988).

Various academics and researchers have proposed several typologies of value, but for understanding consumer behavior towards e-vehicles, this study employed the perceived value typology presented by Sweeney and Soutar (2001), called the PERVAL scale. This scale is composed of three distinct dimensions of value, namely, functional value, emotional value, and social value. The subsequent sections of the paper detail these values with respect to purchase of EV and hypotheses formulated in the framework.

Functional value

The functional value of a product is an essential aspect that pertains to the perceived benefits or usefulness that customers can derive from it. It significantly influences the purchase intention and actual buying behavior of consumers (Forsythe, Liu, Shannon, & Gardner, 2006; Han, Wang, Zhao, & Li, 2017; Sheth, Newman, & Gross, 1991). When it comes to electric vehicles (EVs), the functional value can be seen as the balance between the higher initial cost of EVs compared to traditional vehicles and the long-term cost savings resulting from government incentives, fuel efficiency, and reduced maintenance costs. While electric vehicles (EVs) may have a higher upfront cost compared to traditional gasoline-powered cars, there are several factors that can make them a more cost-effective choice in the long run. For example, many governments offer financial incentives to encourage the purchase of EVs, which can help offset their higher purchase price (Gallagher & Muehlegger, 2008; Langbroek, Franklin, & Susilo, 2016). Additionally, EVs are typically more fuel-efficient than traditional cars, which can help to reduce long-term fuel costs (Lane & Potter, 2007). In addition, Jena (2020) found that maintenance costs for EVs may also be lower than for traditional cars. Given the aforementioned factors, it can be reasonably postulated that the intention to adopt EVs is positively influenced by perceived functional value. Therefore,

H1: Perceived functional value has a positive influence on the intention to adopt EV.

Social values (SV)

Social value, or the extent to which owning a product can help individuals interact with others and improve their social self-concept, can also play a role in consumers' decision to purchase electric vehicles (EVs) (Belk, 1981; Fennis & Pruyn, 2007; Sweeney & Soutar, 2001). Many consumers may be motivated to purchase EVs because they believe it will help them project a positive image to others, particularly if they believe that their efforts to reduce pollution through purchasing an EV will be publicly recognized or praised. Research has shown that this sense of social approval can influence consumer behavior (Bhat, Verma, & Verma, 2022; Griskevicius, Tybur, & Van den Bergh, 2010). Based on this discussion, it can be reasonably postulated that the intention to adopt EVs is positively influenced by perceived social value.

H2: Perceived social value has a positive influence on the intention to adopt EV.

Emotional values (EV)

Emotional value, which refers to a product's capacity to evoke emotions or affective responses in consumers, is a significant factor that influences consumer decision-making (Sheth et al., 1991), particularly when it comes to purchasing electric vehicles (EVs). According to Schulte, Ree, and Carretta (2004), consumers often have specific psychological needs that they are looking to fulfill when making a purchase, and these needs can play a significant role in determining which products they ultimately choose. In the case of electric vehicles (EVs), consumers may be looking to meet a range of psychological needs, such as the desire to be environmentally conscious, the need for a sense of social approval, or the desire to experience certain emotions while driving. The emotional benefits of "green" consumption, such as feeling good about doing something that is environmentally friendly, can be a powerful motivator for customers. Additionally, driving an EV can provide a sense of joy and comfort that may add to the overall emotional value of the car. Having an understanding of these fundamental psychological requirements can aid in comprehending why certain consumers may have a higher tendency to embrace electric vehicles (EVs) compared to others. Therefore, it can be speculated that perceived emotional value can positively influence the adoption of EVs.

H3: Emotional value has a positive influence on the intention to adopt EV.

Pro-Environmental Behaviour

Consumers' decision to buy electric vehicles (EVs) can be influenced by pro-environmental behavior, which involves purposeful efforts to reduce adverse effects on the natural environment. Prior studies has indicated that people who participate in pro-environmental actions tend to have a greater consciousness of the risks associated with pollution and are more compelled to take action to mitigate it (Dunlap & Jones, 2002) and are more likely to adopt the EVs in comparison to others (Dutta & Hwang, 2021). Additionally, as people's understanding of environmental issues grows, they may become more likely to adopt green goods and services, such as EVs (Norazah & Norbayah, 2015; Wang, Fan, Zhao, Yang, & Fu, 2016). Several research studies have indicated that customers are willing to pay extra for environmentally friendly products, provided they perceive that these products have a favorable effect on the environment (Erdem, Şentürk, & Şimşek, 2010; Laroche, Bergeron, & BarbaroφForleo, 2001).

Owning and driving an electric vehicle (EV) can be considered a pro-environmental behaviour because EVs produce significantly less air pollution and greenhouse gas emissions than traditional gasoline-powered vehicles (White & Sintov, 2017). This can lead to a decrease in air pollution and a lessening of the effects of climate change. Engaging in pro-environmental behaviour can make an individual feel good about themselves as they are taking actions to protect the environment (Taufik & Venhoeven, 2018). Owning an EV can also be seen as a socially responsible and forward-thinking choice, which may boost an individual's self-esteem. Overall, owning an EV can be an effective way for an individual to improve their self-image by making a positive impact on the environment and feeling good about their personal choices (Bennett & Vijaygopal, 2018). Owning an EV can also provide a sense of self-efficacy, as the individual feels that they are personally making a positive impact on the environment, which can lead to positive emotions such as hope, optimism, and empowerment. Moreover, possessing an electric vehicle (EV) can have a beneficial influence on an individual's emotional value, as it can provide a sense of contentment and gratification that they are contributing towards a positive change for the environment (White & Sintov, 2017). Overall, it can be inferred that pro-environmental behaviour can have a positive influence on the intention to adopt EV and this is mediated by functional, social and emotional values of owning EV. Therefore,

H4: Pro environmental behaviour has positive influence on the intention to adopt EV.

H5: Pro environmental behaviour has positive influence on the intention to adopt EV.

H6: Pro environmental behaviour has positive influence on the intention to adopt EV.

Based on above discussion, the research model is prepared and presented in figure 1.

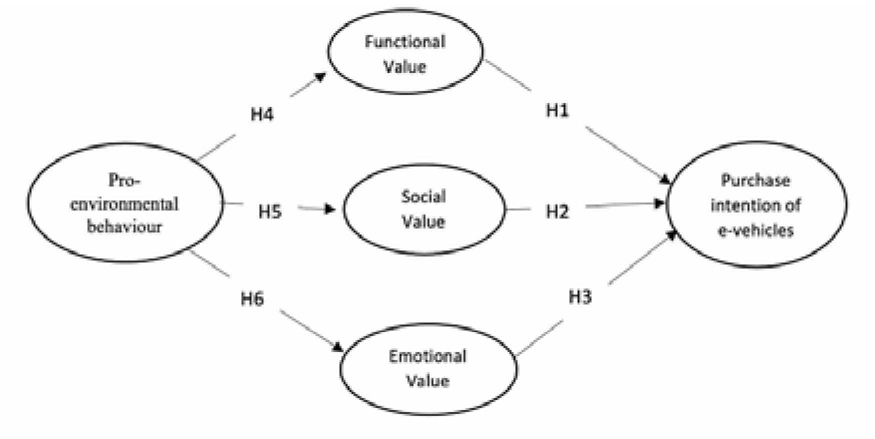


Figure 1: Proposed Research Model

Research Methodology

Operationalization of Constructs

An online survey was developed to gather data to assess the conceptual model and research hypotheses. The survey was divided into three sections for a clear and organized collection of data. demographics, constructs, and purchase intentions. The demographic section is used to gather information about the characteristics of the respondents, such as their gender, age, educational level, and income. This information can be used to understand how these factors may influence the responses to the other constructs of the survey. The second section, which consists of survey items rated on a five-point Likert scale, is used to measure specific constructs of the study. These items quantify the respondents' attitudes or beliefs towards the constructs being studied, such as their willingness to purchase EVs, pro-environment behaviour and their perceptions of functional, social and emotional values of owning an electric vehicle. Finally, the third section may include questions about the respondent's intention to purchase electric vehicles. In this study, the effect of pro-environmental behaviour on purchase intention was examined, with the perceived consumption values acting as a mediating variable. The purchase intention was taken as the outcome being studied, while pro-environmental behaviour was considered as the influencing factor. The survey questions were tailored from prior studies to align with the objectives of the current study.

Samples and Data Collection

Online data collection was done for the study's research question. The data collection occurred for ten weeks from January 2022 to March 2022, whereby the survey was distributed through various online channels, such as emails and social networks (e.g., WhatsApp, Facebook, etc). There were 415 survey responses obtained in all. A total of 372 valid responses were selected for the study after 43 responses with missing values were removed.

Table 2 illustrates the profile of the respondents. On average, respondents were male (48.92 percent) and female (51.07 percent), young (less than 40 years of age - 58 percent), had a college degree (85.75 percent), and had an annual income of less than Indian Rupees 10 lacs (90 percent). Detailed results are shown in Table 1.

Gender:	Male = 48.92%; Female = 51.07%
Age:	Less than 20 years = 12.63%; 21-30 years = 19.89%; 31-40 years = 25.27%; 41-50 years = 22.04%; More than 50 years = 20.16%
Education:	Lower than bachelor degree = 14.25%; Bachelor degree = 57.26%; Master degree or higher = 28.49%
Income (monthly):	Less than INR 30,000 = 9.41%; INR 30,000 – 60,000 = 43.55%; INR 60,000 – 90,000 = 37.36%; More than INR 90,000 = 9.67%

Table 1: Demographic profile of sample

Analysis and Results

First crucial analysis was performed to evaluating the measurement model to ensure the validity and reliability of the scales used in the study. This involved assessing the soundness of the measures used in the study and ensuring that they accurately capture the intended theoretical components. Evaluating the measurement model is critical in ensuring that the results of the hypotheses tests are meaningful. The hypotheses were assessed via structural equation modeling (SEM), utilizing the open-source software R. This approach was taken to ensure that the findings of the study are valid and reliable.

Construct Validity and Reliability of Instruments

First, a reliability test was performed by calculating Cronbach's alpha for each of the constructs adopted in the study. This was done to purify the measurement scale and ensure that the scale measures what it is supposed to measure consistently. All measurement scales of the study. i.e., functional values ($\alpha = 0.946$), social values ($\alpha = 0.890$), emotional values ($\alpha = 0.835$), pro-environmental behaviour ($\alpha = 0.901$) and purchase intention ($\alpha = 0.919$) surpassed $\alpha = 0.70$ reference (Nunnally & Bernstein, 1994) and were used for further investigation.

Next, confirmatory Factor Analysis (CFA) is used to assess the validity of a measurement model by testing whether the observed variables are reliable measures of the underlying latent constructs that they are supposed to represent in the study. When conducting confirmatory factor analysis (CFA), the goodness of fit of the data to the hypothesized model is assessed by comparing the observed covariance matrix of the measured variables with the covariance matrix implied by the model (Gefen, Straub, & Boudreau, 2000). The goodness of fit of the model was evaluated using several indices. The chi-square fit statistic was 505.154 with 179 degrees of freedom ($p \approx 0.00$). The root mean square error of approximation (RMSEA) was 0.070, which falls within the recommended range of 0.08. The other indices, including the Comparative Fit Index (CFI) at 0.948, Root Mean Square Residual (RFI) at 0.909, Tucker-Lewis Index (TLI) at 0.939, and Normed Fit Index (NFI) at 0.922, all exceeded the commonly used threshold of 0.90, indicating a good fit between the observed data and the hypothesized model (Hair, Anderson, Black, & Babin, 2016). These results indicate that the measured variables are valid and reliable for the study.

To examine convergent validity in this study, factor loadings, average variance extracted (AVE), and composite reliability were tested. As shown in Table 2, results showed that composite reliability (CR) was greater than 0.70, indicating a high level of consistency (Hair et al., 2016). Factor loadings were above the recommended value of 0.5 and AVE values exceeded 0.6, which established convergent validity (Fornell & Larcker, 1981; Hair et al., 2016). Given the number of indicators, the measurement quality was good for all indicators used in the study.

Items	Factor Loadings	AVE	CR	Cronbach's Alpha
Functional Value (FV)		0.816	0.945	0.946
FV1	0.890			
FV2	0.893			
FV3	0.959			
FV4	0.865			
Social Value (SV)		0.677	0.890	0.890
SV1	0.844			
SV2	0.897			
SV3	0.798			
SV4	0.732			
Emotional Value (EV)		0.638	0.835	0.835
EV1	0.860			
EV2	0.682			
EV3	0.852			
Pro-Environmental Behaviour		0.572	0.901	0.901
PEB1	0.739			
PEB2	0.724			
PEB3	0.774			
PEB4	0.710			
PEB5	0.792			
PEB6	0.746			
PEB7	0.828			
Purchase Intention (INT)		0.797	0.919	0.919
INT1	0.860			
INT2	0.944			
INT3	0.875			

Table 2: Confirmatory factor analysis results and Cronbach's alpha

Hypotheses Testing

After testing the measurement suitability, the path coefficient of the structural model was estimated using the laavan package of open source software R. Results of the same are shown in Table 5. Verification of the research model confirmed that the overall fit of the model meets the appropriate level ($\chi 2/df = 3.61$, $p < 0.001$; CFI = 0.924; NFI = 0.898; TLI = 0.913; RMSEA = 0.084). Therefore, the research model is considered appropriate.

The results showed that variables of perceived consumption value i.e., functional value ($\beta = 0.313$, $p < 0.01$), social value ($\beta = 0.213$, $p < 0.01$), and emotional value ($\beta = 0.270$, $p < 0.01$) positively affect purchase intention of e-vehicles. Therefore, H4, H5, and H6 are supported. Similarly, pro-environmental behaviour positively affect variables of perceived consumption values - functional value ($\beta = 0.792$, $p < 0.01$), social value ($\beta = 0.848$, $p < 0.01$), and emotional value ($\beta = 0.534$, $p < 0.01$). Therefore, H1, H2, and H3 are supported.

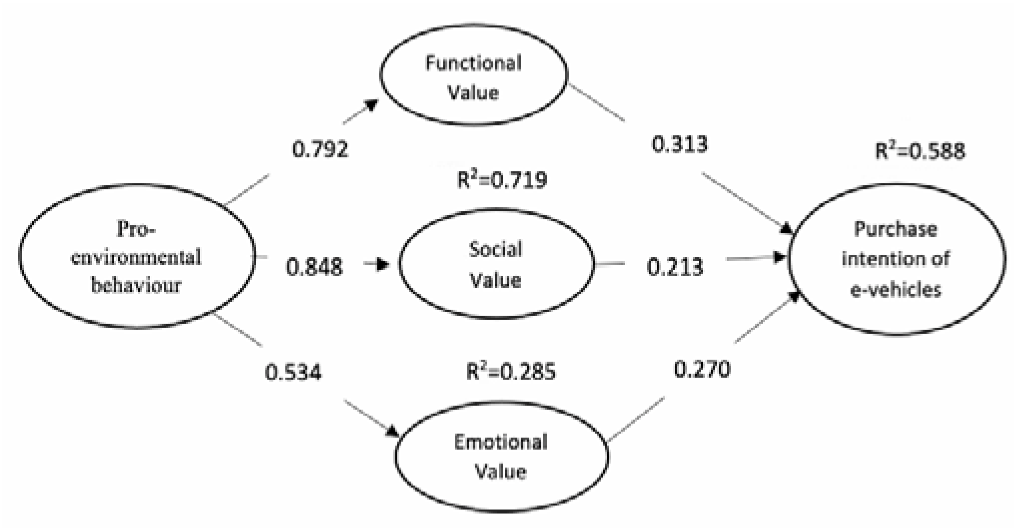


Figure 2: Result of path model

Discussion and Conclusions

This research study stands out as one of the few that focuses on exploring the factors that impact customers' inclination to buy electric vehicles in Gujarat, India. The objective of this study was to create and evaluate a research model that scrutinizes the correlation between customers' pro-environmental behavior and their intentions to purchase electric cars. Furthermore, the study aimed to investigate whether the consumption values, which comprises functional, social, and emotional values, plays a mediating role in this relationship. The study revealed that pro-environmental behavior has a positive impact on customers' intentions to buy electric vehicles, and this correlation is influenced by consumption values. These findings are significant as they integrate consumption value theory's concepts into the existing literature on electric vehicle purchase behavior.

From a managerial perspective, the findings of this study provide manufacturers and marketers of electric vehicles with a better understanding of consumer purchase behavior. The research provides valuable insights that can help promote the adoption of electric vehicles in developing economies like India. By identifying the significant role of pro-environmental behavior and consumption values in shaping purchase intentions, policymakers and marketers can develop targeted strategies that appeal to these factors. For instance, campaigns promoting the environmental benefits of electric vehicles, emphasizing the functional, social, and emotional value of owning an electric vehicle, and providing incentives for customers who opt for electric vehicles can be effective in encouraging adoption. These insights can inform the development of policies and marketing campaigns that effectively promote the adoption of electric vehicles in developing economies such as India. Additionally, the study suggests that pro-environmental behaviour is positively associated with electric vehicle adoption, so manufacturers and marketers may want to consider ways to appeal to environmentally-conscious consumers. Overall, the research offers valuable insights for manufacturers and marketers looking to increase electric vehicle adoption in India and other developing economies.

This research provides valuable insights and conclusions, but it is important to acknowledge some limitations of the study. The study was only conducted in Gujarat, India, and therefore, the findings may not be generalizable to other regions or countries. Future researchers are encouraged to expand the scope of the research by recruiting participants from other locations to provide a more comprehensive and definitive study. Therefore, the findings of this research should be interpreted with caution when generalizing to other contexts.

References

Belk, R. W. (1981). Determinants of consumption cue utilization in impression formation: An association derivation and experimental verification. Advances in Consumer Research 8, 170-175.

Bennett, R., & Vijaygopal, R. (2018). Consumer attitudes towards electric vehicles. European Journal of Marketing, 52(3/4), 499-527. doi:10.1108/EJM-09-2016-0538

Bhat, F., Verma, M., & Verma, A. (2022). Measuring and Modelling Electric Vehicle Adoption of Indian Consumers. Transportation in Developing Economies, 8.

Dunlap, R., & Jones, R. (2002). Environmental Concern: Conceptual and Measurement Issues. 484-524.

Dutta, B., & Hwang, H.-G. (2021). Consumers Purchase Intentions of Green Electric Vehicles: The Influence of Consumers Technological and Environmental Considerations. 13(21), 12025.

Erdem, C., Şentürk, İ., & Şimşek, T. (2010). Identifying the factors affecting the willingness to pay for fuel-efficient vehicles in Turkey: A case of hybrids. Energy Policy, 38, 3038-3043.

Fennis, B. M., & Pruyn, A. T. H. (2007). You are what you wear: Brand personality influences on consumer impression formation. Journal of Business Research, 60(6), 634-639.

Forsythe, S., Liu, C., Shannon, D., & Gardner, L. (2006). Development of a Scale to Measure the Perceived Benefits and Risks of Online Shopping. Journal of Interactive Marketing, 20, 55-75.

Gallagher, K., & Muehlegger, E. (2008). Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology. Journal of Environmental Economics and Management, 61, 1-15.

Griskevicius, V., Tybur, J. M., & Van den Bergh, B. (2010). Going green to be seen: Status, reputation, and conspicuous conservation. Journal of Personality and Social Psychology, 98(3), 392-404.

Hair, J., Anderson, R., Black, B., & Babin, B. (2016). Multivariate Data Analysis: Pearson Education.

Han, L., Wang, S., Zhao, D., & Li, J. (2017). The intention to adopt electric vehicles: Driven by functional and non-functional values. Transportation Research Part A: Policy and Practice, 103, 185-197.

Jena, R. (2020). An empirical case study on Indian consumers' sentiment towards electric vehicles: A big data analytics approach. Industrial Marketing Management, 90, 605-616.

Komulainen, H., Mainela, T., & Tähtinen, J. (2013). Customer's Potential Value: The Role of Learning. Journal of business market management, 6, 1-21.

Kotler, P. T., & Armstrong, G. (2021). Principles of Marketing (Vol. 18 Global Edition): Pearson Education

Lane, B., & Potter, S. (2007). The adoption of cleaner vehicles in the UK: exploring the consumer attitude–action gap. Journal of Cleaner Production, 15(11), 1085-1092.

Langbroek, J., Franklin, J., & Susilo, Y. (2016). The effect of policy incentives on electric vehicle adoption. Energy Policy, 94, 94-103.

Laroche, M., Bergeron, J., & BarbaroφForleo, G. (2001). Targeting consumers who are willing to pay more for environmentally friendly products. Journal of Consumer Marketing, 18(6), 503-520.

Malik, B. (2021). India's EV market to grow by 90% to touch $150 billion by 2030: Report. Retrieved from https://www.businesstoday.in/latest/story/indias-ev-market-to-grow-by-90-to-touch-150-billion-by-2030-report-314116-2021-12-01

Mint. (2022). Electric Vehicles in India; miles covered and miles to go. Retrieved from https://www.livemint.com/auto-news/electric-vehicles-in-india-miles-covered-and-miles-to-go-11644845581284.html

Norazah, M. S., & Norbayah, M. S. (2015). Consumers' environmental behaviour towards staying at a green hotel. Management of Environmental Quality: An International Journal, 26(1), 103-117.

Nunnally, J. C., & Bernstein, I. H. (1994). Psychometric Theory (3 ed.): Tata McGraw-Hill Education.

Oliver, R. L., & DeSarbo, W. S. (1988). Response Determinants in Satisfaction Judgments. Journal of Consumer Research, 14(4), 495-507. doi:10.1086/209131 %J Journal of Consumer Research

Schulte, M., Ree, M., & Carretta, T. (2004). Emotional intelligence: Not much more than G and personality. Personality and Individual Differences, 37, 1059-1068.

Sheth, J. N., Newman, B. I., & Gross, B. L. (1991). Why we buy what we buy: A theory of consumption values. Journal of Business Research, 22(2), 159-170.

Sweeney, J. C., & Soutar, G. N. (2001). Consumer perceived value: The development of a multiple item scale. Journal of Retailing, 77(2), 203-220.

Taufik, D., & Venhoeven, L. (2018). Emotions and Pro-Environmental Behaviour. In Environmental Psychology (pp. 189-197).

Wang, S., Fan, J., Zhao, D., Yang, S., & Fu, Y. (2016). Predicting consumers' intention to adopt hybrid electric vehicles: using an extended version of the theory of planned behavior model. Transportation, 43, 1-21. doi:10.1007/s11116-014-9567-9

White, L. V., & Sintov, N. D. (2017). You are what you drive: Environmentalist and social innovator symbolism drives electric vehicle adoption intentions. Transportation Research Part A: Policy and Practice, 99, 94-113.

3

TECHNO-ECONOMIC ANALYSIS OF PHOTOVOLTAIC-THERMAL (PV-T) IN THE PERSPECTIVE OF MSME SECTOR

Gaurav Patel and Dr. Lalit Kumar Khurana

ABSTRACT: The energy demand in the typical MSME (Micro, Small and Medium Enterprises) sector, 60% - 70% energy is required for the heating and the remaining portion of the electricity consumption. Considering the attractive solar policy and targets in India with financial assistance from the Governments, solar PV has been adopted for electricity generation. The rooftop program has gained momentum considering beneficial for clients as well as distribution companies. However, solar PV technology gives the electrical output, and the beneficiary (client) requires to depend on other fuel sources for the heating requirements. The PV-T technology can produce electricity and heat from the system. This paper discusses the performance of 20.5 kWp PV-T technology for the MSME. The various assumption and technical considerations are given in the paper. The electrical output saves the grid dependency on the power requirement and heat generation can reduce the dependency on the LPG fuel source. The paper shows with the economical assessment, for the considered case the PV-T technology is viable technology without any financial assistance from the government.

KEYWORDS

Renewable energy, PV-T, heating, clean energy

Introduction

The world economic growth is now dependent on extensive use of renewable energy. The fossil fuel stock of the world is going to deplete within a very short time. Worldwide efforts are nowadays concentrating on generating energy from renewable sources. Thus, renewable energy-based power generation may be the solution to future energy problems. This trend will continue as ensuring everyone has sufficient access to energy is an ongoing and pressing challenge for global development (Kumar, A., 2020). Despite the global push for renewable energy adoption, the increased consumption of fossil fuel is a greater concern for the sustainable environment. Globally coal demand is rising at around a 4.5% growth rate, with more than 80% growth derived from Asia (IEA, 2021). A similar rise of natural gas consumption increase by around 3.2% in 2021. The end requirement of these fuel sources (fossil or renewable) can be mainly required for electricity generation or heat generation. Globally, efforts are given by the government and corporates for the adoption of renewable energy sources for electricity requirement and heat generation.

Considering India, renewable energy projects have been adopted drastically over the past decade in India. This major adoption was mainly limited to solar photovoltaics (PV) and wind energy. Solar PV gave the distinct advantage to cater the local electricity demand by serving the distributed energy needs. Solar PV adoption alleviated the electricity demand from polluting coal-based thermal power plants. The country has installed 53.9 GW of solar PV installations by the end of March 2022 (MNRE, 2022), out of which 6.64 GW of solar rooftop PV was installed.

The electricity demand in India is likely to increase by around 6% year-on-year (Economic Times, 2021). With this increase in the power demand across the country, and shifting from coal power to renewable power by the government, solar energy can play an essential role in the Indian power segment.

The solar rooftop helps urban distributing companies to reduce the distribution infrastructure deferrals, reduces T&D losses and provides cheaper power than other power generating options. Rooftop solar also helps customers to reduce their electricity bills (by reducing the import from the costlier electricity generated from various sources). The customers can sell their surplus power to the discoms. The rate of power sold is different as per their respective state solar policies.

Regarding heating derived from renewable energy, solar thermal collectors are one of the most adopted technology across the world. The use of solar thermal can be used for mainly three temperature ranges, (i) low temperature (< 150 °C), (ii) medium temperature (150°C to 450°C), and (iii) high temperature (> 450 °C). Mainly for the residential hot water requirement and industrial water heating (or pre-heating) requirements, non-imaging solar thermal collectors are mainly adopted. These non-imaging collectors are mainly flat-plate collectors, evacuated tube collectors, and evacuated tube collectors with reflectors. By the end of 2021, 18.2 million m2 of solar thermal collectors had been installed in India (Epp, 2022).

Though both technologies are being adopted separately as solar PV, and solar thermal, the hybrid version of these technologies has distinct advantages. This hybrid version is known as Photovoltaic-Thermal (PV-T) collector, which can provide electricity as well as heat energy from the collector. As this technology is new comparatively in India, but it has been adopted abroad for space heating and low-temperature heat requirements. PV-T can be deployed in the MSME sector, where both heating and electricity is required. MSME sector is significant in India, producing 40% of the country's manufacturing output, and estimated employment of 40 million people (Joshi & Kishore, 2017).

Due to the developing stage of PV-T development in India, the standard testing and performance measurement are not known in the Indian market. Like solar PV, this technology generates electricity but is not considered financial assistance program of MNRE. However, after a successful demonstration of the PV-T technology in the Indian market, financial assistance can bring much faster adoption of the technology. Such adoption shall help to realise the 450 GW of renewable energy target by 2030 declared by the Government of India (MNRE, 2021). Additionally, this shall reduce the usage of fossil fuels for generating heat energy.

This study aims to answer some questions through Techno-Economic Analysis (TEA) of Photovoltaic-Thermal (PV-T). Techno-economic analysis (TEA) is an important tool for evaluating economic viability and plays a significant role in directing further research to evaluate suitability of scale-up. Although TEA is subject to high uncertainties, doing this provides several points of advice for future investigations. The paper is organised into five parts. Part 1 is all about introduction and part 2 illustrates with literature review. Material and method is described in part 3 and part 4 displays data analysis and discussion. Finally, Conclusions are drawn in part 5.

Literature Review

This section of the paper looks into the technical aspects of PV-T technology to facilitate framework of study. Description of various components of PV-T technology, Drivers of Solar Photovoltaic (PV) performance, standard testing condition and the benefits of the PV-T technology are identified. The section also reviews existing literature of study to avoid duplication of already researched matter.

A successful implementation of Solar Photovoltaic (PV-T) contributes towards sustainable energy supply in the future. It is important to explore technical and economic factors before deployment of technology. TEA has importance in risk minimization before commercial deployment. Solar PV electricity production is mainly driven by solar radiation availability at the site. Solar Photovoltaic (PV) collector performance is driven by weather parameters. However, there are other parameters like temperature, clouds, and rain that causes impact the performance.

A total of 65%-70% of the solar electromagnetic spectrum energy can be converted for heat utilization and a small portion of the spectrum is utilized by solar PV technologies (Lämmle, Manuel; Herrando, María; Ryan, Glen, 2020). Fig. 1 represents 100% of the air mass (AM) 1.5 spectrum in which electrical gains are 15%, and heat gains for 61%.

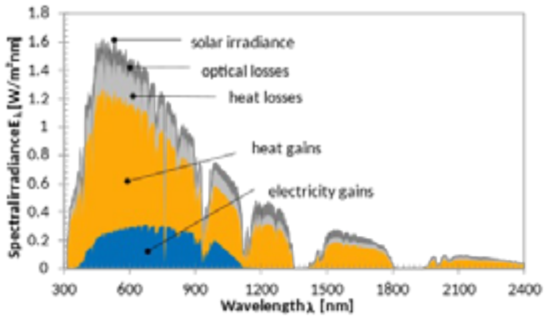


Figure 1: Electromagnetic Solar Spectrum Utilization by PV-T Collector (Lämmle, 2020)

The standard testing condition (STC) for solar PV module testing is at 25 °C and 1000 W/m2. The other efficiencies are measured at the normal operating cell temperature (NOCT) which is 800 W/m2 and 20°C, and wind speed of 1 m/s. At NOCT, the solar PV module-rated capacity performance is lower compared to STC.

Mostly all silicon-based photovoltaic cells electrical output efficiency reduces with the increase in cell temperature. Each degree rise in the cell temperature reduces the cell efficiency by around 0.4 – 0.5%. The removal of heat from the panel reduces the cell temperature and increases electrical efficiency. The solar PV performance at various operating temperatures is shown in Fig. 2.

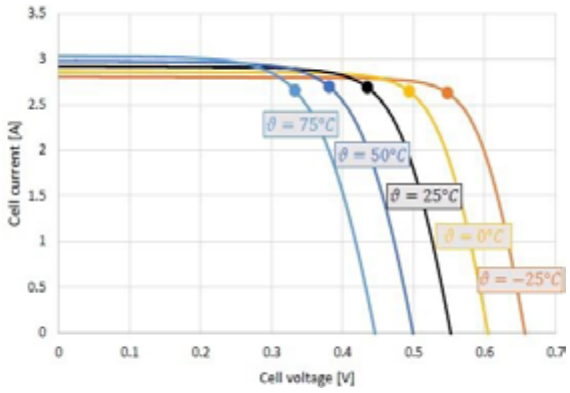


Figure 2: Solar PV performance at various operating temperatures

The benefits of the PV-T technology are as follows:

- Removal of heat from the Panel which increases the PV efficiency
- Extracted heat utilization for needed uses (such as water heating, process heating etc.)
- Efficient use of space (separate solar thermal water heating system can be avoided)

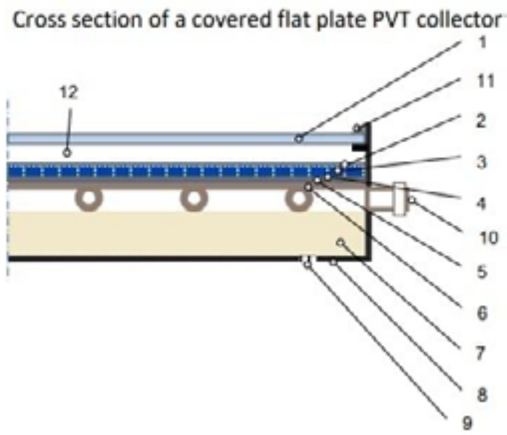


Figure 3 : Cross Section of a covered flat plat PV-T collector (Hadorn, et al., 2020)

As per the Fig. 3, the description of the components is given in the following Table 1. These are the tentative components of the PV-T, which means in the actual case some optional components can be absent in the actual PV-T Collector.

Sr. No.	Description	Remarks
1.	Transparent cover	Optional
2.	Front cover glass of PV module & Encapsulant	PV
3.	Solar PV cells	PV
4.	Encapsulant	PV - Optional
5.	Back sheet / Cover	PV - Optional
6.	Absorber & Heat Transfer Medium	Thermal
7.	Insulation	Thermal - Optional
8.	Casing	Optional
9.	Air vent	Optional
10.	Fluid Outlets	Thermal
11.	Sealing	For Cover – Optional
12.	Gap	Optional

Table 1: Components of the PV-T collector (Hadorn, et al., 2020)

Globally, the cumulative installation of PV-T collector area of 1.27 million m2 was installed, and the installation is increasing at 9% growth rate from 2018 to 2020 (IEA-SHC, 2021).The new larger market for PV-T technologies is the Netherlands, China, France, Ghana and Germany (REN21, 2021).

The PV-T technology is ideal for electricity and heat energy requirement conditions such as residential houses, hotels, guest houses, hospitals and process heat industries. The four-year discounted payback for PV-T for a 200-bedroom hotel in Barcelona, Spain was reported (Epp, Bärbel, 2020). The selection criteria for PV-T with the separate solar PV or solar thermal collector depend on the heat energy and thermal energy requirement at the site with the same occupied area.

In the literature were found some relevant studies. Barun K. Das et al. analysed economic and environmental benefits of stand-alone and grid integration with different system configurations of a PV/Wind/Diesel/Battery based hybrid energy system (HES) for five different climatic regions using hybrid optimization model for electric renewables (HOMER) (Das, et al., 2021). Faizan A. Khan et al. analysed social aspects of the renewable energy system in a distinguished manner, based on the techno-economic and socio-environmental parameters (Khan, Pal, Saeed, & Yadav, 2022). Soowon Chang et al evaluated the energy, economic, and environmental performance of rooftop PV and EVs for the five built forms in Korea and different building types in Seoul (Chang, Cho, Heo, Kang, & Kobashi, 2022).

Material and Method

This section presents the methodologies used in this study to achieve the goals of this study. TEA is a methodological approach to analyse the technical and economic performance of a process, product, or product system (AW, et al., 2020). The study has been designed to be based on the inductive approach. A solar PV module operates in the field at high temperature and its efficiency performance varies based on the range of radiance. The study required an appropriate geographical location. Taking this into account, we have considered the temperature conditions of a major city (Ahmedabad) located in India. In India, the major part of the country has a daytime temperature above 25 °C. As per the standard testing conditions, solar PV modules are tested at 1000 W/m2 radiation and 25 °C. The rise in temperature can reduce the power generated by the solar PV module. The per degree Celsius rise in the module (or cell) temperature, reduces the power from the panel in the range of -0.3% to -0.5%. Considering the hot and dry climatic conditions, Ahmedabad, Gujarat, the module peak temperature rise approx. 75 °C in the summer months. The average module temperature rises above 55 °C in most of the months in a year. The module temperature rise in the summer month is shown in Fig. 3. It is visible from Fig. 3 that, the module temperature is much higher than STC condition, i.e. 29.92 °C difference for the considered day.

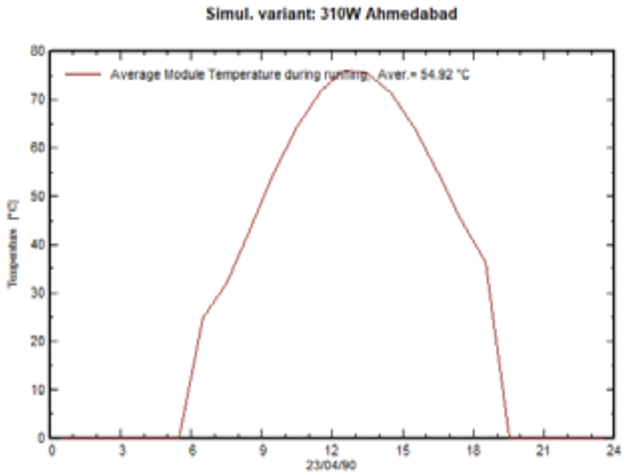


Figure 4: Solar PV module temperature rise in a summer day at Ahmedabad using PVSyst 6.88 (PVsyst, 2020)

The solar power output reduction can be calculated using Eq. (1):

Solar Power Loss due to temperature = Temperature Difference from STC * Temperature Co-efficient for power

For the temperature co-efficient for power -0.4%/°C, the solar power loss due to temperature will result into a loss of 12%. For the plant capacity of 1 kWp, the loss due to temperature ranges from 200 kWh to 380 kWh based on the local temperature condition.

The month-wise ambient temperature, solar PV module temperature during the operating time, and their difference are shown in Table 2. The average difference between the ambient temperature and the module temperature during operation is 24.2 °C.

	Ambient Temperature °C	Solar PV Module Temperature at Normal Operation °C	Day Time Temperature Difference (Panel Temp - Ambient Temperature) °C
January	25.7	53.5	27.8
February	31.0	60.8	29.8
March	35.3	64.4	29.1
April	41.0	68.0	27.0
May	39.0	62.3	23.3
June	35.6	54.7	19.1
July	30.5	47.6	17.1
August	29.4	46.3	16.9
September	29.4	53.1	23.7
October	29.5	56.7	27.2
November	27.8	53.8	26.0
December	26.2	53.3	27.2
Year	**32.0**	**56.2**	24.2

Table 2: Solar PV panel temperature and ambient temperature difference for Ahmedabad (Blair, et al., 2021)

In the PV-T technology, the panel consist of a heat transfer pipe below the solar PV module, which carries the heat away from the panel using fluid (mostly water). This reduces the panel temperature, increasing the solar PV output and getting extra heat energy for further utilization.

Using testing standard EN 12975 (QAiST, 2012), the heat energy from the PV-T technology can be derived from the following Eq. (2):

$$Q/A = G*\eta_0 - a_1*(t_m - t_a) - a_2*(t_m - t_a)^2$$

where, Q = Thermal output (W), A = Area (m2), G = Solar irradiation (W/m2), φ0 = Optical efficiency (%), a1 & a2 = heat loss co-efficient, tm = mean module temperature (K), ta = ambient temperature (K)

The performance of the PV-T module is derived from the Eq. (1), Eq. (2) and the weather data available in PVsyst v6.88 (PVsyst, 2020). The output water heating temperature from PV-T module is considered 45 °C. The reduction in temperature difference will increase the solar PV performance according to Eq. (1). This increased generation is added to the generation estimated using PVsyst v6.88 (PVsyst, 2020). The thermal output was estimated using Eq. (2).

Analysis & Results

This section discusses technical and economic factors in the TEA framework to allow for an objectivity in the feasibility.

Technical Analysis:

The PV-T technology converts solar radiation into useful electrical energy and heat energy, which can be further utilised by the beneficiary. Considering the MSME unit, where there is a constant need for heating energy, and the electricity requirement for the running plant, the PV-T techno-economic viability is shown in this section.

For evaluating the techno-economic assessment of the PV-T technology one MSME located in Ahmedabad, Gujarat is considered. The considered MSME can utilise electricity produced by PV-T and also pre-heat the water produced by PV-T. The photovoltaic capacity considered is 20.5 kWp for the analysis. The LPG gas is considered the fuel source utilised in MSME for the heating requirement. The heat energy derived from the PV-T shall reduce the heating requirement from the LPG fuel source. The heating temperature required from the PV-T is considered 45 °C. The electrical energy produced by the PV-T shall be consumed by the MSME, which means saving imports from the grid. The other assumptions for the techno-economic viability are shown in Table 3.

Description	Value	Unit
PV-T – Electrical Capacity	20.5	kWp
PV-T Area	110	m^2
Inverter Capacity	10	kVA
No. of Inverters	2	Nos.
GHI	1946	$kWh/m^2/year$
Required Hot Water Temperature	45	°C
LPG Calorific Value	10500	Kcal/Kg of LPG
LPG Burner Efficiency	90%	%
PV-T Warranty – Electrical	25	Years
PV-T Warranty – Thermal	15	Years
Inverter Replacement Year	13	Year (beginning)

Table 3: Technical values and assumptions for the PV-T case study

The performance of the PV-T is calculated using the PVSyst Software (version 6.88) (PVsyst, 2020), manufacturer data sheet, Eq. (1) and Eq. (2). The performance for the PV-T for the above case study is shown in Table 4.

	GlobEff kWh/m^2	E_Grid kWh_e	Performance Ratio - PV	E_thermal kWh_th
January	176	3,129	0.84	2,960
February	177	3,084	0.82	2,788
March	201	3,416	0.80	3,074
April	190	3,200	0.79	2,902
May	183	3,071	0.78	2,902
June	145	2,478	0.79	2,540
July	109	1,877	0.80	2,158
August	112	1,940	0.80	2,100
September	146	2,513	0.80	2,578
October	176	3,007	0.80	2,998
November	167	2,891	0.82	2,902
December	166	2,926	0.83	3,017
Year	**1,946**	**33,533**	**0.81**	**32,920**

Table 4: Estimated PV-T performance (PVsyst, 2020) (Dualsun Wave, 2017) (QAiST, 2012)

It can be seen from Table 4, that the electrical energy from the PV-T system is around 4.5% higher than the only solar PV installation of the same capacity. This is due to limiting the temperature rise up to 45 °C, and hence limiting the power loss due to temperature rise. The performance ratio also increases by around 5% compared to the solar PV installation of the same capacity. The predicted electricity generation from the 20.5 kWp PV-T system is 33,533 kWh and the thermal energy generation is 32,920 kWh.

Economic Analysis:

The assumptions and values considered for economic assessment are shown in Table 5.

Description	Value	Unit
Electricity Rates	7.5	INR/kWh
LPG Gas (Non – Subsidized)	89.1	INR/Kg
LPG Cost Escalation	4%	%/Year
Annual PV-T module degradation – Electrical	-1%	%/year
Annual PV-T module degradation – Thermal	-1%	%/year
O&M Inflation Rate	5%	%
Annual Maintenance Contract with Purchase	5	Year
Electricity Price Escalation	4%	%/Year
Loan Interest Rate	10%	%/Year
Loan Duration	10	Years
PV-T Panel Cost	65	INR/Wp
Thermal Storage Cost	36,750	INR
Solar BoS Cost	21	INR/Wp
Piping & Control Cost	10,000	INR
Discount Factor	8%	%
Debt	70%	%
Equity	30%	%
Effective Income Tax	25.17%	%
Reinvestment Interest Rate	8%	%

Table 5: Economic values and assumptions for the PV-T case study

Considering the financial benefits in the first year, PV-T system can save the electricity imported from the Grid around INR. 2.5 lacs and saves the LPG gas worth INR. 2.6 lacs. The life of thermal output is considered 15 years and the electricity production is considered 25 years as per the manufacturer's warranty terms. The economic analysis summary is shown in Table 6.

Description	Value
Project IRR	21%
Project MIRR	12%
Project Payback Period	5 Years 9 Months
Discounted Project Payback Period	5 Years 3 Months
Discounted Net Present Value (INR)	22,71,420

Table 6: Economic analysis results for PV-T

Considering the heat energy and electricity replacement from 20.5 kWp PV-T technology, the investment can give the project internal rate of return (IRR) is 21% and modified internal rate of return turns-out to 12%. The discounted payback period for the investment is 5 years and 3 months.

Conclusion

In the present paper, a comprehensive study of PV-T technology for industrial heating and electricity replacement has been carried out. The PV-T technology can save electricity imports from the grid and reduces the imports of fuel sources for the heating requirement. This paper shows the case study of the installation of 20.5 kWp capacity PV-T technology at MSME located in Ahmedabad, Gujarat, India. The technology can give around 5% more electrical output compared to a normal solar PV plant of the same capacity and saves around 2900 Kg of LPG for the heating requirement. The investment can give discounted payback period of 5 years and 3 months with the project IRR of 21%. The payback period can vary based on the heat energy replacement, and existing fuel source (coal, biomass, biogas, LPG, PNG, FO, SKO etc.). The positive NPV shows the attractiveness of the investment. Further, any financial assistance from the government, shall reduce the payback period and also increase the IRR.

References

AW, Z., J, W., L, M., GA, B., A, M., S, M., . . . R, S. (2020). Techno-Economic Assessment Guidelines for CO2 Utilization. Front. Energy Res. doi:https://doi.org/10.3389/fenrg.2020.00005

Blair, N., DiOrio, N., Freeman, J., Gilman, P., Janzou, S., Neises, T., & Wagner, M. (2021). System Advisor Model (SAM). USA. Retrieved from https://sam.nrel.gov/

Chang, S., Cho, J., Heo, J., Kang, J., & Kobashi, T. (2022). Energy infrastructure transitions with PV and EV combined systems using techno-economic analyses for decarbonization in cities. 319. doi:https://doi.org/10.1016/j.apenergy.2022.119254

Das, B. K., Alotaibi, M. A., Das, P., Islam, M., Das, S. K., & Hossain, M. A. (2021). Feasibility and techno-economic analysis of stand-alone and grid-connected PV/Wind/Diesel/Batt hybrid energy system: A case study. Energy Strategy Reviews, 37. doi:https://doi.org/10.1016/j.esr.2021.100673

Dualsun Wave. (2017). Technical Brochure. Retrieved from https://my.dualsun.com/wp-content/uploads/DualSun-EN-Datasheet-Wave.pdf

Economic Times. (2021, July 14). Power demand in India expected to grow 6 pc in 2021-22: ICRA. (The Economic Times) Retrieved 04 20, 2021, from https://energy.economictimes.indiatimes.com/news/power/power-demand-in-india-expected-to-grow-6-pc-in-2021-22-icra/84397368

Epp, B. (2022, Feb.). India close to the Solar Mission target of 20 million m2 collector area. Retrieved from Solar Thermal World: https://solarthermalworld.org/news/india-close-to-the-solar-mission-target-of-20-million-m2/

Epp, Bärbel. (2020). Hybrid solutions maximise solar yield per area. Solar Thermal World.

Hadorn, J. C., Lämmle, M., Kramer, K., Munz, G., Ryan, G., Herrando, M., & Brottier, L. (2020). Design Guidelines for PVT Collectors. IEA-SHC. doi:10.18777/ieashc-task60-2020-0003

IEA. (2021). Global Energy Review 2021. Paris: IEA. Retrieved from https://www.iea.org/reports/global-energy-review-2021

IEA-SHC. (2021). PVT Systems: Heat or Electricity From Solar – Why Only One When You Can Have Both? . IEA-SHC.

Joshi, Y. C., & Kishore, K. (2017). DO MSMEs PRACTICE ENERGY CONSERVATION PRINCIPLE: A CASE OF GUJARAT. Journal of Energy and Management, 1(2). Retrieved from https://pdpu.ac.in/downloads/5_does_MSME.pdf

Khan, F. A., Pal, N., Saeed, S., & Yadav, A. (2022). Techno-economic and feasibility assessment of standalone solar Photovoltaic/Wind hybrid energy system for various storage techniques and different rural locations in India. Energy Conversion and Management, 270. doi:https://doi.org/10.1016/j.enconman.2022.116217

Lämmle. (2020, Feb.). Utilization of solar spectrum of a PVT collector. Retrieved from https://commons.wikimedia.org/w/index.php?curid=87526248

Lämmle, Manuel; Herrando, María; Ryan, Glen. (2020, May 1). Basic concepts of PVT collector technologies, applications and markets. Retrieved March 2022, from https://doi.org/10.18777/ieashc-task60-2020-0002

MNRE. (2021, Oct. 11). India set to achieve 450 GW renewable energy installed capacity by 2030. Retrieved June 2022, from https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=1762960

MNRE. (2022). Programme/Scheme wise Cumulative Physical Progress. Delhi: MNRE. Retrieved 07 21, 2022, from https://mnre.gov.in/the-ministry/physical-progress

PVsyst. (2020, August). PVsyst Photovoltaic Software. Switzerland. Retrieved from https://www.pvsyst.com/release-notes-6-8x/

QAiST. (2012). A guide to the standard EN 12975. Retrieved from http://www.estif.org/fileadmin/estif/content/projects/QAiST/QAiST_results/QAiST%20D2.3%20Guide%20to%20EN%2012975.pdf

REN21. (2021). Renewables 2021 Global Status Report. Paris: REN21 Secretariat.

2

NEUTRAL-POINT-CLAMPED BOOST TRANSFORMER-LESS MULTILEVEL INVERTER FOR SOLAR PV APPLICATION

Kaibalya Prasad Panda

ABSTRACT: Transformer-less multilevel inverters (MLI) are most popular in photovoltaic applications. In such system, a significant leakage current flows that needs to be reduced. One of the method being the common-ground structure and the other most popular is the active neutral-point-clamping (NPC) method, which reduces the common-mode voltage and thus the leakage current. Voltage boosting using minimum number components is also another key requirement. This work proposes a 7-level single-input transformer-less NPC MLI using switched-capacitor (SC) concept. The SC are charged to the input voltage magnitude in parallel and discharged in series, which retains the self-voltage balancing ability. The SC voltage and the dc-link voltage in combination thus produce 1.5 times boosted output. The voltage stress in the proposed topology is also limited to input voltage magnitude. Compared to the recently developed 7-level similar topologies, the proposed topology has lower conduction loss and higher efficiency. Detailed simulations are carried out under change in modulation index, load variation, change in supply input and change in load frequency, to validate the efficacy of the proposed MLI.

KEYWORDS

Boost multilevel inverter, Neutral-point-clamping, Reduced switch, Single-input, Seven-level, Switched-capacitor, Voltage-balancing

Introduction

Emergence of green energy utilization in the energy sector has put forward rigorous development of new power electronic converters in the recent years (Pawar, 2019). Green energy sources such as photovoltaic (PV), wind, etc. are more popular for impactful energy generation and utilization (Joshi et al., 2017; Shah, 2018). In such systems, dc-dc converter and dc-ac converters are the heart of the systems. The two stage system generally includes and dc-dc stage and recently developed single-stage systems avoids dc-dc stage (Budhrani et al., 2018; Sen et al., 2019). A single-stage system also avoids a high-cost transformer and such transformer-less single-stage PV systems thus need an inherent boosting ability. Inherent boosting ability can be achieved by designing boost type inverters and recent-art multilevel inverters (MLIs) are one of such types (Bana et al., 2019; Bharath et al., 2020).

Conventionally, MLIs are cascaded H-bridge (CHB) type, flying capacitor (FC) based and neutral-point-clamped (NPC) type. All the three topologies have been widely deployed in PV systems to improve the power quality and efficiency (Bana et al., 2019; K. P. Panda, Anand, et al., 2018). More number of components has been a major concern in conventional MLIs and thus in (K. P. Panda et al., 2019; K. P. Panda & Panda, 2018) new structures have been introduced with reduced number of components. Structures in (K. P. Panda, Bana, et al., 2018; K. P. Panda et al., 2020b) are other such types of MLI that reduces the number of switches. These structures are competitive with respect to high-level output generation. However, the switch count with respect to number of levels and the source count with respect to number of levels is very high. These structures are based on H-bridge and require multiple numbers of sources. More number of sources imposes issues on controlling each of the individual panels in PV application. Another concern is the absence of boosting feature in conventional MLIs, which is a mandatory requirement in PV application when feeding power to the load or utility grid. Only suitable solution to design a transformer-less dc-ac converter with inherent boosting feature is switched-capacitor (SC) based MLIs.

SC MLIs have been a recent emerging alternative that is highly suitable for PV and high-frequency applications. Structures in (Babaei & Gowgani, 2014; Hinago & Koizumi, 2012) requires a single-source to produce a boosted output utilizing reduced number of components than the conventional structures. The SCs used in the circuit are charged in parallel and discharge in series, which enables maintaining of the required voltage in the continuous operation. The basic modules in these MLIs produce a 5-level (5L) output using two switches, one capacitor and a diode. A key advantage is the self-balancing and boosting ability of the capacitors, which does not burden the control design. Significant reduction in number of switches is still possible using (K. P. Panda et al., 2020c; Peng et al., 2019). These structures produce a 7-level (7L) output using single-source and a few capacitors. Both structures can be suitably extended to synthesize higher voltage levels at the output. Similar other SC MLIs proposed in (Khan et al., 2020; K. P. Panda et al., 2022) are extendable to higher levels. Although these MLIs need fewer switches, but requires a full-bridge along with a basic module to produce the 7L output. The four switches in the full-bridge sums up to a high voltage stress, which needs special attention. To produce high-quality output while avoiding the full-bridge, 13-level (13L) structures proposed in (K. P. Panda et al., 2020a; P. Panda et al., 2020) are the best alternatives. Using single-source the three to six-times voltage boosting is possible using minimum number of capacitors and reduced switch count compared to recent-art topologies.

The above-disclosed topologies have different advantages as mentioned. However, with respect to integrating with single-stage grid-tied PV systems another key concern is the leakage current. None of the structures discussed above as the ability to reduce the leakage current by keeping the common mode voltage minimum. Leakage current magnitude though very less can introduce significant issues in the system as well as impose restrictions to the customers. Retaining all the advantages, a straight-forward solution to get rid of the leakage current is enabling a common-grounded (CG) connection (Barzegarkhoo et al., 2021) and NPC type connection (K. P. Panda et al., 2020d). Fig. 1 shows the generalized presentation of both these types of transformer-less MLIs. As can be clearly seen, the ac neutral is connected to negative of the dc-link in CG MLIs and the ac neutral is connected to the common dc-link neutral clamping point.

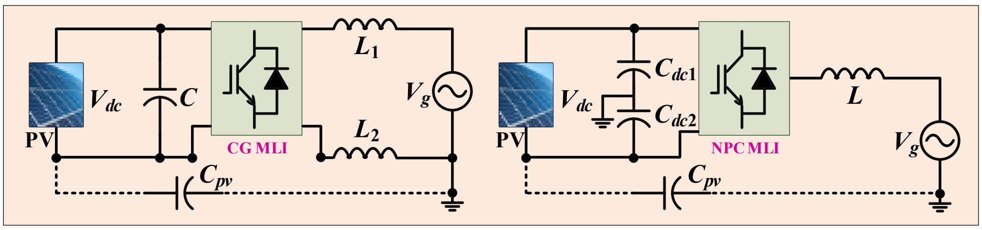


Figure 1: Generalized design of transformer-less MLI

Active NPC type SC MLIs have been proposed with an aim to utilize in transformer-less PV systems. The structure in (Siwakoti et al., 2019) is one such type, which has the disadvantage of voltage boosting while generating a 7L output. With regard to voltage boosting, which is an essential requirement, NPC type boost structures (NPC-B-MLI) in (Lee et al., 2019, 2020; Lee & Lee, 2019; Sathik et al., 2019) are the improved alternative topologies. These structures need reduced number of switches and a single input voltage. Some structure has high voltage stress and the other MLI has high rating of the capacitors. A most compact structure recently proposed in (K. P. Panda et al., 2020d) that has all the discussed advantages. With this motivation, this work proposes a 7L NPC-B-MLI with maximum advantages for utilization in single-stage PV systems.

The operational analysis of the proposed MLI is carried out in the Section 2, which also includes the design guidelines and voltage balancing investigation in detail. A comparative summary is included in Section 3 to justify the benefits of newly developed structure. Section 4 analyzes the results using MATLAB simulations. At the end, conclusions are drawn.

2. Design and Operation of the Proposed NPC-B-MLI

Fig. 2 shows the proposed 7L NPC-B-MLI topology consisting of one input source (V_{dc}), 2 dc-link capacitors (C_{dc1} & C_{dc2}), two switched capacitors (C_1 & C_2), 4 diodes (D_1 – D_4) and 7 switches (S_1 – S_7). One of the switches S3 is a bidirectional switch and all other switches are unidirectional.

An inductor L is additionally connected in the charging path of the SCs, which plays an important role in reducing the high current spikes in capacitor arises due to the potential difference between the source voltage and steady-state capacitor voltage. The switches $S_1 - S_3$ conducts only once in each half-cycles. On the other hand, switches S_4 & S_5 conducts completely in the positive half cycle and S_6 & S_7 conducts only in the negative half cycle. In this way, the proposed MLI produces 7 level output with 0, $\pm 0.5V_{dc}$, $\pm V_{dc}$, $\pm 1.5V_{dc}$ levels.

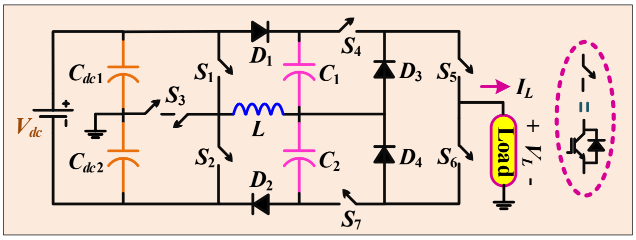


Figure. 2: Proposed 7-level NPC-B-MLI

Considering the steady-state voltage across the dc-link capacitors as $V_{dc}/2$ and the steady-stage voltage across the SCs as V_{dc}, the circuit operation is analyzed. The zero level is synthesized due to the conduction of the bidirectional switch S_3 and alongside the switches S_5 and S_6 turned on to freewheel the load current. The capacitors are idle under this condition. As stated earlier, switches S_4 & S_5 conducts completely in the positive half cycle and S_6 & S_7 conducts only in the negative half cycle. The SCs C_1 and C_2 are charged while the dc-link capacitor produces the first level of output, i.e., $+0.5V_{dc}$ and $-0.5V_{dc}$, respectively due to conduction of S_2 and S1 additionally in the positive and negative half cycles. The bidirectional switch conducts in the next level during $\pm V_{dc}$ and only the SCs are accountable for generation of this voltage level. The peak voltage level is produced by turning on S_1 and S_2 additionally in the positive and negative half cycles. Both the dc-link capacitor and SC are accountable for generation of the peak voltage level $\pm 1.5V_{dc}$. The equivalent circuit in each level is shown in Fig. 3 without the inductor, as the selected value of the inductor is very small.

V_L	On switch (1) and Off switch (0)						
	S_1	S_2	S_3	S_4	S_5	S_6	S_7
$1.5V_{dc}$	1	0	0	1	1	0	0
$1V_{dc}$	0	0	1	1	1	0	0
$0.5V_{dc}$	0	1	0	1	1	0	0
0	0	0	1	0	1	1	0
$-0.5V_{dc}$	1	0	0	0	0	1	1
$-1V_{dc}$	0	0	1	0	0	1	1
$-1.5V_{dc}$	0	1	0	0	0	1	1

Table 1: Conduction of the Switches to Generate 7L Output

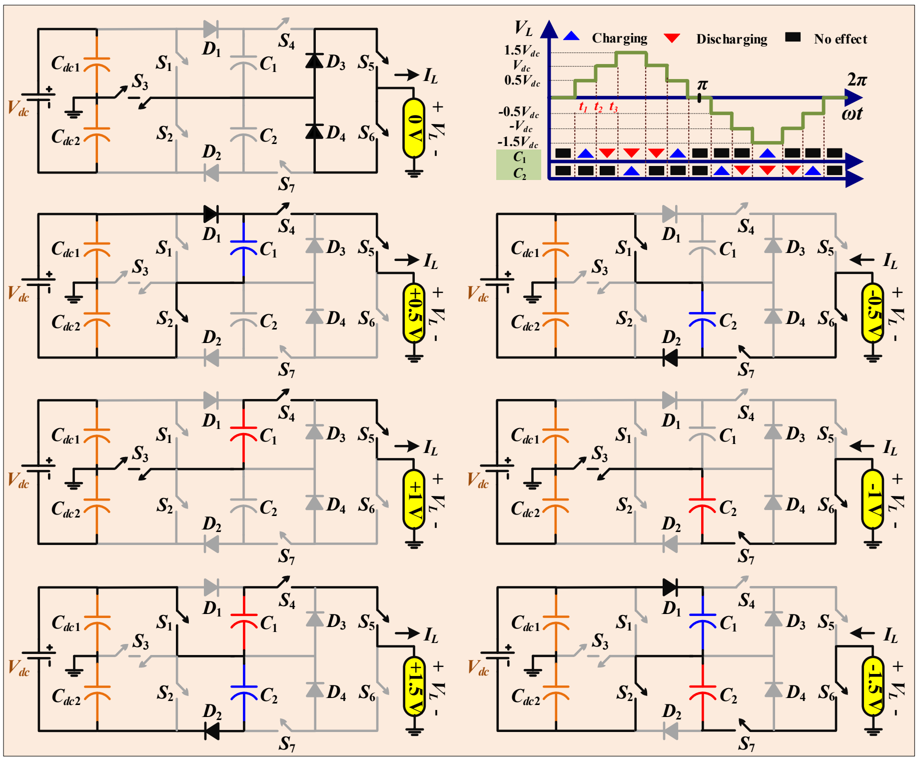


Figure 3: Operational Modes Of The Proposed 7-Level Npc-B-Mli

2.1 Self-voltage Balancing Analysis

The capacitor C_2 are charged when S_1-D_2 conducts simultaneously and similarly C_1 is charged when S_2-D_1 conducts simultaneously. Both these capacitors are charged to V_{dc} in parallel with the dc source and discharged in series with the source within a cycle of conduction. In other words, both capacitors charging-discharging duration is sufficiently less than one full cycle. This in turn enables self-balancing of the voltage across SCs. On the other hand, the input voltage is divided equally across the dc-link capacitors due to type of connection. Thus, the steady-state voltage across the dc-link capacitors is $V_{dc}/2$. This proves all the capacitors used in the proposed circuit are self-balanced type and does not require any additional control circuit for voltage balancing.

2.2 Design Guidelines

The capacitors in the proposed MLI are responsible for voltage levels generation. Therefore, the capacitor ratings and sizing is a key factor for smooth operation of the proposed MLI. Considering the duration of discharging of the capacitors, the voltage ripple (ΔV_c) and the peak load current (ILp), SCs can be selected. From Fig. 3, both the SCs discharge for the same duration that is during [t_2 to π-t_2]. Therefore, supposedly considering a voltage ripple of (x = 5%), the capacitance of the SCs (C_1 or C_2) is expressed as follows:

$$C \geq \frac{\Delta Q_c}{\Delta V_c} = \frac{2 I_{Lp} \cos t_2 \cos \Phi}{x \omega V_{dc}}$$

where ΔQc is the discharging quantity, Φ is the phase angle and ω = 2πfo.

On the other hand, the dc-link capacitors carry equal voltage and current as per the connection. Considering the peak load current ILp is flowing in the dc-link capacitors, the capacitance (Cdc1 or Cdc2) can be calculated as,

$$C_{dc} = \frac{\Delta Q_{dc}}{\Delta V_{dc}} = \frac{I_{Lp}}{\omega \Delta V_{dc}}$$

where ΔQdc is the discharging quantity and ΔVdc is the voltage ripple across the dc-link capacitors.

Comparative Analysis with Existing Boost Type MLIs

To justify the advantages of the proposed MLI, similar topologies developed recently are taken into comparative analysis. All the structures require a single dc source to produce 7L output of 1.5 times the voltage gain. In terms of number of switches, the proposed MLI requires minimum number of switches similar to the structure (K. P. Panda et al., 2020d). Only 7 drivers are required, which is also minimum compared to the existing MLIs. In terms of number of switches in the conducting path, the proposed MLI is superior as it is minimum. This indicates lower conduction loss in the proposed topology. Minimum voltage stress is another key advantage of the proposed MLI. The peak voltage stress is not more than the input voltage. These advantages clearly indicate the superiority of the proposed MLI in single-stage transformer-less PV application.

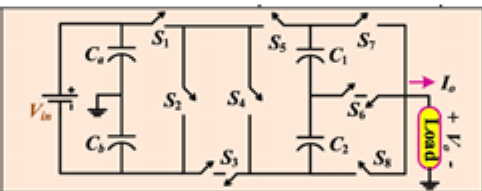
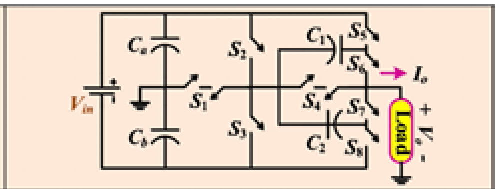
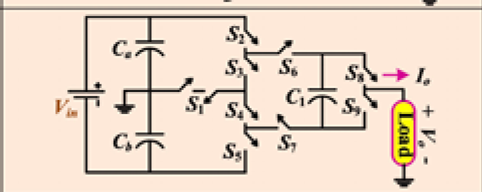
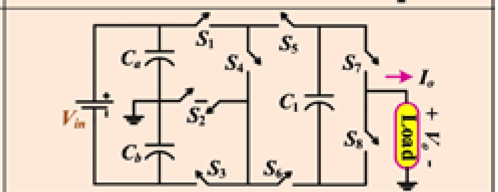
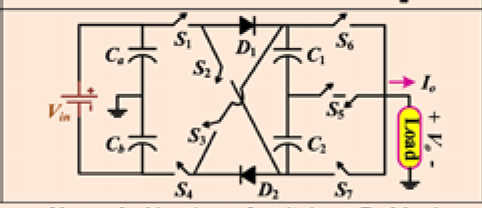
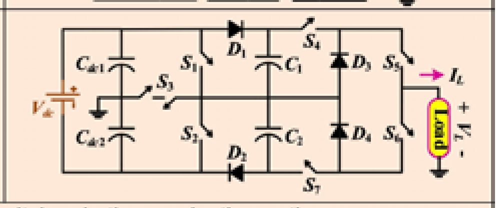
MLI in (Lee et al., 2019) A = 10 B = 6		MLI in (Lee & Lee, 2019) A = 10 B = 5	
MLI in (Sathik et al., 2019) A = 10 B = 5		MLI in (Lee et al., 2020) A = 9 B = 5	
MLI in (K. P. Panda et al., 2020d) A = 8 B = 4		Proposed MLI A = 8 B = 3	
Note: A: Number of switches, **B:** Maximum number of switches in the conducting path			

Table 2: Comparison of the Proposed MLI with Similar 7-level Structures

Simulation results

Simulations are carried out in Simulink platform to verify the correct functioning of the proposed MLI. Several modulation schemes have been disclosed in the literature (Bana et al., 2019; K. P. Panda et al., 2020b). Fundamental switching schemes are easier to implement, whereas carrier-based modulation techniques are useful in closed-loop control systems. The objective of the work here is to justify the operation ability only. Therefore, using a fundamental frequency modulation, switching angles are pre-computed and used for pulse generation. The topology is designed in simulink with an input voltage of 100 V and for an output frequency of 50 Hz. The dc-link capacitor values are 1500 μF and the SCs of 2200 μF are selected. A small inductor of 8 μH is used in the circuit. Fig. 4 shows the output with continuous change in modulation index from time to time. The switching angles are stored in form of a look-up table for each modulation index before they are processed. At higher modulation index of 0.95, THD is about 10 % and THD goes on increasing from 15 % to 19 % with reduction in modulation index from 0.65 to 0.1. Note that, the capacitor voltages are balanced at the steady state voltage in the ratio of 1:2.

Further, to justify the self-voltage balancing and voltage boosting ability, the input voltage change is applied as in Fig. 5 from 80 V to 100 V. The capacitor tracks the required voltage naturally. The SC voltages changes from almost 80 V to 100 V, whereas the dc-link capacitor voltages balances inherently. In this way, the peak output voltage changes from almost 120 V to 150 V smoothly. This result is taken under a steady-state resistive-inductive (RL = 50 ohm – 0.2 H) loading.

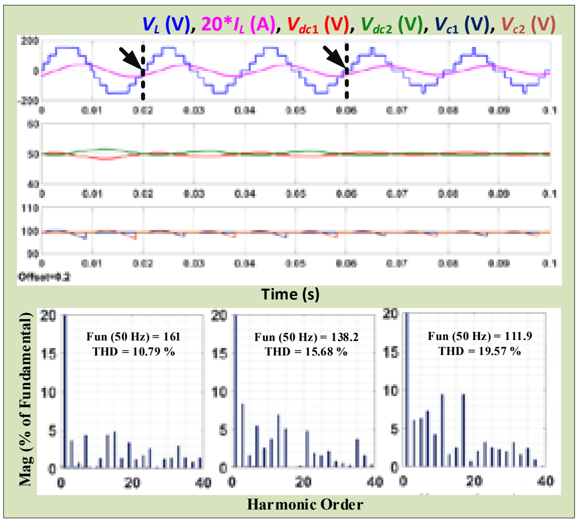


Figure 4: Results under a change in modulation index

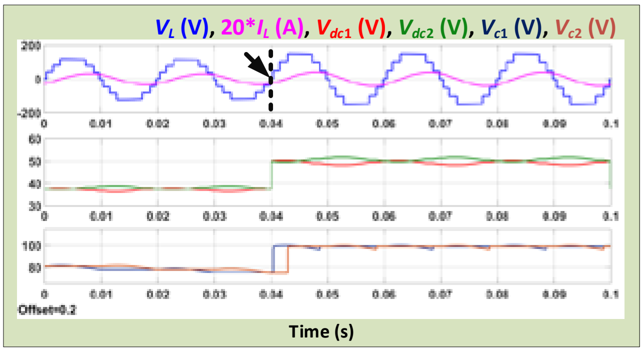


Figure 5: Results under sudden increase in input voltage

Sudden change in load is inevitable for inverter integrated systems. Considering this, first the load is varied from resistive (R = 80 ohm) to resistive-inductive (RL = 50 ohm – 0.2 H) loading. As can be seen from Fig. 6, the load current changes the pattern from staircase type to sinusoidal type. The SC voltage ripple reduces and the ripple in dc-link increase with a decrease in loading. Similar, results are observed when the load changes from 120 ohm – 0.1 H to 50 ohm – 0.2 H. It can be noticed that, the 7-level and 1.5 times boosted load voltage is unaffected.

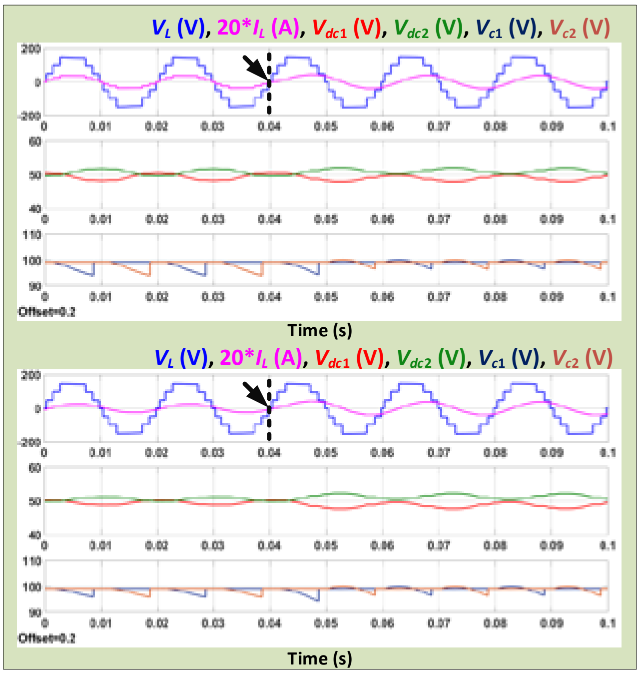


Figure 6: Results under sudden change in loading

Fig. 7 shows the results under change in load frequency. SC type MLIs will be useful in high-frequency applications as the charging current reduces at high frequency. As the frequency changes from 50 Hz to 100 Hz, load voltage changes and the capacitor voltage reduces notably. With an inductor in the charging loop, the charging current with 50 Hz load frequency is very low. Also, with 100 Hz load frequency the capacitor current drops to a very low value.

Fig. 8 shows the voltage stress across each of the switches, power losses and efficiency. Voltage stress across all the switches is limited to the magnitude of input voltage. It can also be verified that except the switch S3, all other switches are unidirectional. Further, the switching loss (PsL), conduction loss (PcL) and the ripple loss in capacitors (PrL) that majorly contributes to the total power loss is evaluated by detailed circuit simulation. The power loss increases with increase in output power, but the efficiency of the proposed circuit is preserved more than about 95 %.

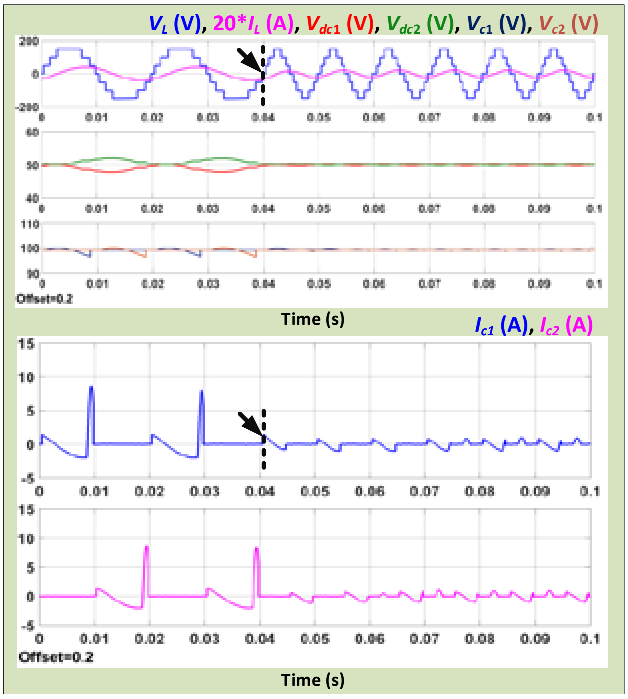


Figure 7: Results under increase in load frequency

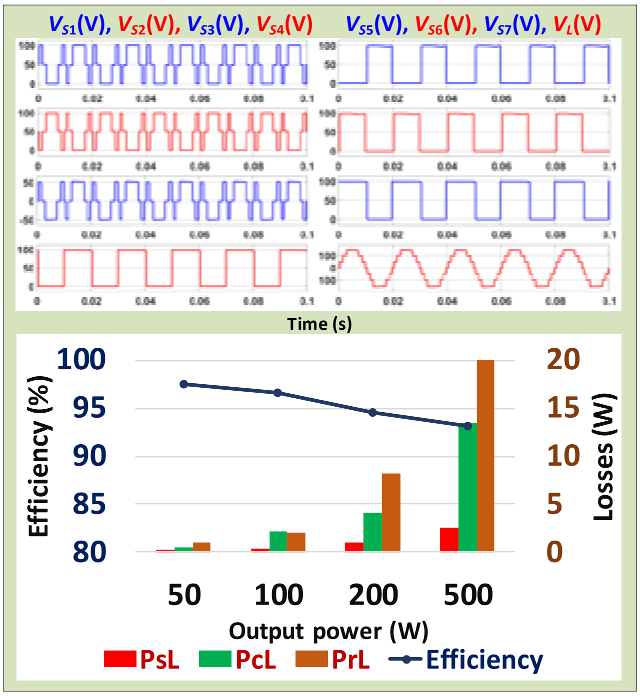


Figure 8: Voltage stress and Efficiency evaluation

Conclusion

This work has introduced a novel NPC MLI based on SC concept suitable for transformer-less PV application. NPC connection reduces the common-mode voltage and therefore, the leakage current issue is resolved. The proposed MLI consists of a single-source and reduced number of components that synthesizes a 7-level output. The SC assists in voltage boosting to 1.5 times by maintaining the desired voltage across it inherently. Therefore, control complexity is simplified. The voltage stress across the switches is kept within the limit of the input voltage magnitude that avoids the design complexities in high-voltage application. The detailed operation of the circuit in different mode shows that the proposed MLI can work effectively under any load power factor. Additionally, only a maximum of three-switches are in conduction in any level, which maintains lower power loss. All these advantages have been verified through detailed comparison with state-of-art 7-level NPC-type boost MLIs. Simulation results under different condition justify the operation under low-high modulation index, different loading condition and change in input voltage.

References

Babaei, E., & Gowgani, S. S. (2014). Hybrid Multilevel Inverter Using Switched Capacitor Units. IEEE Transactions on Industrial Electronics, 61(9), 4614–4621.

Bana, P. R., Panda, K. P., Naayagi, R. T., Siano, P., & Panda, G. (2019). Recently Developed Reduced Switch Multilevel Inverter for Renewable Energy Integration and Drives Application: Topologies, Comprehensive Analysis and Comparative Evaluation. IEEE Access, 7, 54888–54909.

Barzegarkhoo, R., Lee, S. S., Khan, S. A., Siwakoti, Y., & Lu, D. D.-C. (2021). A Novel Generalized Common-Ground Switched-Capacitor Multilevel Inverter Suitable for Transformerless Grid-Connected Applications. IEEE Transactions on Power Electronics, 36(9), 10293–10306.

Bharath, G. V., Hota, A., & Agarwal, V. (2020). A New Family of 1-φ Five-Level Transformerless Inverters for Solar PV Applications. IEEE Transactions on Industry Applications, 56(1), 561–569.

Budhrani, A. H., Bhayani, K. J., & Pathak, A. R. (2018). Design Parameters Of Shunt Active Filter For Harmonics Current Mitigation. PDEU JOURNAL OF ENERGY AND MANAGEMENT, 2(2).

Hinago, Y., & Koizumi, H. (2012). A Switched-Capacitor Inverter Using Series/Parallel Conversion With Inductive Load. IEEE Transactions on Industrial Electronics, 59(2), 878–887.

Joshi, S., Pandya, V., & Dhandhia, A. (2017). Simulation on MPPT Based Solar PV Standalone System. PDEU JOURNAL OF ENERGY AND MANAGEMENT, 2(1).

Khan, M. N. H., Forouzesh, M., Siwakoti, Y. P., Li, L., & Blaabjerg, F. (2020). Switched Capacitor Integrated (2n + 1)-Level Step-Up Single-Phase Inverter. IEEE Transactions on Power Electronics, 35(8), 8248–8260.

Lee, S. S., Bak, Y., Kim, S.-M., Joseph, A., & Lee, K.-B. (2019). New Family of Boost Switched-Capacitor Seven-Level Inverters (BSC7LI). IEEE Transactions on Power Electronics, 34(11), 10471–10479.

Lee, S. S., & Lee, K. (2019). Dual-T-Type Seven-Level Boost Active-Neutral-Point-Clamped Inverter. IEEE Transactions on Power Electronics, 34(7), 6031–6035.

Lee, S. S., Lim, C. S., & Lee, K.-B. (2020). Novel Active-Neutral-Point-Clamped Inverters With Improved Voltage-Boosting Capability. IEEE Transactions on Power Electronics, 35(6), 5978–5986.

Panda, K. P., Anand, A., Bana, P. R., & Panda, G. (2018). Novel PWM Control with Modified PSO-MPPT Algorithm for Reduced Switch MLI Based Standalone PV System. International Journal of Emerging Electric Power Systems, 19(5).

Panda, K. P., Bana, P. R., Naayagi, R. T., & Panda, G. (2022). A Dual-Source Self-Balanced Switched-Capacitor Reduced Switch Multilevel Inverter With Extending Ability. IEEE Access, 10, 61441–61450.

Panda, K. P., Bana, P. R., & Panda, G. (2018). FPA Optimized Selective Harmonic Elimination PWM Technique Application in Reduced Switch Count Multilevel Inverter. 2018 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), 1–6.

Panda, K. P., Bana, P. R., & Panda, G. (2020a). A Reduced Device Count Single DC Hybrid Switched-Capacitor Self-Balanced Inverter. IEEE Transactions on Circuits and Systems II: Express Briefs, 1–1.

Panda, K. P., Bana, P. R., & Panda, G. (2020b). FPA Optimized Selective Harmonic Elimination in Symmetric–Asymmetric Reduced Switch Cascaded Multilevel Inverter. IEEE Transactions on Industry Applications, 56(3), 2862–2870.

Panda, K. P., Bana, P. R., & Panda, G. (2020c). A Self-Balanced Switched-Capacitor Boost Seven-Level Inverter for Photovoltaic Systems. 2020 IEEE International Conference on Computing, Power and Communication Technologies (GUCON), 338–343.

Panda, K. P., Bana, P. R., & Panda, G. (2020d). Reduced Switch Count Seven-level Self-Balanced Switched-Capacitor Boost Multilevel Inverter. 2020 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), 1–6.

Panda, K. P., Lee, S. S., & Panda, G. (2019). Reduced Switch Cascaded Multilevel Inverter with New Selective Harmonic Elimination Control for Standalone Renewable Energy System. IEEE Transactions on Industry Applications, 55(6), 7561–7574.

Panda, K. P., & Panda, G. (2018). Application of swarm optimisation-based modified algorithm for selective harmonic elimination in reduced switch count multilevel inverter. IET Power Electronics, 11(8), 1472–1482.

Panda, P., Bana, P. R., & Panda, G. (2020). A Switched-Capacitor Self-Balanced High-Gain Multilevel Inverter Employing a Single DC Source. IEEE Transactions on Circuits and Systems II: Express Briefs, 1–1.

Pawar, M. (2019). A Study On Implementation Of 'Smart Grid' Technology In Indian Power Sector. PDEU JOURNAL OF ENERGY AND MANAGEMENT, 4(1).

Peng, W., Ni, Q., Qiu, X., & Ye, Y. (2019). Seven-Level Inverter With Self-Balanced Switched-Capacitor and Its Cascaded Extension. IEEE Transactions on Power Electronics, 34(12), 11889–11896.

Sathik, M. J., Sandeep, N., & Blaabjerg, F. (2019). High Gain Active Neutral Point Clamped Seven-Level Self-Voltage Balancing Inverter. IEEE Transactions on Circuits and Systems II: Express Briefs, 1–1.

Sen, P., Bana, P. R., & Panda, K. P. (2019). Firefly Assisted Genetic Algorithm for Selective Harmonic Elimination in PV interfacing Reduced Switch Multilevel Inverter. International Journal of Renewable Energy Research (IJRER), 9(1), 32–43.

Shah, N. (2018). Analysis Of The Key Factors Affecting Levelized Cost Of Electricity Of Solar Pv In India. PDEU JOURNAL OF ENERGY AND MANAGEMENT, 3(1).

Siwakoti, Y. P., Mahajan, A., Rogers, D. J., & Blaabjerg, F. (2019). A Novel Seven-Level Active Neutral-Point-Clamped Converter With Reduced Active Switching Devices and DC-Link Voltage. IEEE Transactions on Power Electronics, 34(11), 10492–10508.

1

KEY DETERMINANTS BEHIND AN INTERNATIONAL FINANCIAL SERVICES CENTRE: AN EXPLORATORY STUDY OF INDIA'S MAIDEN IFSC AT GANDHINAGAR, GUJARAT

Dipesh Shah and Dr. Pawan K. Chugan

ABSTRACT: Several countries in Asia and Middle East established new age International Financial Centres e.g. Singapore, Dubai, Abu Dhabi, Qatar to name a few. India, which is one of the largest and fastest growing major economies in the world, established its maiden International Financial Services Centre (IFSC) at GIFT City, Gandhinagar in State of Gujarat, India. This research paper focuses on the journey of operationalizing India's maiden IFSC in GIFT City. It highlights some of the compelling factorings behind the setting up of an IFSC in India and provides insights into the key determinants for its development.

KEYWORDS

IFSC, GIFT IFSC, Global Financial Centres, Offshore Financial Centres (OFCs), India International Bullion Exchange (IIBX).

1. Introduction

International Financial Centres (IFCs) have assumed prominence in the global financial system primarily because of two reasons, one, they have contributed enormously to the growth in the volumes of international financial transactions and two, these centres have played a pivotal role in accelerating the pace of financial globalization. Broadly speaking, an IFC is a jurisdiction with a heavy concentration of a variety of financial institutions, that offer specialized financial services and products to non-residents as well as residents, in an environment that facilitates the development of financial markets.

Typically, scholars distinguish and divide the IFCs into two broad categories (IMF 1987): Traditional IFCs are the ones that have evolved during the 19th and 20th Century in the cities of Europe and the United States of America and the Offshore Financial Centres (OFCs), which are relatively of recent origin and have come up in developing countries as a carve-out jurisdiction. While the traditional centres evolved as a result of growth in international trade and commerce, the new age OFCs have been developed by countries through a more calibrated approach with a view to onshore international financial services business and acquire global expertise in niche and emerging financial services activities.

The advent of OFCs can be categorized as an inflection point for the global financial system as it paved the way for onshoring of highly specialized and niche international financial services business into Asia and the Middle East. In the early 1980's China took the lead by developing Hong Kong as a leading offshore financial centre, which would later emerge as a second engine of growth for the country, subsequently, several other countries established OFCs including Malaysia, which established the Labuan International Business and Financial Centre (IBFC) in 1990, UAE established the Dubai International Financial Services Centre (DIFC) in

2000 and Abu Dhabi Global Markets (ADGM) in 2015 and Qatar established the Qatar Financial Centre (QFC) in Doha in 2005.

India, on the other hand, was a rather late entrant in establishing an international financial centre, however, several compelling arguments can be put forth for the relative delay, which inter alia, are as follows: one, the liberalization of the Indian economy began only after the 1991 LPG reforms (Prasad, 2021), which paved the way for gradual and calibrated integration of Indian economy into the global financial system. Second, the Indian financial markets were at an evolutionary stage and not mature enough to deal with the vagaries associated with international financial transactions and most importantly, the 2008 Global Financial Crisis was a big setback for the entire developing world.

However, the inflection point came about in 2015 when Government of India implemented a major financial sector reform by operationalizing India's maiden International Financial Services Centre (IFSC) in GIFT City located at Gandhinagar, State of Gujarat, India.

It was only in 2015, that India's tryst with operationalizing the maiden International Financial Services Centre (IFSC) in GIFT City became a reality. A spin-off advantage of being a late entrant in the global IFC ecosystem, was that India could evaluate, assess and learn from the development models adopted by other offshore financial centres in their respective jurisdictions.

On the policy front, three-four compelling factors can be attributed to India's setting up of its maiden IFSC. First, as one of the largest and fastest growing major economies in the world, India could not afford to play a passive role in International Financial Services business, by merely being a consumer of International Financial Services. Therefore, GIFT IFSC was operationalized to transform India from being an importer of International Financial Services to become self-sufficient as well as an exporter of International Financial Services. Moreover, it was estimated that even under conservative assumptions, purchases by Indian households and firms of IFS will be nearly $50 billion by 2015 and could exceed $120 billion by 2025 (DEA, 2016).

Secondly, a vibrant IFSC has the potential to act as a catalyst for growth of domestic India economy. Banking services, asset management, stock market and intermediary services provided in an IFSC attracts huge amounts of global capital inflows (Mangaldas, 2021), which can then be channelized into domestic Indian economy for development purpose.

Thirdly, India has the inherent advantage of having vast young talent pool, in the field of finance as well as Informational Technology. Therefore, operationalization of IFSC in India would give huge employment opportunities to talented young professionals in financial segments such as Banking, Fund Management, FinTech, Insurance, etc.

GIFT-IFSC: Journey

Recognizing the substantial contribution which can be made by an OFC to the socio-economic growth and development of a country, Indian policy makers legally incorporated the concept of an International Financial Service Centre (IFSC) in the Special Economic Zones Act 2005 (SEZ India). Section 18 of the act provides that Central Government may approve the setting up of an IFSC in a Special Economic Zone and may prescribe the requirements for setting up and operation of such centre.

On the policy front, another major development occurred in the year 2007, when the High-Power Expert Committee Constituted by Finance Ministry to examine the feasibility of setting up an IFC in India, submitted its report to the Government. The committee made a range of recommendations which, inter alia, included regulatory and policy reforms that would be required if India were to develop an IFC. However, with the onset of 2008 Global Financial Crisis, the proposal was put on backburner.

The committee in its report observed that the rapid growth of Indian economy had created substantial local demand for International Financial Services and a failure to respond to on the supply side would result in purchase of such international financial services from overseas financial centres (DEA, 2016).

Later, it was only after the Indian economy started showing signs of economic recovery, in the aftermath of 2008 financial crisis, that the breakthrough moment finally arrived. Government of India in the Union Budget 2015-16 made the following announcement:

"87. While India produces some of the finest financial minds, including in international finance, they have few avenues in India to fully exhibit and exploit their strength to the country's advantage. GIFT in Gujarat was envisaged as International Finance Centre that would actually become as good an International Finance Centre as Singapore or Dubai, which, incidentally, are largely manned by Indians. The proposal has languished for years. I am glad to announce that the first phase of GIFT will soon become a reality. Appropriate regulations will be issued in March (Union Budget, 2016)".

The Union Budget announcement paved the way for operationalizing the maiden IFSC in GIFT City Multi-Service SEZ, Gujarat. To set the ball rolling, the domestic financial regulators namely RBI, SEBI and IRDAI notified the initial set off regulations to allow for financial institutions to commence operations in IFSC. Most importantly, in 2015 RBI's foreign exchange rules under the FEMA, inter alia, provided that financial institution set up in IFSC would be treated as Person Resident Outside India under Foreign Exchange Management Act 1999, thereby removing capital control restrictions on the flow of foreign capital into and out of IFSC. This in effect made the maiden IFSC in GIFT City a separate international financial jurisdiction.

Despite the regulatory enablers provided by the Government of India, the IFSC did not achieve desired results because the growth and development of an IFSC is a rather complex and evolving concept, which is contingent on a host of other determinants, which is discussed in the following paras.

Key Determinants for Setting up an International Financial Services Centre (IFCS) in India:

The Global Financial Centres Index (GFCI) Report is a leading international report published by China Development Institute (CDI) in Shenzhen and Z/Yen Partners in London, which evaluates and assesses more than 100 financial centers on predetermined competitiveness factors. The instrumental factors used in the GFCI model are grouped into five broad areas of competitiveness: **Business Environment, Human Capital, Infrastructure, Financial Sector Development, and Reputation (GFCI 2020)**.

This research paper attempts to discuss and evaluate the current position of GIFT IFSC across the 4 broad determinants highlighted in GFCI report.

The institutional and regulatory environment is an essential component of Business environment. To provide for dedicated institutional & regulatory intervention at the maiden IFSC in India, the policymakers evaluated the regulatory architecture prevailing in several international financial centres such as Hong Kong, Singapore, Dubai & Qatar and acknowledged the prevalence of a unified financial regulatory body in some form or the other, in all the aforesaid financial centres. Therefore, to promote ease of doing business, the Union Parliament passed the International Financial Services Centres Authority Act 2019 and established the International Financial Services Centres Authority (IFSCA), as a unified financial regulator for development and regulation of financial institutions, financial products, and financial services.

The IFSCA, which assumed regulatory powers with effect from 1st Oct 2020, worked primarily on three fronts: **one**, to bring internationally aligned regulatory regime across various verticals including Banking, Capital Markets, Fund Management, Insurance, etc. thereby moving away from India centric regulatory regime, **second**, to onshore new financial services and products which were previously being purchased from offshore jurisdictions, including services such as Aircraft Leasing and Finance, International Bullion Exchange, FinTech, etc. and **third**, proactively working towards facilitating ease of doing business for the financial services industry (Shah and Chugan, 2015).

Another key component of the Business Environment is Tax competitiveness. Towards this end, the Government of India provided a special tax incentive in the form of Section 80 LA of Income Tax Act 1961 which exempted firms in IFSC to pay tax on business profits for a 10 year bracket out of first 15 years (Income tax India, 2019). Additionally, various other tax concessions were extended in IFSC so as to position GIFT IFSC at a par with overseas financial centres.

Availability of **Human Capital** is the next key determinant of success as per GFCI Report. In this regard, India has an inherent and natural advantage on account of favorable demographic dividend. The country produces some of the brightest minds in Finance and IT sector. In addition to this, GIFT City is strategically located between Ahmedabad and Gandhinagar, both of which are established education hubs with IIM's, IITs, National Law Schools all established in close vicinity. Moreover, GIFT IFSC is also accelerating inter-city migration with professionals moving from Mumbai, Delhi, Bangalore to GIFT IFSC on account of new and favorable job opportunities.

For any International Financial Centre to thrive, it is crucial that **physical and social infrastructure** is world class. On this particular determinant, GIFT City truly stands out as it is India's first fully operational greenfield Smart City. The city is planned on 886 acres of land with 62 Mn. sq. ft. of Built Up Area which includes Office spaces, Residential apartments, Schools, Hospitals, Hotels, Clubs, Retail and various Recreational facilities (GIFT City, India 2022 c).

The Civic infrastructure of the city includes:

a) Automated Waste Collection System (AWS) through chute system provides end to end automated waste management services without any human intervention

b) District cooling system is an Energy Efficient and Sustainable air conditioning system which conserves up to 30% energy as compared to traditional air conditioning systems (GIFT City, India 2022 a).

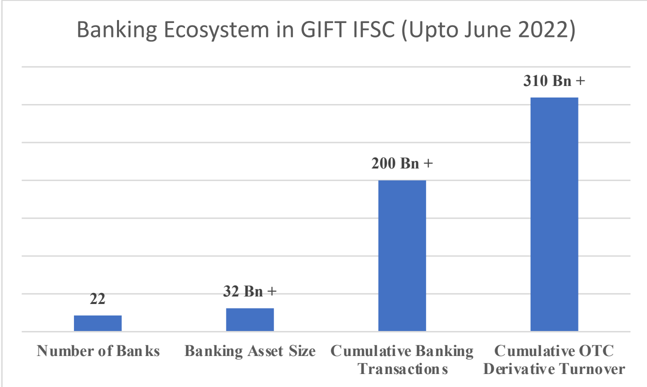
c) To achieve the vision of "Digging Free City", a Utility Tunnel has been dug across the city so that there is no need to excavate the roads in future for repair/ maintenance /renovation/up gradation of any utility. The provisions are made in the tunnel for smooth access, separation of utilities, proper drainage, lighting, and other long-term concerns, such as maintenance and security (GIFT City, India 2022 b).

The next important determinant in the GFCI Report is "Financial Sector Development", which inter alia, evaluates the depth and breadth of the financial sector in any financial jurisdiction. GIFT IFSC in its short journey has been able to provide an attractive and competitive platform to avail full spectrum of International financial services. This can be attributed to the internationally aligned regulatory ecosystem that has been created by IFSCA since 2019. Some of the key financial services being offered in GIFT IFSC are:

I. International Banking: Banking sector is the most important pillar of an international financial centre both as a financial intermediary and provider of other services. In general, international banking activities may include foreign trade financing, foreign exchange trading, transfer of fund across national boundaries (foreign currency deposits), foreign borrowing and lending and foreign investment. Further, the banking system maintains a coordination among all the units like mutual funds, AIF, stock exchanges thus helping in effectiveness in their functioning.

To develop a vibrant banking ecosystem, Banking Regulations 2020 (IFSCA Banking Regulations 2020) were notified by the IFSCA, which are essentially principle-based regulations and lays down the regulatory framework for setting up International Banking Units (IBU) in IFSC. The IBUs are permitted to offer a range of financial services including but not limited to Wholesale Banking, Retail Banking, Treasury Management, Merchant Banking, etc.

The key highlights of the Banking ecosystem in IFSC are provided below:



II. Capital Markets: Well-functioning and innovative capital markets is essential for enabling firms, households and governments to access stable funding and saving opportunities that are vital for consumption, investment and, ultimately, economic growth and employment (ECB Europa 2020). The unique position of IFSC enables it to become a preferred jurisdiction for Indian firms, IFSC firms as well as foreign firms to raise global capital at competitive cost through various debt and equity instruments.

The capital market regulatory ecosystem comprises of the Market Infrastructure Institutions Regulations, 2021, Issuance and Listing of Securities Regulations, 2021 and Capital Market Intermediaries Regulations, 2021. In terms of market infrastructure institutions, IFSC has the two international stock exchanges namely, India INX and NSE-IFSC which are operational for more than 20 + hours daily and offer various products including Index Derivates, Commodity Derivatives and Currency derivatives. The highlights of the capital marker ecosystem are as under:

III. Insurance & Reinsurance: GIFT-IFSC has the potential to become a hub for Reinsurance and retail insurance, particularly for Indian diaspora living abroad. To facilitate the development of this business segment, IFSCA notified (Registration of Insurance Business) Regulations, 2021 as well as (Insurance Intermediary) Regulations, 2021. The Insurance business landscape is rapidly evolving with GIFT IFSC emerging as a Reinsurance and retail insurance hub.

IV. International Bullion Exchange: India is the second largest consumer of Gold in the world (next only to China) and is the largest importer of Silver. Also, the country is presumed to possess close to 25,000 tonnes of gold as above the ground/ household stocks. Despite its position as a principal consumer in the precious metals market, India continues to be a price-taker and not in setting the price for gold in global markets. On the other hand, the existing dominant centers of bullion trade which are neither producing or consuming countries, play a major role in influencing the prices of the bullion. Further, Options Derivatives in commodities appeared in 1990´s and became popular tool of hedging and risk management (Kaur and Rattol 2016).

In the Union Budget 2020, Hon'ble Finance Minister announced the setting up of an International Bullion Exchange at the International Financial Services Centre in GIFT City (E-Parliament 2020). To implement this key budget announcement, the bullion spot delivery contract and bullion depository receipt (with bullion as underlying) were notified as Financial Products and related services as Financial Services and IFSCA was entrusted with the responsibility of operationalization of this Exchange.

The setting up of India International Bullion Exchange (IIBX), thus comes at a most opportune time which got inaugurated on 29th July 2022 by the Hon'ble Prime Minister of India which will serve as a watershed in the growth story of India's financial markets. With the Market Infrastructure Institutions already in place, the Bullion Exchange is expected to go live shortly and is envisaged to reform the gold ecosystem in India by virtue of the following:

i. **Price Discovery:** It shall harness all the synergies available locally, bring all the market participants at a common transparent platform of bullion trading and provide an efficient price discovery by channelling demand-supply information into a central mechanism. Increase in use of gold bars and gold-backed financial products replacing the demand for jewelry specially for investment which may be effortlessly liquidated. The channelization of demand-supply information into a central mechanism shall enhance the discovery of price at the International Bullion Exchange.

ii. **Price Influencer:** IBE shall enable the country to become a dominant trading hub for bullion with transparency, speed and efficiency which is unparalleled and enable India to be a major player and price setter in the global bullion ecosystem.

iii. **Supply chain integrity:** Sourcing integrity and quality of bullion can be easily established in a system-based tracking module, brought in as a consequence of the International Bullion Exchange shall enable enforcement agencies to curb malpractices.

iv. **Financialization of Gold:** Greater integration with other segments of financial markets and routing retail investment into gold by increase in use of gold bars and gold-backed financial products replacing the demand for jewellery specially for investment. Also, India has an opportunity to ensure that gold being designated as a Financial Product as 'Bullion Depository Receipts' will play a major role in the financialization of bullion holdings. There is a possibility of mainstreaming a portion of household holdings of 25000 tonnes approx. which is currently estimated to be lying unused and locked. (IFSCA 2022).

V. Aircraft Leasing and Financing:

The size of the global aircraft leasing industry was estimated to be USD 290.07 billion in 2019. From owning just 25% of the total commercial fleet in 2000, aircraft lessors have grown to owning about 48.9% of the total fleet in 2020. The leasing model is even more popular in India with close to 80% of the total commercial fleet operating under lease compared with the global average of 53% (PWC 2021).

Despite the fact that aircraft leasing and financing is one of the most profitable business segments in the entire aviation value chain, this crucial business segment was entirely absent in India was being purchased by commercial airlines from offshore jurisdictions like Ireland, Singapore, etc. To onshore this crucial business activity in GIFT-IFSC, IFSCA with support of Ministry of Civil Aviation developed and implemented a comprehensive strategy and within a short span of 1 year, a globally competitive regulatory and tax architecture was put in place.

This business is expected to gain significant traction as India is already the 3rd largest domestic aviation market in the world and is expected to have a fleet strength of 5000 strong aircrafts by 2050 (Shah and Chugan, 2019).

Challenges in the development of GIFT-IFSC

Globally, when we look at the evolution of new-age offshore financial centres, we find that the federal governments have adopted a targeted and focused development strategy to bring in place an internationally aligned regulatory regime, beneficial tax structures and robust legal and dispute redressal system. In addition to the above, countries have also worked on creating world class social and physical infrastructure with a view to attract best in class financial talent from across the globe. In the case of GIFT IFSC, the Government in consultation with relevant stakeholders has worked on all the major determinants to ensure the centre emerges as a globally recognized international financial centre with trusted business regulations and ease of doing business.

The availability of robust, cost effective and time bound dispute settlement system is one of the prerequisites of a successful financial centre. According to the current legal process in IFSC, there is no uniform and streamlined dispute resolution mechanism, which can cater to the needs and demands of the offshore business and foreign players, who may be looking out to set up their businesses in IFSCs. This problem is further amplified by the fact that there exist multiple laws which are applicable in IFSCs, accompanied by multiple judicial mechanisms.

Further, the state of dispute resolution which is available presently for the entities established in IFSCs is complicated, due to various reasons including

i. Absence of Alternative Dispute Resolution system.

ii. Absence of any Special Court designated under Section 23 of the SEZ Act, 2000.

iii. Local courts at Gandhinagar having jurisdiction to try all civil/commercial/criminal disputes which may arise in the SEZ.

On the other hand, if we study leading global financial centres such as Dubai International Financial Centre (DIFC), its parent statute itself establishes DIFC Judicial Authority (DJA) for the effective resolution of legal disputes based on Common Law principles.

Further, the Law establishing the Judicial Authority at the DIFC establishes the DIFC Courts of First Instance and Appeal and prescribes the jurisdiction of the DIFC Courts. The Dubai Law provides for the appointment of the DIFC Courts Justice, including the Chief Justice of the DIFC Courts.

The Law allows the courts to deal exclusively with all claims and disputes arising from or within the DIFC. The Law also provides for the enforcement of judgments, orders and awards made by the DIFC Courts. The Law gives the Chief Justice the responsibility for administering the courts and any other circuits or divisions that are established.

To facilitate ease of doing business and provide for a robust dispute settlement mechanism in GIFT IFSC comparable with global standards, Hon'ble Finance Minister in Union Budget 2022-23 announced that an International Arbitration Centre would be set up in the GIFT City for timely settlement of disputes under international jurisprudence. The fast -track implementation of this key budget announcement would give further confidence to global financial industry to do business with GIFT-IFSC.

Conclusion

Considering the fact that India's maiden IFSC has come of age and has firmly taken roots in the mindshare of the global as well as Indian financial services industry, it is now an opportune time to utilize this special carve-out jurisdiction to onshore International Financial Services business generated from India and make India truly "Atma Nirbhar" (Self-reliant) in the field of International Financial Services.

It would be critical to see how the key determinants namely Business friendly Regulations, Competitive tax regime, Alternate Dispute Resolution Mechanism, Corporate Law for ease of doing business, Skill Manpower and High-Quality Infrastructure & Quality of Life play an important role in the success of the IFSC in India.

References

Abu Dhabi Global Market (2022). https://www.adgm.com/about-adgm/overview accessed on April 05, 2022.

DEA (2016). High Powered Expert Committee Report on Mumbai – An International Financial Centre. Department of Economic Affairs https://www.dea.gov.in/high-powered-expert-committee-report-mumbai-international-financial-centre accessed on May 27, 2022.

Dubai International Finance Centre (2022). https://www.difc.ae/business/ accessed on April 04, 2022.

E-Parliament (2020). https://eparlib.nic.in/bitstream/123456789/787674/1/bs_2020-21.pdf (Pg 28).

ECB Europa (2020). https://www.ecb.europa.eu/press/inter/date/2020 Accessed on April 25, 2022.

GFCI (2020) https://www.zyen.com/publications/public-reports/global-financial-centres- index-28/ accessed on April 26, 2022.

GIFT City, India (2022a). https://www.giftgujarat.in/district-cooling-system accessed on April 16, 2022.

GIFT City, India (2022b) https://www.giftgujarat.in/utility-tunnel accessed on April 17, 2022.

GIFT City, India (2022c) https://www.giftgujarat.in/genesis accessed on April 15, 2022.

Global Financial Centre Index (2022). https://www.longfinance.net/publications/long-finance-reports/global-financial-centres-index-31/ accessed on April 10, 2022.

IFSCA Banking Regulations (2020) https://ifsca.gov.in/Regulation accessed on May 05, 2022.

IFSCA 2022 https://ifsca.gov.in/Regulation accessed on May 6, 2022.

IMF (1987). Report on the World Current Account Discrepancy 203. https://www.imf.org/en/Publications/Books/Issues/2016/12/30/Report-on-the-World-Current-Account-Discrepancy-25 accessed on June 02, 2022.

Income Tax India (2019). https://www.incometaxindia.gov.in accessed on April 22, 2022.

India International Bullion Exchange (2022). https://www.iibx.co.in/ accessed on August 8, 2022.

International Financial Services Centres Authority (Banking) Regulations (2020). https://www.ifsca.gov.in/ accessed on 01/06/2022.

Kaur Amandeep and Rattol Amandeep S. (2016) Commodity Hedging through Zero-Cost Collar and its Financial Impact. PDEU Journal of Energy and Management (issn 2456-6705), Vol. 1., No.1., Oct 2016 pp. 44-57

Labuan International Business and Finance Centre (2022). https://www.labuanibfc.com/who-we-are/the-market-development-arm accessed on March 02, 2022.

Mangaldas, CA (2021). https://www.cyrilshroff.com/publications/doing-business-in-ifsc/# accessed on April 07, 2022.

Prasad, P (2021). The importance of LPG Reforms of 1991 and its underlying controversy. IPleaders Intelligent Legal Solutions. Nov. 1. https://blog.ipleaders.in/the-importance-of-lpg-reforms-of-1991and-its-underlying-controversy/ accessed on May 25, 2022.

PWC (2021). Air Craft Leasing in India Ready to Take Off. https://www.pwc.in/assets/pdfs/research-insights/2021/aircraft-leasing-in-india-ready-to-take-off.pdf (Pg 7).

Qatar Finance Centre (2022). https://www.qfc.qa/en/about-qfc/overview accessed on April 05, 2022.

Shah, D and Chugan, PK. (2016). Key requirements for setting up a successful International Financial Services Centre (IFSC) in India. New Age Ecosystem for Empowering Trade, Industry and Society, Eds., Pawan K. Chugan, Deepak Srivastava, Nikunj Patel and Nirmal C. Soni, Excel India Publishers, New Delhi, for Institute of Management, Nirma University, Ahmedabad India. Jan., pp. 397-406.

Shah, D and Chugan, PK. (2019). Aircraft Financing and Leasing in India Challenges & Opportunities: An Exploratory Study of Developing Aircraft Financing and Leasing in India. Business, Economy and Environment: Corporate Perspectives", Eds. Parag Rijwani, Samik Shome and Deepak Danak, Himalaya Publishing House Pvt. Ltd., Mumbai for Institute of Management, Nirma University, Ahmedabad

Union Budget (2016) https://www.indiabudget.gov.in/budget2016-2017/budget.asp accessed on April 05, 2022.