International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 10 | October - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

A Review on Control Methods of SEPIC Converters

Mudadla Venkatesh[2], Namballa Usha Sri[1], Vemakoti Akhila[1], Marturu Hinduja[1], Kondeti Navya[1], Sadhu Sasikanth[1]

[1] Undergraduate Student, Department of Electrical and Electronics Engineering, GMR Institute of Technology, Rajam-532127, Andhra Pradesh, India

[2]Assistant Professor, Department of Electrical and Electronics Engineering, GMR Institute of Technology, Rajam-532127, Andhra Pradesh, India

**Email: ushasri.namballa504@gmail.com*

---***---

Abstract - In recent years, electric vehicles have witnessed a surge in popularity due to their energy-saving and eco-friendly attributes. Unlike conventional internal combustion engine vehicles, electric vehicles exhibit superior performance and operational efficiency. Within the realm of modern electric vehicles, power electronic circuits, notably including DC-DC converters, play a pivotal role. Among these converters, single-ended primary-inductor converters (SEPIC) find extensive use in scenarios where minimizing input and output ripple currents is essential. The primary objective of this project is to conceive and put into action advanced controllers for SEPIC converters, catering to a diverse range of applications, encompassing battery-powered devices, solar energy systems, and LED lighting systems.

***Key Words*:** DC-DC converter, SEPIC converter, PID, SMC, ASMC, Fuzzy logic Control.

1.INTRODUCTION

DC-DC converters, which belong to the field of power electronics, find extensive utility in various sectors such as DC motor control, communication devices, and providing power to personal computers [1]. The requirement for voltage variability in electric networks, where certain loads necessitate higher voltage than the input while others require lower voltage, underscores the crucial role played by DC-DC converters. These converters, characterized by intricate designs, high efficiency, and precision, are essential for applications involving voltage step-up and step-down [2]. DC-DC converters have the potential to be employed in regenerative braking systems for DC motors, allowing the recapture of energy and thereby leading to energy efficiency gains in transportation systems characterized by frequent stops [3]. The DC-DC converter is extensively employed to convert voltage for a multitude of applications. The primary types of DC-DC converters include the Buck converter, Boost converter, Buck-Boost converter, Cuk converter, and SEPIC converter [4]. Because of its adaptable output gain, the single-ended primary inductor converter (SEPIC) functions as a DC-DC converter that can both decrease and increase its output voltage by adjusting its duty cycle [5].

The SEPIC converter is constructed with components such as an active power switch, a diode, two inductors, and two capacitors, making it a fourth-order nonlinear system. This Single-Ended Primary Inductor Converter (SEPIC) is versatile, capable of functioning in both voltage step-up and step-down modes, and notably avoids the issue of polarity reversal [6]. SEPIC can produce an output voltage higher, lower, or equal to the input voltage. It features a non-inverting output with an easily controllable ground-referenced switch, and minimal input current pulsation, making it highly desirable and essential for accurately tracking the maximum power point in photovoltaic systems. This also helps in reducing electromagnetic interference (EMI) and, consequently, the need for additional filtering components [7]. The presence of the coupled inductor at the converter's input stage, along with its associated leakage inductance, leads to either discontinuous input current or significant current fluctuations. As a result, these characteristics make it less ideal for use in renewable energy applications [8]. The SEPIC converter is highly advantageous for power conversion because it can produce a broad range of non-inverted output voltages [1]. The boost converter typically exhibits greater efficiency compared to the SEPIC, but it consistently produces an output voltage that exceeds the input voltage, leading to limitations in extracting maximum power due to this inherent inflexibility. The classical SEPIC configuration offers a notable benefit in comparison to the Buck-Boost and Cuk configurations: it ensures that both the output and input voltages share the same polarity. Furthermore, similar to the Cuk converter, the SEPIC converter boasts the advantageous characteristic of having its switch control terminal linked to the ground [9].

When dealing with the management of DC-DC converters, there are two distinct goals to consider: optimizing performance and maximizing efficiency. Since DC-DC converters naturally exhibit variable structure characteristics, employing a control

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 10 | October - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

strategy rooted in the sliding mode theory seems to be an attractive option [10]. This approach demands lower inductor current but leads to more pronounced fluctuations in both voltages and currents when contrasted with passivity-based control. A significant drawback of nonlinear control techniques is the necessity for the installation of four sensors to measure voltages and currents across capacitors and inductors, respectively [11]. A Proportional-Integral-Derivative controller, commonly known as a PID controller, is a prevalent feedback control system utilized across various industries. It calculates an error signal by comparing the measured process variable to a target setpoint and then seeks to minimize this error by making adjustments to the system using a controlled variable [12]. In recent times, the fuzzy logic controller (FLC) has gained growing interest among researchers for its application in controlling converters, motor drives, and various other process control systems. It is preferred over conventional controllers due to its ability to deliver superior responses. Fuzzy controllers can effectively handle the imprecise nature of weather variations encountered by PV arrays. However, a common limitation of many fuzzy-based Maximum Power Point Tracking (MPPT) algorithms is that they tend to shift the tracking point away from the maximum power point when weather conditions change [5].

2. MODELLING AND OPERATION OF SEPIC CONVERTER

2.1. OPERATION OF SEPIC CONVERTER:

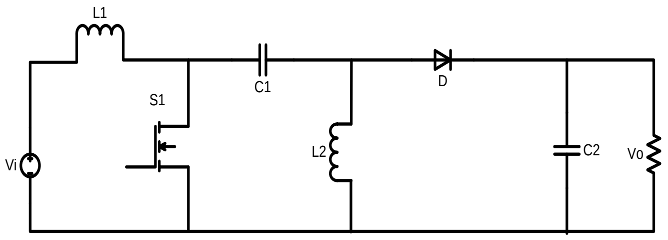

Figure 1. Circuit Diagram Of SEPIC Converter

The SEPIC converter comprises an active power switch (MOSFET), a diode, two inductors (L1, L2), and two capacitors (C1, C2) as illustrated in Figure 1. When operating in the Continuous Conduction Mode (CCM), there are two switching modes to consider: Mode 1 occurs when the switch is in the ON position, and Mode 2 happens when the switch is in the OFF position. [4]

2.1.1 MODE 1(SWITCH ON STATE):

When switch S is in the ON position, inductor l1 is charged by the source voltage Vs. Assuming that coupling capacitor c1 is initially charged to the source voltage Vin when switch S is ON, the coupling capacitor discharges through inductor l2. By considering the polarities of the diode we can say that the diode is in reverse-biased, and the output capacitor supplies current to the load [4].

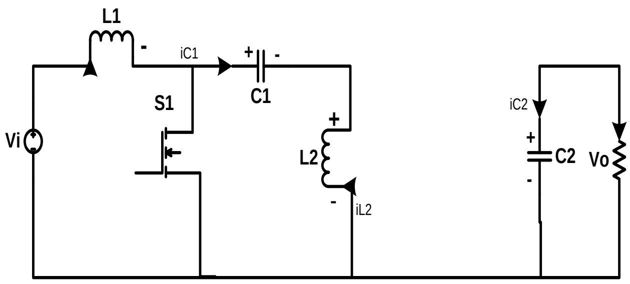

Figure 2. circuit diagram in the ON state of the switch.

$$v_{input} = l_1 \frac{di_{l_1}}{dt} \quad (1)$$

$$v_{c_1} = l_2 \frac{di_{l_2}}{dt} \quad (2)$$

$$\frac{v_{c_2}}{R} = -c_2 \frac{dv_{c_2}}{dt} \quad (3)$$

2.1.2 MODE 2 (SWITCH OFF STATE):

When switch S is turned OFF, the circuit configuration, as depicted in Figure 1(b), comes into play. In this state, inductor l1 releases its stored energy, causing the coupling capacitor c1 to charge. As a result, the polarity of inductor l2 changes to counteract the shift in the current direction, leading to the activation of diode D. Consequently, inductor l2 discharges energy, flowing through both the output capacitor and the load in the circuit [4].

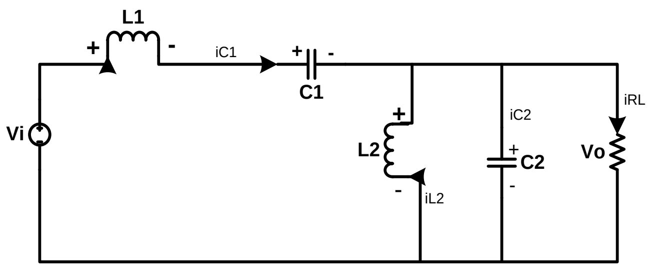

Figure 3. Circuit diagram in the off state of switch

$$v_{input} + l_1 \frac{di_{l_1}}{dt} = v_{c_1} + v_{c_2} \quad (4)$$

$$v_{c_2} \frac{dv_{c_2}}{dt} + \frac{v_{c_2}}{R} = i_{l_1} + i_{l_2} \quad (5)$$

$$v_{c_2} = l_2 \frac{di_{l_2}}{dt} \quad (6)$$

2.2 MODELLING OF SEPIC CONVERTER:

Fig. 1 displays the schematic representation of a SEPIC converter. The equations that describe how the SEPIC converter operates can be expressed in the following manner.

$$\frac{di_{L0}}{dt} = \frac{V_{input}}{L0} \text{ - (1-m) } \frac{V_{C0}+V_{output}}{L0} \quad (7)$$

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 10 | October - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

$$\frac{di_{L1}}{dt} = \frac{V_{C0}}{L2} m - (1\text{-}m) \frac{V_{output}}{L1} \qquad (8)$$

$$\frac{dV_{C0}}{dt} = (1\text{-}m) \frac{i_{L0}}{C0} - \frac{i_{L1}}{C0} m \qquad (9)$$

$$\frac{dV_{C0}}{dt} = (1\text{-}m) \frac{i_{L0}+i_{L1}}{C1} - \frac{V_{output}}{C2R_L} \qquad (10)$$

In this context, 'm' signifies the control input, taking on a value of 1 when switch S is in the ON state and 0 when it's in the OFF state. It's clear that the converter's mathematical model consists of four interconnected differential equations.

3. DIFFERENT CONTROL METHODS FOR SEPIC CONVERTERS:

3.1 PROPORTIONAL INTEGRAL DIFFERENTIAL CONTROLLER:

PID control has gained global acceptance, particularly in intricate industrial processes requiring precise system performance. A PID controller combines proportional, integral, and derivative components of the error signal. Each element contributes specific advantages to enhance the overall system response. The PID control method is suggested to establish a precise operational point for the SEPIC system. It adjusts the SEPIC configuration to stay closely aligned with this point, even when unexpected disturbances, changes in set points, or noise occur. The PID controller generates specific PWM pulses to regulate the SEPIC converter's switch. By comparing the sensed output voltage with the desired reference voltage, any discrepancies are detected. The PID controller then corrects this difference by adjusting the duty cycle value used in PWM generation. To design a PID controller for a SEPIC converter, it is crucial to determine the appropriate values for the proportional, integral, derivative, and anti-windup (P, I, D, N) coefficients. However, finding the right combination of coefficients that ensures optimal performance for the control system is a challenging endeavor that requires careful analysis [13].

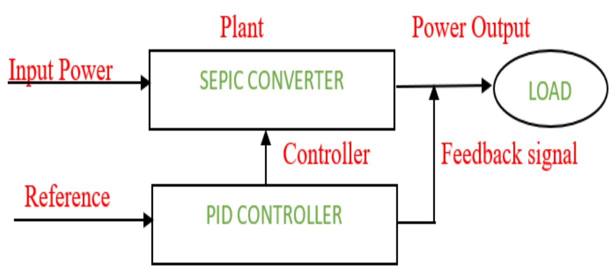

Figure 3. Block diagram of a system featuring a PID controlled SEPIC converter

3.1 FUZZY LOGIC-BASED CONTROL METHOD:

Fuzzy logic stands out among various intelligent controllers due to its easy integration into systems. In the context of the SEPIC MPPT scheme, a fuzzy controller demonstrates remarkable accuracy in current transitions and maintains stable voltage even under variable loads. This leads to minimal steady-state errors and overshoots. In photovoltaic systems utilizing inverters, Fuzzy Logic Control (FLC) enhances the output sine wave precision, provides superior dynamic performance amidst rapidly changing atmospheric conditions, maximizes power utilization, and reduces Total Harmonic Distortion (THD) compared to traditional PI-controlled converters. The Pulse Width Modulation (PWM) adjusts its duty cycle based on the control signal, creating feedback from the output signals like voltage, current, and power to generate a reference signal. This signal adjusts itself unpredictably, depending on the maximum power achieved through changes in the duty cycle. The system can attain the maximum power point in scenarios such as grid-connected setups, full-load conditions, or during battery charging in standalone systems [5].

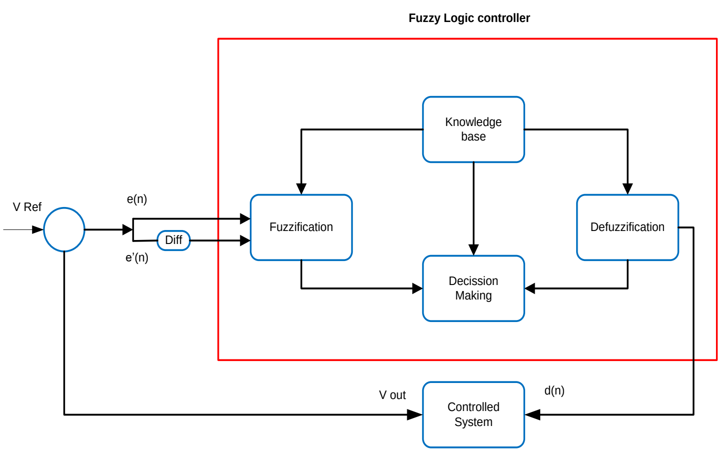

Figure 4.Block diagram of Fuzzy logic control

3.3 SLIDING MODE CONTROL:

Sliding Mode Control is a nonlinear control method employed for Variable Structure Systems, including DC-DC converters. In DC-DC converters, various orders of Sliding Mode Control, ranging from first order to third order, have been applied. The choice of Sliding Mode Control order is contingent upon the number of state variables being controlled. An important benefit of Sliding Mode Control is the ability to reduce the order, which is a notable advantage. Moreover, this approach can be seamlessly combined with consistent switching frequency strategies, PWM control, and soft computing methodologies. Sliding Mode Control has applicability across Variable Structure Systems (VSS) as a versatile technique. DC-DC converters are said to be VSS since they have different structures depending on the switching conditions. Among all the control techniques, the SMC method deserves recognition due to its remarkable performance in meeting the mentioned control goals.

Nevertheless, despite the notable advantages of current SMC approaches, they face challenges related to a lack of a systematic controller design methodology and increased complexity. It was demonstrated that indirect attainment of output voltage control is possible by employing a sliding surface function based on the error in input current.[14][1].

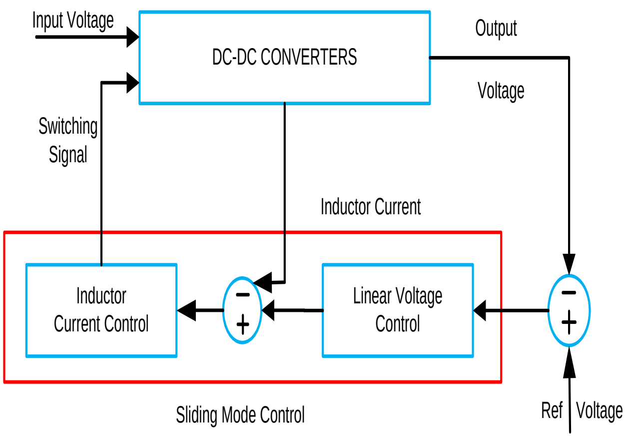

Figure 5. Block diagram of sliding mode controller

3.4 ADAPTIVE SLIDING MODE CONTROL:

An adaptive sliding mode controller represents a specialized control system that dynamically tunes its parameters and strategies to effectively manage a dynamic system, particularly when confronted with uncertainties or fluctuations in the system's behaviour. The primary challenges in implementing Sliding Mode Control are closely linked phenomena chattering and the excessive intensity of control actions. It's a widely recognized fact that the level of chattering is directly proportional to the discontinuous nature of the control. These issues can be effectively addressed concurrently by minimizing the magnitude to the lowest acceptable threshold, as defined by the conditions necessary for the existence of the sliding mode. This adaptability serves to achieve robust and stable control, even when confronted with changing conditions or disturbances. Adaptive sliding mode controllers find widespread application in various domains like robotics, aerospace, and automotive control systems, where they prove invaluable in addressing the complexities posed by unpredictable and dynamic environments. Utilizing adaptive control is a highly effective method for managing changes in parameters. Consequently, adaptive sliding mode control offers the benefits of merging the robustness seen in variable structure methods with the tracking capabilities found in adaptive control strategies [15][16].

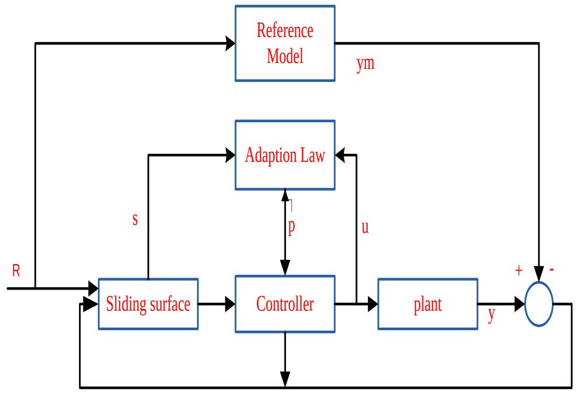

Figure 6. *Block diagram of Adaptive sliding mode controller*

Table-1: Comparison between the controllers:

	DESIGN AND IMPLEMENTATION	**OPERATING POINT**	SETTLING TIME
PID CONTROLLER	Straightforward in its design and straightforward in its execution, requiring uncomplicated planning and execution.	React promptly and specifically when encountering significant disruptions or disturbances in a substantial load scenario.	The time taken to reach a stable state is greater than that of the standard PID controller, indicating a prolonged period for the system to settle into equilibrium.
FUZZY LOGIC CONTROLLER	Straightforward in design and execution.	React promptly to fluctuations in the operating point and instability in the load conditions	The time required to stabilize is greater compared to the traditional PID controller.
SLIDING MODE CONTROLLER	Incredibly straightforward in both concept and implementation.	Respond suitably to changes in the operating conditions and disturbances in the load.	The settling time is extremely short.
ADAPTIVE SLIDING MODE CONTROLLER	The design and implementation of adaptive sliding mode control can be challenging and complex.	The operating point in Adaptive Sliding Mode Control (ASMC) represents the ideal	The function of settling time is to ensure that the output voltage stabilizes within an acceptable range as rapidly as

		state where the controlled system converges , minimizing the tracking error and ensuring stability.	possible after a disturbance or change in load, improving the converter's transient response and overall performance.

4. CONCLUSIONS

The study has evaluated its effectiveness of different control methods used for SEPIC converters. The control approaches like fuzzy logic, PID, sliding mode and adaptive sliding mode are compared and discussed. These controllers find extensive use across diverse applications. Each one carries its unique set of pros and cons, and determining the most suitable controller for a specific application hinge on various factors, including the system's behavior, desired performance, and financial and implementation limitations. If the way a system behaves is complicated or not clear, it's better to use a controller that can handle uncertainty. If you need the system to work really fast and accurately, a controller that can process information quickly is a good idea. But if you're on a tight budget or have limited ways to put the system in place, a simpler controller is a better option. PID controllers are a good choice for most applications. However, if the system dynamics are complex or poorly understood, or if fast and accurate performance is required, then SMC, ASMC, or fuzzy logic controllers may be a better choice.

REFERENCES

[1] H. Komurcugil, S. Biricik, and N. Guler, "Indirect Sliding Mode Control for DC-DC SEPIC Converters," *IEEE Trans. Ind. Informatics*, vol. 16, no. 6, pp. 4099–4108, 2020, doi: 10.1109/TII.2019.2960067.

[2] A. Yadav and A. Verma, "Sepic DC-DC Converter: Review of Different Voltage Boosting Techniques and Applications," *2nd Int. Conf. Innov. Mech. Ind. Appl. ICIMIA 2020 - Conf. Proc.*, vol. 2, no. Icimia, pp. 733–739, 2020, doi: 10.1109/ICIMIA48430.2020.9074897.

[3] S. A. Lopa, S. Hossain, M. K. Hasan, and T. K. Chakraborty, "Design and Simulation of DC-DC Converters," pp. 63–70, 2016.

[4] M. Verma and S. S. Kumar, "Hardware Design of SEPIC Converter and its Analysis," *Proc. 2018 Int. Conf. Curr. Trends Towar. Converging Technol. ICCTCT 2018*, no. 4, pp. 2018–2021, 2018, doi: 10.1109/ICCTCT.2018.8551052.

[5] A. El Khateb, N. A. Rahim, J. Selvaraj, and M. N. Uddin, "Fuzzy-logic-controller-based SEPIC converter for maximum power point tracking," *IEEE Trans. Ind. Appl.*, vol. 50, no. 4, pp. 2349–2358, 2014, doi: 10.1109/TIA.2014.2298558.

[6] V. Eng and C. Bunlaksananusorn, "Modeling of a SEPIC converter operating in discontinuous conduction mode," *2009 6th Int. Conf. Electr. Eng. Comput. Telecommun. Inf. Technol. ECTI-CON 2009*, vol. 1, no. 4, pp. 140–143, 2009, doi: 10.1109/ECTICON.2009.5136983.

[7] F. M. TUZTASI, A. B. Yildiz, and H. Kelebek, "Modeling and Analysis of DC-DC CUK Converter with Coupled Inductors," *WSEAS Trans. Circuits Syst.*, vol. 21, pp. 188–192, 2022, doi: 10.37394/23201.2022.21.21.

[8] R. Moradpour, H. Ardi, and A. Tavakoli, "Design and implementation of a new SEPIC-based high step-up DC/DC converter for renewable energy applications," *IEEE Trans. Ind. Electron.*, vol. 65, no. 2, pp. 1290–1297, 2017, doi: 10.1109/TIE.2017.2733421.

[9] P. Applications, "DC-DC Converters Using Different MPPT Methods for," 2022.

[10] R. Priewasser, M. Agostinelli, C. Unterrieder, S. Marsili, and M. Huemer, "Modeling, control, and implementation of DC-DC converters for variable frequency operation," *IEEE Trans. Power Electron.*, vol. 29, no. 1, pp. 287–301, 2014, doi: 10.1109/TPEL.2013.2248751.

[11] S. Biricik, T. Ngo, H. Komurcugil, and M. Basu, "Nonlinear control methods for single-ended primary-inductor power converters," *Proc. IECON 2017 - 43rd Annu. Conf. IEEE Ind. Electron. Soc.*, vol. 2017-Janua, pp. 1337–1340, 2017, doi: 10.1109/IECON.2017.8216227.

[12] B. Paranthagan, M. Marimuthu, and S. P. Shamili, "Comparative Analysis of Performance the SEPIC Converter Using PID and Fuzzy Logic Controllers for LED Lighting Applications," vol. 12, no. 2, pp. 34–42, 2015.

[13] S. I. Khather and M. A. Ibrahim, "Modeling and simulation of SEPIC controlled converter using PID controller," *Int. J. Power Electron. Drive Syst.*, vol. 11, no. 2, pp. 833–843, 2020, doi: 10.11591/ijpeds.v11.i2.pp833-843.

[14] A. Tharanya, "Four controls of Sliding Mode Control of a SEPIC converter," *2014 Int. Conf. Comput. Power, Energy, Inf. Commun. ICCPEIC 2014*, pp. 235–240, 2014, doi: 10.1109/ICCPEIC.2014.6915371.

[15] J. Fei and M. Hua, "A novel design of adaptive sliding mode observer," *Proc. World Congr. Intell. Control Autom.*, no. 09, pp. 843–848, 2010, doi: 10.1109/WCICA.2010.5554116.

[16] X. Zhang, H. Ma, Z. Li, and W. Zao, "An Adaptive Sliding Mode Controller with the Exponential and Power Reaching Law for Discrete Systems," *Chinese Control Conf. CCC*, vol. 2018-July, pp. 2711–2716, 2018, doi: 10.23919/ChiCC.2018.8484072.

[17] A. K. Sharma, A. Vyas, and P. Sharma, "Comparative Study of DC-DC Converter With Different Control Techniques," *SSRN Electron. J.*, no. January, 2021, doi: 10.2139/ssrn.3808564.