

Mitigation of Voltage Sag and Swell by using DVR as PWM switched Autotransformer

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Abstract

This paper investigates the voltage regulation in a single-phase power system utilizing a Pulse Width Modulation (PWM) switched transformer. Conventional transformer-based voltage regulation methods often suffer from limitations such as limited tap-changing range and slow response times. The proposed system overcomes these drawbacks by employing a series connected transformer with a primary winding and multiple secondary windings, primary is connected to a power electronic switch in the form of an inverter controlled by a PWM technique. By dynamically adjusting the on-time of the inverter, the effective primary voltage of this series connected transformer can be continuously varied, thereby enabling the precise and rapid voltage regulation on the load side. The PWM control strategy is designed to optimize the switching frequency and duty cycle to minimize power losses while achieving the desired voltage output. The Simulation results demonstrate the effectiveness of the proposed system in achieving accurate and fast voltage regulation under various load conditions, showcasing its potential for improved voltage profile and enhanced grid stability.

Keywords: voltage regulation, PWM, DVR, transformer

1. Introduction

Voltage sags and swells are temporary fluctuations in the electrical supply voltage. Sags are momentary decreases in voltage, often caused by events like motor startups, short circuits, or transformer switching. Swells, on the other hand, are momentary increases in voltage, commonly triggered by the sudden disconnection of large loads, single-phase faults, or capacitor switching. Other contributing factors include overloaded transformers, loose connections, long power lines, and instability within the power grid. The severity and duration

of these events can vary significantly, impacting sensitive electronic equipment and disrupting operations [1].

In modern electrical grids, maintaining stable and reliable voltage levels is paramount. Voltage fluctuations, such as sags, swells, and harmonics, can have detrimental effects on sensitive equipment, leading to malfunctions, reduced lifespan, and even catastrophic failures. These fluctuations can originate from various sources, including load variations, grid disturbances, and the increasing penetration of renewable energy sources [2]. To mitigate these issues and ensure the integrity of the power system, effective voltage regulation techniques are essential [3]. Traditional methods of voltage regulation have relied heavily on passive components like transformers with tap changers. While these methods have been effective in certain scenarios, they suffer from several limitations. Tap changers offer discrete voltage adjustments, often insufficient for precise control, especially in dynamic environments with rapidly changing loads [4]. The mechanical nature of tap changers results in sluggish response times, hindering their ability to effectively address transient voltage fluctuations. Regular maintenance is required to ensure the proper functioning of tap changers, increasing operational costs [5].

The advent of power electronics has revolutionized the field of power systems, offering a plethora of solutions for enhancing control and efficiency. Pulse Width Modulation (PWM) techniques, in particular, have emerged as a powerful tool for manipulating electrical signals with high precision and flexibility [6, 7]. By rapidly switching power electronic devices on and off, PWM allows for the generation of waveforms with varying amplitudes and frequencies, enabling precise control over voltage and current [8].

To mitigate the disruptive effects of voltage sags and swells on sensitive equipment, various compensation techniques are employed. Uninterruptible Power Supplies (UPS) provide backup power during sags and stabilize voltage fluctuations [9]. Voltage regulators maintain a consistent output voltage regardless of input variations. Dynamic Voltage Restorers (DVR) swiftly inject voltage into the system to counteract sags and swells [10]. Power Line Conditioners filter out voltage spikes and harmonics, enhancing overall power quality. The selection of the most suitable technique depends on factors such as the severity and frequency of the voltage disturbances, the sensitivity of the equipment, and the cost-effectiveness of the chosen solution.

This paper explores the application of PWM techniques to transformer-based voltage regulation. By incorporating power electronic switches into the transformer's secondary

winding can be dynamically adjusted, providing a continuous range of voltage control. The ability to continuously vary the secondary voltage of transformer enables precise voltage control, surpassing the limitations of discrete tap changers. The electronic nature of the switching process allows for rapid response to voltage fluctuations, ensuring stable system operation even under dynamic conditions.

2. DVR using PWM Switched Transformer

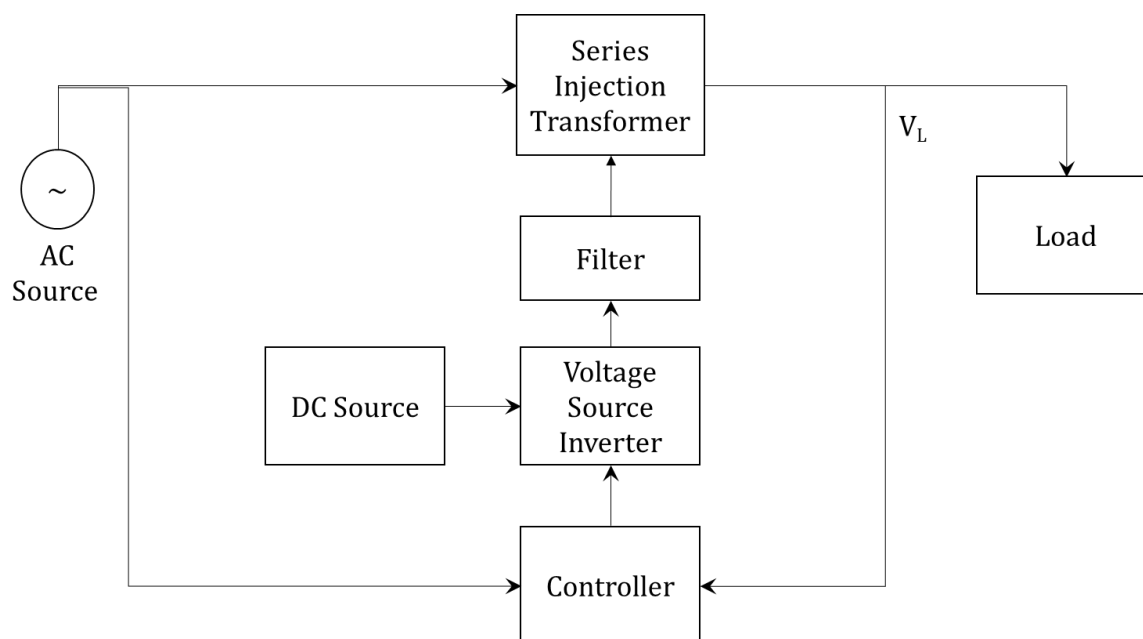


Figure 1: functional block diagram of DVR as PWM switched transformer

The block diagram of a DVR using PWM switched transformer for voltage regulation is seen in figure 1 and detailed specification are mentioned in table 1. The system consists of a series injection transformer having its secondary winding connected in series with the load. The primary winding is fed through a voltage source inverter. The voltage source inverter is controlled through a closed loop controller which continuously takes the feedback of the source voltage and load voltage. The controller controls the duty cycle and phase angle of the inverter

and thereby injects desired compensating voltage into the load and regulate the load voltage.

Table 1: Specification of the system

Voltage	220V (RMS)
Frequency	50Hz
Load power	Load 1 Active – 10kW Reactive – 5kW Load 2 Active – 10kW Reactive – 5kW
Series transformer	250V/250V single phase, 15kVA
DC link voltage	300V
Filter inductor	0.1μH
Switching frequency	10kHz
Controller	PI controller

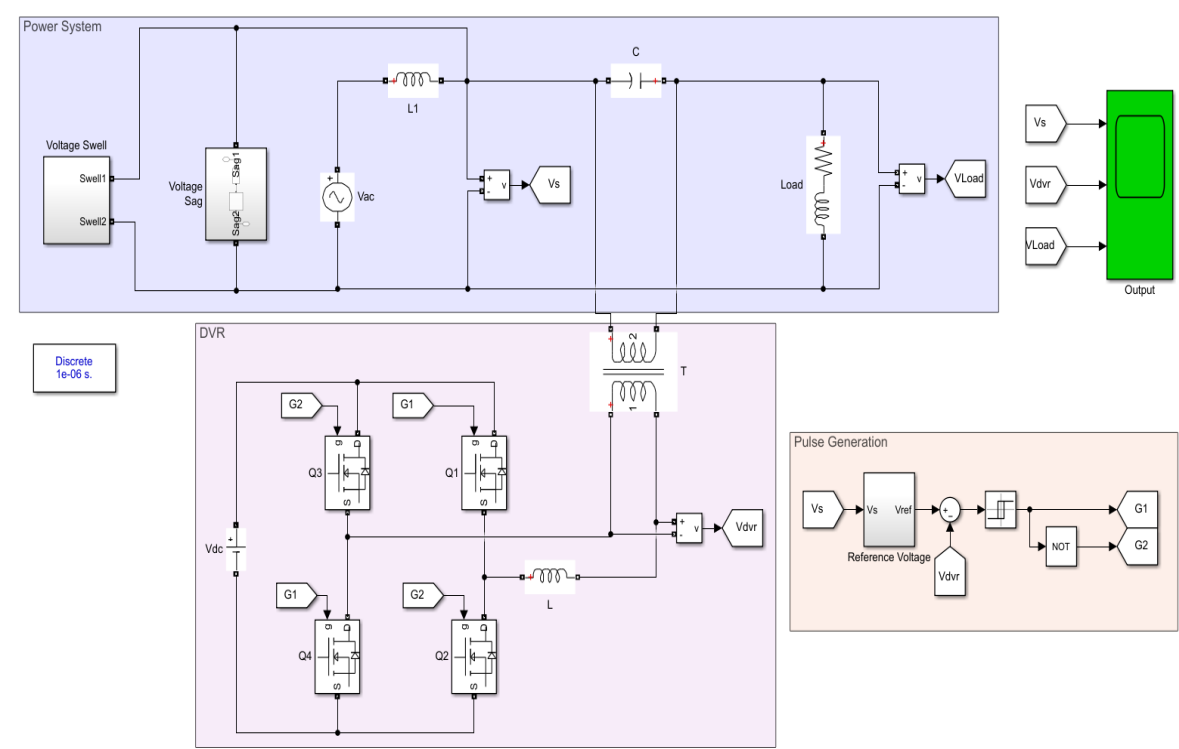


Figure 2: MATLAB Model of DVR using PWM switched transformer

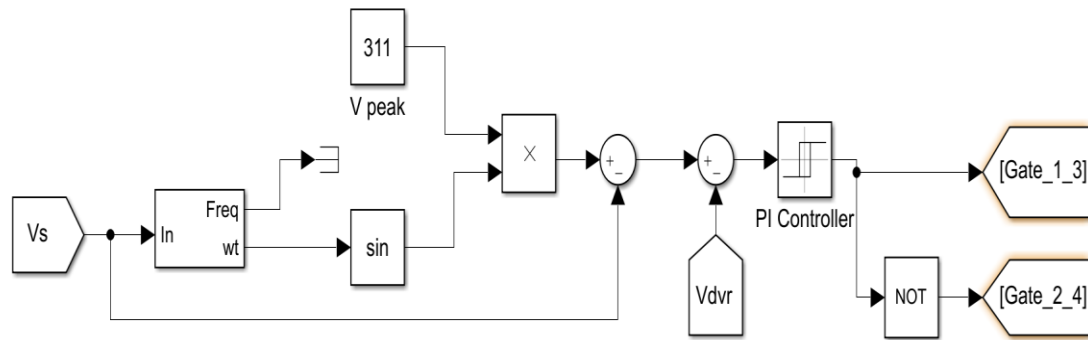


Figure 3: Control scheme

The MATLAB simulation model of the system is seen in figure 2. The control scheme of this model is shown in figure 3. In the control scheme a reference voltage is generated with the help of PLL. The PLL is used to identify the phase angle and frequency of the supply voltage. With the knowledge of the phase angle, the reference voltage is calculated which is desired to be sinusoidal and of the desired magnitude. The multiplication with peak amplitude of desired output voltage and sinusoidal component of the phase angle generates the sinusoidal reference voltage. The control scheme takes feedback of the load voltage and compares it with the reference value. The error signal generated by subtracting the actual load voltage from reference voltage is fed to a PI controller with saturation limits. The output of this block gives the PWM switching pulses for the gate terminals of the MOSFETs of the inverter. The produced gate pulses drives the inverter and injects a proportional voltage in series with load and thereby regulates the load voltage.

The results of the voltage regulation are shown in figure 4. The graphs shows the waveforms of source voltage, source current voltage generated by PWM switched transformer i.e. DVR voltage and voltage across the load. It is to be noted that the simulation model is execute for a period of 0.7 seconds. Between time instance, 0 – 0.15S, and 0.28 – 0.36S, normal operation is executed where the source voltage sufficient and no voltage regulation is desired. At time instance 0.15S, source voltage is decrease from is normal value. During this interval, a compensating voltage is generated by the system in phase with source voltage and injected in series with source voltage. At time instance 0.26S, when source voltage is increased from its normal value, the system is observed to generate a compensating voltage in phase opposition with the source. The generated compensating voltage is fed in series with the source voltage. At the load side, a smooth sinusoidal voltage is observed. The voltage across the load is hence

maintained constant by controlling the PWM duty cycle of the inverter. The duty cycle of the inverter and phase angle are in accordance with the source voltage. The PWM waveforms of the controller output during decrease in source voltage are mentioned in figure 5.

The graph of load voltage harmonics is mentioned in figure 6. The load voltage harmonics are recorded to be 2.69%.

As seen in figure 4, a load change is introduced at the time instance 0.5S is reflected in increase in the source current. Corresponding to the increase value of current, the graph of THD is plotted in figure 7. The current THD in this case is recorded to be 0.36%.

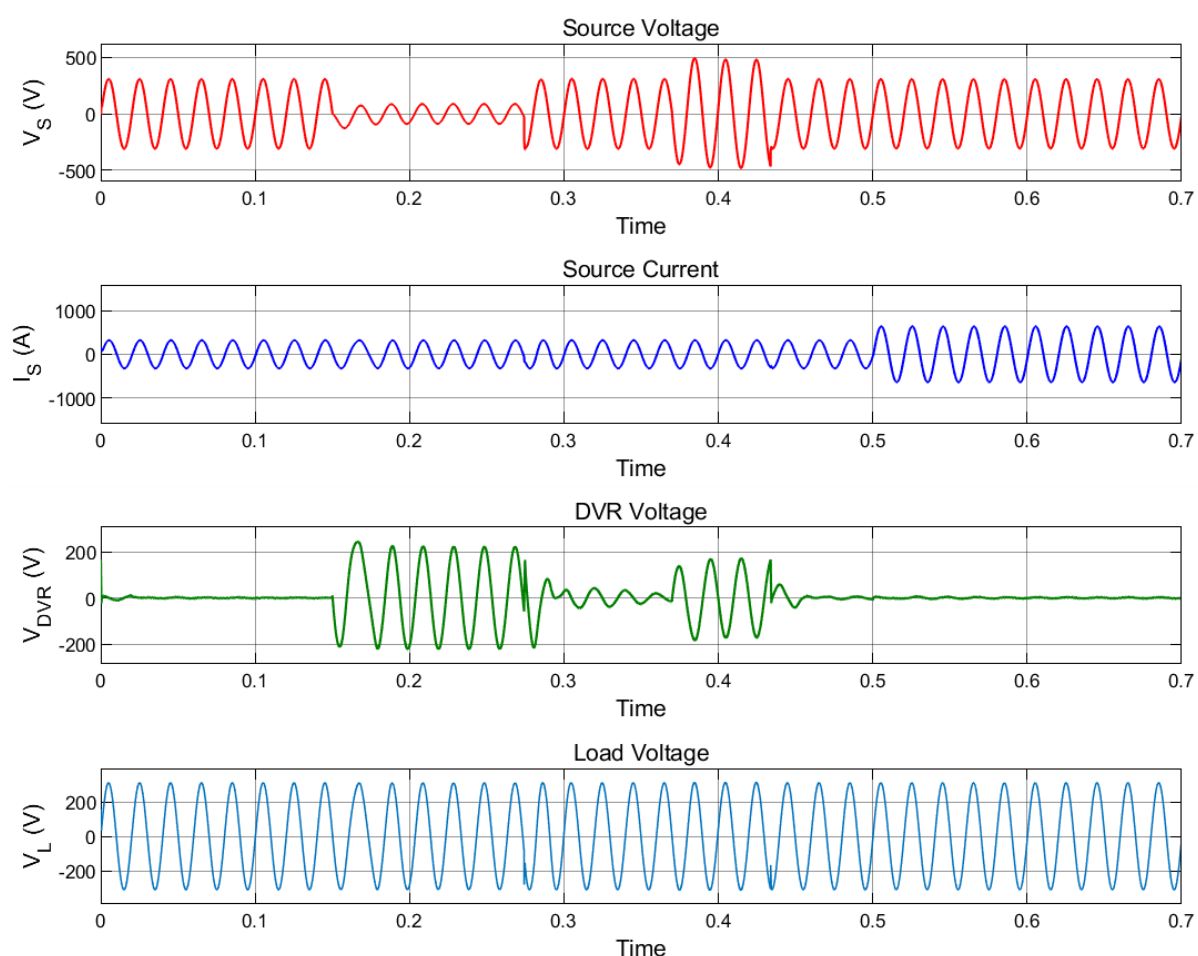


Figure 4: Source Voltage, DVR voltage and load voltage

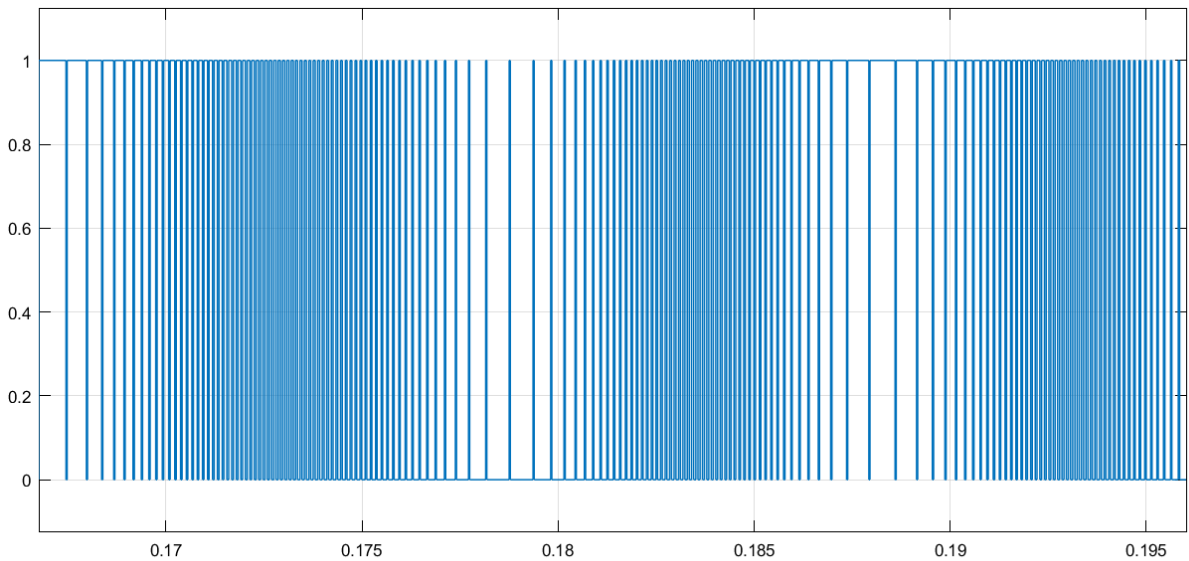


Figure 5: PWM Pulses for one cycle during decrease in source voltage

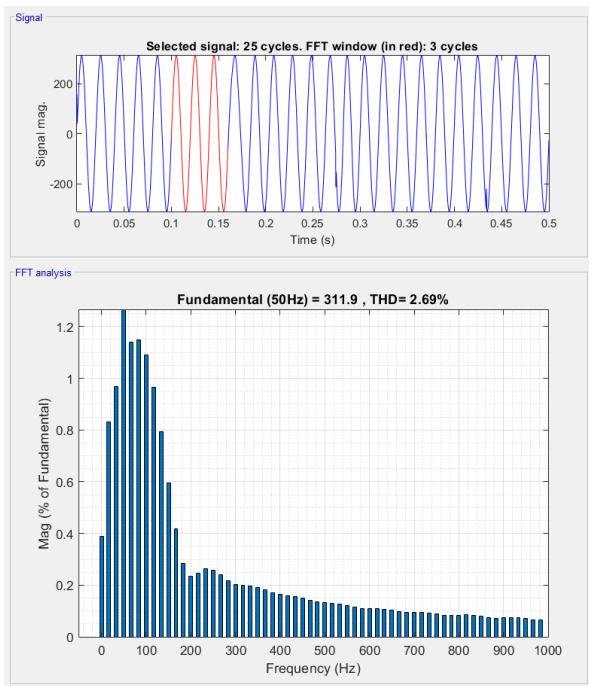


Figure 6: Voltage harmonics at half load

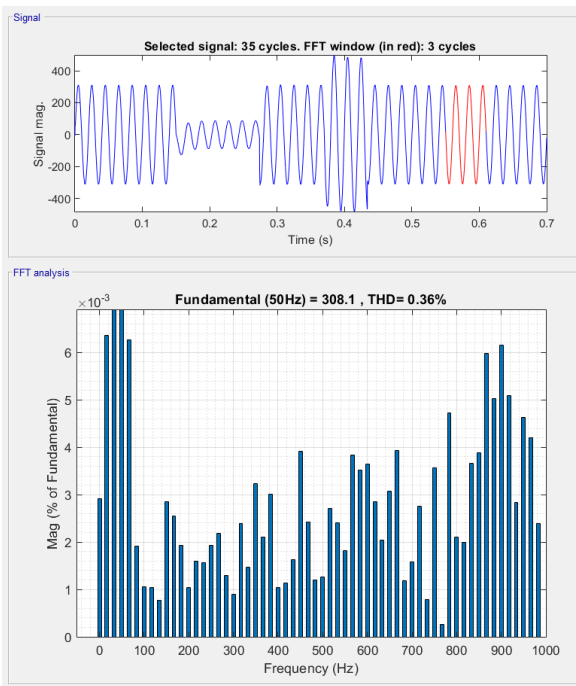


Figure 7: Voltage harmonics at full load

Conclusion

This research has demonstrated the feasibility and effectiveness of employing a PWM switched transformer for voltage regulation in single-phase power systems. The PWM technique enables precise and continuous adjustment of the output voltage, surpassing the limitations of discrete tap-changing mechanisms. The system can respond quickly to dynamic load changes, ensuring

stable voltage levels even under fluctuating conditions. The findings of this research suggest that PWM switched transformers have the potential to become a promising technology for enhancing voltage regulation in various applications, including residential, commercial, and industrial power systems.

References

- [1] K. Nikum, R. Saxena and A. Wagh, "Effect on power quality by large penetration of household non-linear load", ICPEICES, Delhi, India, 2016, pp. 1-5
- [2] S. Pal and S. Nath, "An intelligent on line voltage regulation in power distribution system," *International Conference on Power, Control and Embedded Systems*, Allahabad, India, 2010, pp. 1-5
- [3] A. Bedawy, Y. Sasaki, Y. Zoka and N. Yorino, "An Effective Voltage Control Approach for Distribution Systems with High Penetration of Renewable Energy Resources," *MEPCON*, Mansoura, Egypt, 2023, pp. 1-6
- [4] R. E. Nambiar, D. M, L. B, P. K. AJ and V. Priyadarshini, "Comparative Study Between Different Controllers Of DVR For Power Quality Improvement", *ICDI3C*, Bangalore, India, 2021, pp. 84-87
- [5] D. M. Lee, et al. "A Voltage Sag Supporter Utilizing a PWM-Switched Autotransformer," in *IEEE Transactions on Power Electronics*, vol. 22, no. 2, pp. 626-635, March 2007
- [6] P. Aldi, S. Shrigiri and K. Smita, "Study of Topologies, Power Converters, and Control Techniques for the Dynamic Voltage Restorer (DVR)," *ICIIC*, Kalaburagi, India, 2023, pp. 1-7
- [7] S. M and M. R. M. K. P, "Power Quality Improvement Using ZSI-DVR," *ICFCR*, Malappuram, India, 2022, pp. 1-6
- [8] S. K N, N. S, J. E.A and B. Jayanand, "Power Quality Improvement of Distribution System Using DVR with H-bridge Topology and Differential Inverter Control," *ICCISc*, Idukki, India, 2021, pp. 1-8
- [9] B. M. T. L. Simbolon and A. Rajagukguk, "Simulation and Analysis of the Use of Dynamic Voltage Resoster (DVR) on the Power Line Against the Effect of Voltage Sag and Voltage Swell," *ICon EEI*, Pekanbaru, Indonesia, 2024, pp. 22-27
- [10] S. Manmadha Rao, R. J. Satputaley, R. K. Keshri, N. R. Patne and G. Buja, "Voltage Sag Mitigation using DVR in Grid fed EV Fast Charging Station," *AEIT AUTOMOTIVE*, Torino, Italy, 2021, pp. 1-6