Single switch Z-source/quasi Z-source DC-DC converters

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ABSTRACT
This paper analyzes a family of high step up single switch switched capacitor boost converters and Z-source/quasi Z-source dc-dc converters to provide high output dc voltage gain with single stage conversion having low voltage stress on active switches, capacitors, and diodes. The operating principles, parameters design guideline of these converters are presented along with simulation results. The discussed topologies in this paper are aimed to increase the conversion system reliability and efficiency with decreased cost, volume, and weight. These power converter topologies are used for various applications such as photovoltaic (PV) systems, wind energy conversion, fuel cells, uninterruptible power systems, motor drives, energy storage systems, electric vehicle and power factor correction. Simulations are carried out in MATLAB/Simulink environment.

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1. INTRODUCTION
Photovoltaic (PV) applications, low voltage DC grid systems, fuel cell systems, grid connected inverters, electric vehicles, motor drives and electronic loads requires a desired DC link voltage either at the point of coupling or at the subsequent power converter arrangements, which should have constant or regulated DC voltage. However in reality, output DC voltages derived out from these DC sources such as PV systems are not uniform due to various reasons like source variability, intermittency and absence of appropriate power converter topologies. To avoid these issues, various DC power converter topologies are developed by various authors having the features of regulated voltage with adequate voltage gain are illustrated as mentioned in [1-7]. They had realized these necessities with the help of isolated/non-isolated, conventional boost/buck-boost, resonant converter topologies having high step up DC gains, when operated at certain duty ratio. However it produces a large current ripple in the inductor leading to higher conduction and switching loss. DC-DC converters having high step up voltage gain experiences variety of problems like voltage stress, power losses due to interfacing transformers. Switching losses in the diode and voltage unbalance on the output capacitors affect the performance of these converters with low efficiency in the form of reverse recovery/electromagnetic interference problems [8-17]. In this paper, switched capacitor ZSI and QZSI converter family based topologies are deliberated for the application of DC-DC conversion. The comparative key factors influencing the use of the proposed topologies are: continuous input current and voltage gain, connection of source and load at the common ground point, voltage stress across the capacitor and quantity of diode and switching devices. By employing a single active switch (MOSFET or IGBT), these converters can realize better DC-DC voltage conversion at duty cycle of value ranging from 0.1 to 0.9. Also the buck and boost features of this converters subjected to duty ratio.
2. **BASIC SWITCHED CAPACITOR BOOST CONVERTER TOPOLOGIES**

A third order boost DC-DC converter is presented in Figure 1, which contains of single switch $S_W$, diodes ($D_1$ and $D_2$), capacitors ($C_1$ and $C_2$), an inductor $L$ and resistive load $R_L$. Following equations associated with boost converter are briefed in [18].

The boost conversion factor, $M$ is given by:

$$ M = \frac{2 - D}{1 - D} \quad (1) $$

Voltage stress on active switch, $V_s$ is given by:

$$ V_s = \frac{V_{in}}{1 - D} \quad (2) $$

Voltage stress across diodes, $V_d$ is given by:

$$ V_d = \frac{V_{in}}{1 - D} \quad (3) $$

Figures 2 and 3 are examples of switched capacitor boost converter topologies. To obtain a better voltage gain, switched capacitors ($C_1$ and $C_2$) are connected in series to supply the load. When the switch $S_W$ is turned on, input voltage source is connected to $C_1$ in series and load is connected to $C_2$ load. Following equations associated with switched capacitor DC-DC converter are briefed [19, 20]. The boost conversion factor, $M$ is given by:

$$ M = \frac{2}{1 - D} \quad (4) $$

Voltage stress on active switch, $V_s$ and voltage stress across diodes, $V_d$ is given by:

$$ V_s = V_d = \frac{V_{out}}{2} \quad (5) $$

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3. Z-SOURCE DC-DC CONVERTER TOPOLOGIES

According to Figure 4, the Z-source converter is operating as a DC-DC boost operation, which consists of diode D₁, two identical inductors (L₁ and L₂) and (C₁ and C₂) are coupled to attain the Z-source operation. Switch (Sₘ) is active switch and L₄ and C₄ are second order low pass filters. The converter supplies power to the resistive load (Rₐ). By the symmetry of Z network, inductor L₁ and L₂ ranges are selected equal to L; capacitor C₁ and C₂ ranges are selected equal to C, therefore iₙ₁= iₙ₂= iₙ, Vₙ₁ = Vₙ₂ = Vₙ and Vₙ₁ = Vₙ₂ = Vₙ. The circuit has a higher input to output DC voltage boost conversion factor and isolates the source and load in case of a short circuit at the load side. MOSFET is switched at a switching frequency of \( f_s = 1/ T_s \) and duty cycle of the switch \( D \) is given by \( D = Ton / T_s \), where \( Ton \) is pulse width and \( T_s \) is the switching period of PWM (pulse width modulation) signal. Following equations associated with Z-source DC-DC converter are briefed [21, 22].

\[
M = \frac{1 - D}{1 - 2D} \quad \text{for } D < 0.5
\]  
(6)

Voltage stress on active switch, \( V_s \) is given by:

\[
V_s = \frac{Vin}{1 - 2D}
\]  
(7)

Voltage stress across diodes, \( V_d \) is given by:

\[
V_d = \frac{Vin}{1 - 2D}
\]  
(8)
Voltage stress across diodes, $V_d$ is given by:

$$V_d = \frac{1 - D}{1 - 2D} \text{Vin}$$

The modified version of Z source DC-DC converter as shown in Figure 5 consists of Z-source network ($L_1$, $L_2$, $C_1$, and $C_2$), a switch $S_W$, two diodes $D_1$ and $D_2$, a filter capacitor $C_f$ and a load resistance $R_L$ [23]. Both from Figures 5 and 6, the input source and load are located on the same side of the Z-source network, which share the same ground to produce high voltage gain with no additional components and low voltage stresses on the switch and diodes [24]. The other modified versions of Z-source DC-DC converter are shown in Figure 7 with additional diodes and capacitors. The Z-source network is consist of “$D_1$, $L_1$, $L_2$, $C_1$, $C_2$” and the switched capacitor network is consist of $C_3$, $C_4$, $C_5$, $D_2$, $D_3$, and $D_4$.

The boost conversion factor, $M$ is given by:

$$M = \frac{2(1-D)}{1-2D} \text{ for } D < 0.5$$

Voltage stress on capacitors, $V_c$ of $C_1$, $C_2$ can be expressed as:

$$V_c = \frac{1 - D}{1 - 2D} \text{Vin}$$

Output voltage $V_{out}$ is given by:

$$V_{out} = \frac{2(1-D)}{1-2D} \text{Vin}$$
4. QUASI Z-SOURCE DC-DC CONVERTER TOPOLOGIES

The quasi Z-source converter is an exclusive Z-source network. It is connected between the input power source and switching circuit for the purpose of increase the DC output voltage of the converter by adjusting the shoot through (ST) duty ratio as illustrated in Figure 8 [25]. During the traditional operation state, only DC current goes through the inductors. During shoot through (ST) mode and non-shoot through mode, inductor current increases and decreases respectively. The other modified versions of quasi Z-source DC-DC converter topologies are exposed in Figures 9 and 10.
By the symmetry of Z network, inductor $L_1$ and $L_2$ ranges are selected equal to $L$; capacitor $C_1$ and $C_2$ ranges are selected equal to $C$. Then the value of $i_{L1}$ and $i_{L2}$ are equal to $i_L$, $V_{L1}$ and $V_{L2}$ are equal to $V_L$, $V_{C1}$ and $V_{C2}$ are equal to $V_C$. The system state equation is given by:

$$
\begin{align*}
I_{L1} &= I_{L2} = \frac{(1-D)^2}{(1-2D)^2 \cdot RL} \cdot V_{in} \\
V_{C1} &= \frac{D}{(1-2D)} \cdot V_{in} \\
V_{C2} &= \frac{1-D}{(1-2D)} \cdot V_{in} \\
I_L &= \frac{(1-D)}{(1-2D) \cdot RL} \cdot V_{in} \\
V_{dc} &= \frac{1}{(1-2D)} \cdot V_{in}
\end{align*}
$$

(13)

Inductor current ($I_L$) is

$$
I_L = \frac{P}{V_{in}}
$$

(14)

when the converter is operating at shoot through state mode, the maximum current ripple occurs due to the nature of the inductor. The range of current ripple ($\delta$) is calculated according to (15):

$$
\Delta I_L = 2 \cdot \delta \% \cdot I_L
$$

(15)

The value of the inductor is calculated according to (16):

$$
L = \frac{VLDTS}{\Delta I_L}
$$

(16)

where $D$ and $T_s$ are the duty cycle at shoot through state and total switching time duration respectively.

In shoot through state operation mode, the ripple current of the converter is reduces because the inductor current ($I_L$) and capacitor current ($I_C$) become equal. The voltage ripple of the converter is depends on $V_C \delta V\%$, the range of the capacitor is calculated according to (17). Quasi Z-source DC-DC converter topologies with switched capacitor network are shown in Figure 11 and Figure 12. The quasi Z-source network is included “$L_1$, $D_1$, $L_2$, $C_1$ and $C_2$” and the switched capacitor network is included $C_3$, $D_3$, $C_4$, $D_5$, $C_5$ and $D_3$ [26, 27]. Some of the very interesting Z-source DC-DC converter topologies of different configurations, better features with scaled down verifications are also presented in [28-30].
The boost conversion factor, $M$ is given by:

$$M = \frac{2}{1-2D} \quad \text{for } D < 0.5$$  \hspace{1cm} (18)

Voltage stress on capacitors, $V_c$ of $C_1$ to $C_5$ can be expressed as:

$$V_{c1} = \frac{1-D}{2} \cdot V_{out}$$

$$V_{c2} = \frac{D}{2} \cdot V_{out}$$

$$V_{c3} = V_{c4} = V_{c5} = \frac{V_{out}}{2}$$  \hspace{1cm} (19)

The inductor value of the Z-source network is calculated by using (20), $\Delta I_L$ is a maximum value of the current ripple.

$$L_1 = L_2 = \frac{D(1-D)Vin}{(1-2D) \cdot \Delta I_L f}$$  \hspace{1cm} (20)

The capacitor value of the Z-source network is calculated by using (21), $\Delta I_C$ is a maximum value of the voltage ripple.
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5. RESULTS AND DISCUSSION

The analysis of these discussed converter topologies are based on the following assumptions.
1) Diode and switching devices are operating at ideal conditions, 2) The resistor, capacitor and inductor are assumed as frequency dependent, time invariant linear elements. 3) The value of the capacitor is assumed large with constant voltage in one switching time duration. 4) The converters operating in continuous conduction mode.

The chosen simulation values for all the discussed topologies are: \( V_{in} = 12 \) V, source side inductors \( L_1 \) and \( L_2 \) values are 330 μH and capacitors \( C_1 \) and \( C_2 \) values are 470 μF, filter values \( L_f \) and \( C_f \) values are 330 μH and 470 μF respectively, \( f_s = 40 \) kHz, duty cycle = 0.1 to 0.99 for switched capacitor DC-DC converter topologies and duty cycle = 0.1 to 0.6 for Z-source/quasi Z-source DC-DC converter topologies. Resistive load \( R_L \) of value 50Ω is chosen for all these converter topologies. Simulations are carried for these topologies for the corresponding duty ratio for the selected range in steps of 0.05 and the obtained output DC voltages are noted. The maximum output DC voltage for the corresponding duty ratio is presented in the following tables and the values for these ranges are shown in respective figures.

It can be observed that switched capacitor converter topologies exhibit very higher voltage gain for the duty ratio above 0.9 and Z-source/quasi Z-source topologies does the same at a duty ratio value ranging from 0.44 to 0.48. Table 1 gives the performance of switched capacitor DC-DC converter topologies, where the maximum output DC voltage obtained is tabulated with its corresponding duty ratio and Figure 13 plots the output DC voltage of these converter topologies as a role of \( D \).

| Switched capacitor DC-DC converter topologies | Maximum output DC voltage(Volts) | Corresponding duty ratio |
|----------------------------------------------|----------------------------------|-------------------------|
| Third order boost DC-DC converter            | 135.4                            | 0.95                    |
| Switched capacitor DC-DC converter (topology 1) | 132.1                            | 0.92                    |
| Switched capacitor DC-DC converter (topology 2) | 213.2                            | 0.93                    |

Figure 13. Output DC voltage of switched capacitor DC-DC converter topologies as a function of \( D \)
Table 2 gives the performance of Z-source DC-DC converter topologies, where the maximum output DC voltage obtained is tabulated with its corresponding duty ratio and Figure 14 plots the output DC voltage of these Z-source DC-DC converter topologies as a role of D. Table 3 gives the performance of quasi Z-source DC-DC converter topologies, where the maximum output DC voltage obtained is tabulated with its corresponding duty ratio and Figure 15 plots the output DC voltage of these quasi Z-source DC-DC converter topologies as a function of D. It is observed that output DC voltage of switched capacitor DC-DC converter topologies are high at higher duty ratio, whereas Z-source/quasi Z-source DC-DC converter topologies exhibit better DC voltage boosting at a value of 0.4 which results in minimum stress to the switch.

### Table 2. Performance of Z-source DC-DC converter topologies

| Z source DC-DC converter topologies | Maximum output DC voltage (Volts) | Corresponding duty ratio |
|-------------------------------------|-----------------------------------|--------------------------|
| Topology 1                          | 87.39                             | 0.48                     |
| Topology 2                          | 88.23                             | 0.47                     |
| Topology 3                          | 87.56                             | 0.47                     |
| Topology 4                          | 85.56                             | 0.44                     |

![Figure 14. Output DC voltage of Z-source DC-DC converter topologies as a function of D](image1)

### Table 3. Performance of quasi Z-source DC-DC converter topologies

| Quasi Z source DC-DC converter topologies | Maximum output DC voltage (Volts) | Corresponding duty ratio |
|------------------------------------------|-----------------------------------|--------------------------|
| Topology 1                               | 87.39                             | 0.48                     |
| Topology 2                               | 134.3                             | 0.48                     |
| Topology 3                               | 88.23                             | 0.47                     |
| Topology 4                               | 79.27                             | 0.44                     |
| Topology 5                               | 85.56                             | 0.44                     |

![Figure 15. Output DC voltage of quasi Z-source DC-DC converter topologies as a function of D](image2)
6. CONCLUSION

A family of switched capacitor and Z-source/quasi Z-source DC-DC converter topologies for photovoltaic power applications has been worked in this paper. Steady state analysis of these topologies has been discussed with detailed simulation results to verify its effectiveness. Output DC voltage obtained for all the converter topologies is presented in a comprehensive manner to meet the requirement of various applications. The converters discussed in this paper have the advantages such as continuous input current, reduced capacitor voltage stress, low voltage stress across the output diode and power switches. Also, these converters are suitable for photovoltaic applications where a varying low DC input voltage is converted to a high stabilized DC output voltage.

ACKNOWLEDGEMENTS

This work supported by Indo-Sri Lanka Joint Research Program, Department of Science and Technology, Ministry of Science &Technology, Government of India (ICD -3425.60.798.14.00.31&35).

REFERENCES

[1] W. Li and X. He, “Review of Nonisolated High-Step-Up DC/DC Converters in Photovoltaic Grid-Connected Applications,” in *IEEE Transactions on Industrial Electronics*, vol. 58, no. 4, pp. 1239-1250, April 2011, doi: 10.1109/TIE.2010.2049715.

[2] B. Gu, J. Dominic, J. Lai, Z. Zhao and C. Liu, “High Boost Ratio Hybrid Transformer DC-DC Converter for Photovoltaic Module Applications,” in *IEEE Transactions on Power Electronics*, vol. 28, no. 4, pp. 2048-2058, April 2013, doi: 10.1109/TPEL.2012.219834.

[3] Y. Hsieh, J. Chen, T. Liang and L. Yang, “Novel High Step-Up DC-DC Converter for Distributed Generation System,” in *IEEE Transactions on Industrial Electronics*, vol. 60, no. 4, pp. 1473-1482, April 2013, doi: 10.1109/TIE.2011.2107721.

[4] K. Park and Z. Chen, “A Double Uneven Power Converter-Based DC-DC Converter for High-Power DC Grid Systems,” in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 12, pp. 7599-7608, Dec. 2015, doi: 10.1109/TIE.2015.2458301.

[5] W. Chen, X. Wu, L. Yao, W. Jiang and R. Hu, “A Step-up Resonant Converter for Grid-Connected Renewable Energy Sources,” in *IEEE Transactions on Power Electronics*, vol. 30, no. 6, pp. 3017-3029, June 2015, doi: 10.1109/TPEL.2014.2336893.

[6] A. Chub, D. Vinnikov, E. Liivik and T. Jalakas, “Multiphase Quasi-Z-Source DC-DC Converters for Residential Distributed Generation Systems,” in *IEEE Transactions on Industrial Electronics*, vol. 65, no. 10, pp. 8361-8371, Oct. 2018, doi: 10.1109/TIE.2018.2801860.

[7] G. R. Walker and P. C. Sermia, “Cascaded DC-DC Converter Connection of Photovoltaic Modules,” in *IEEE Transactions on Power Electronics*, vol. 19, no. 4, pp. 1130-1139, July 2004, doi: 10.1109/TPEL.2004.830090.

[8] E. H. Ismail, M. A. Al-Saffar, A. J. Sabzali and A. A. Fardoun, “A Family of Single-Switch PWM Converters with High Step-Up Conversion Ratio,” in *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 55, no. 4, pp. 1159-1171, May 2008, doi: 10.1109/TCSL.2008.916427.

[9] L. Yang, T. Liang and J. Chen, “Transformerless DC-DC Converters with High Step-Up Voltage Gain,” in *IEEE Transactions on Industrial Electronics*, vol. 56, no. 8, pp. 3144-3152, Aug. 2009, doi: 10.1109/TIE.2009.2022512.

[10] A. Shahin, M. Hinaje, J. Martin, S. Pierfederici, S. Rael and B. Davat, “High Voltage Ratio DC-DC Converter for Fuel-Cell Applications,” in *IEEE Transactions on Industrial Electronics*, vol. 57, no. 12, pp. 3944-3955, Dec. 2010, doi: 10.1109/TPEL.2010.2045996.

[11] C. Pan and C. Lai, “A High-Efficiency High Step-Up Converter with Low Switch Voltage Stress for Fuel-Cell System Applications,” in *IEEE Transactions on Industrial Electronics*, vol. 57, no. 6, pp. 1998-2006, June 2010, doi: 10.1109/TIE.2009.2024100.

[12] Y. Tang, D. Fu, T. Wang and Z. Xu, “Hybrid Switched-Inductor Converters for High Step-Up Conversion,” in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 3, pp. 1480-1490, March 2015, doi: 10.1109/TIE.2014.2364797.

[13] B. Poorali, A. Torkan and E. Adib, “High Step-Up Z-Source DC-DC Converter with Coupled Inductors and Switched Capacitor Cell,” in *IET Power Electronics*, vol. 8, no. 8, pp. 1394-1402, 8 2015, doi: 10.1049/iet-pel.2014.0200.

[14] K. Vijayalakshmi and C. R. Balamurugan, “Z-Source Multilevel Inverter based on Embedded Controller,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 6, no. 1, pp. 1-8, April 2017.

[15] Deepa Sankar and C. A. Babu, “Design and Analysis of a Novel Quasi Z Source based Asymmetric Multilevel Inverter for PV applications,” *International Journal of Power Electronics and Drive System*, vol. 11, no. 3, pp. 1368-1378, 2020.

[16] S. Bala Kumar, Samuel Kefale, and Azath M., “Comparison of Z-Source EZ-Source and TZ-Source Inverter Systemsfor Wind Energy Conversion,” *International Journal of Power Electronics and Drive System*, vol. 9, no. 4, pp. 1693-1701, Dec. 2018.

[17] M. Veerachary, “Third-order boost converter,” in *IET Power Electronics*, vol. 11, no. 3, pp. 566-575, 2018, doi: 10.1049/iet-pel.2017.0186.
[18] X. Zhu, B. Zhang, Z. Li, H. Li and L. Ran, "Extended Switched-Boost DC-DC Converters Adopting Switched-Capacitor/Switched-Inductor Cells for High Step-up Conversion," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 5, no. 3, pp. 1020-1030, Sept. 2017, doi: 10.1109/JESTPE.2016.2641928.

[19] G. Wu, X. Ruan, and Z. Ye, "Nonisolated High Step-Up DC–DC Converters Adopting Switched-Capacitor Cell," in IEEE Transactions on Industrial Electronics, vol. 62, no. 1, pp. 383-393, Jan. 2015, doi: 10.1109/TIE.2014.2327000.

[20] G. Wu, X. Ruan and Z. Ye, "High Step-Up DC-DC Converter based on Switched Capacitor and Coupled Inductor," in IEEE Transactions on Industrial Electronics, vol. 65, no. 7, pp. 5572-5579, July 2018, doi: 10.1109/TIE.2017.2774773.

[21] V. P. Galigekeere and M. K. Kazimierczuk, "Analysis of PWM Z-Source DC-DC Converter in CCM for Steady State," in IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 59, no. 4, pp. 854-863, April 2012, doi: 10.1109/TCSI.2011.2169742.

[22] M. K. Kazimierczuk, "Small-Signal Modeling of Open-Loop PWM Z-Source Converter by Circuit-Averaging Technique," in IEEE Transactions on Power Electronics, vol. 28, no. 3, pp. 1286-1296, 2012, doi: 10.1109/TPEL.2012.2207437.

[23] J. Zhang and J. Ge, "Analysis of Z-source DC-DC Converter in Discontinuous Current Mode," 2010 Asia-Pacific Power and Energy Engineering Conference, Chengdu, 2010, pp. 1-4, doi: 10.1109/APPEEC.2010.5448927.

[24] H. Shen, B. Zhang, D. Qiu and L. Zhou, "A Common Grounded Z-Source DC–DC Converter With High Voltage Gain," in IEEE Transactions on Industrial Electronics, vol. 63, no. 5, pp. 2925-2935, May 2016, doi: 10.1109/TIE.2016.2516505.

[25] H. Liu, P. Liu and Y. Zhang, "Design and Digital Implementation of Voltage and Current Mode Control for The Quasi-Z-Source Converters," in IET Power Electronics, vol. 6, no. 5, pp. 990-998, May 2013, doi: 10.1049/iet-pel.2012.0366.

[26] Y. Zhang et al., "Wide Input-Voltage Range Boost Three-Level DC–DC Converter with Quasi-Z Source for Fuel Cell Vehicles," in IEEE Transactions on Power Electronics, vol. 32, no. 9, pp. 6728-6738, Sept. 2017, doi: 10.1109/TPEL.2016.2625327.

[27] Y. Zhang, C. Fu, M. Sumner and P. Wang, "A Wide Input-Voltage Range Quasi-Z-Source Boost DC-DC Converter With High-Voltage Gain for Fuel Cell Vehicles," in IEEE Transactions on Industrial Electronics, vol. 65, no. 6, pp. 5201-5212, June 2018, doi: 10.1109/TIE.2017.2745449.

[28] Y. Liu, H. Abu-Rub and B. Ge, "Front-End Isolated Quasi-Z-Source DC-DC Converter Modules in Series for High-Power Photovoltaic Systems-Part I: Configuration, Operation, and Evaluation," in IEEE Transactions on Industrial Electronics, vol. 64, no. 1, pp. 347-358, Jan. 2017, doi: 10.1109/TIE.2016.2598673.

[29] Y. Liu, H. Abu-Rub and B. Ge, "Front-End Isolated Quasi-Z-Source DC-DC Converter Modules in Series for High-Power Photovoltaic Systems-Part II: Control, Dynamic Model, and Downscaled Verification," in IEEE Transactions on Industrial Electronics, vol. 64, no. 1, pp. 359-368, Jan. 2017, doi: 10.1109/TIE.2016.2598675.

[30] J. Liu, J. Wu, J. Qiu and J. Zeng, "Switched Z-Source/Quasi-Z-Source DC-DC Converters with Reduced Passive Components for Photovoltaic Systems," in IEEE Access, vol. 7, pp. 40893-40903, 2019, doi: 10.1109/ACCESS.2019.2907300.

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