Industrial Engineering Journal
ISSN: 0970-2555
Volume: 53, Issue 4, No. 1, April: 2024

APPLICATION OF MULTI-LEVEL CONVERTER FOR FAST CURRENT CONTROL IN SMALL-SCALE DC POWER NETWORK

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Abstract
DC microgrids are emerging as the next generation of small-scale electrical power networks due to their exceptionally low line impedance. Because of this occurrence, even a little voltage shift can result in high currents in the micro girds; for this reason, a power flow controller’s rapid response time and precision are crucial. In this work, power flow controllers that offer high-precision power regulation of flow in a dc microgrid at fast speeds are multi-level converters. Due to the usage of multiple-level converters, the output filter may be tiny. This study also covers the design of the multi- level converter's output LC filter, which aims to satisfy the requirement for a current ripple.

Keywords: -
Microgrids, DC-DC Power Converters, Power flow controller

I. Introduction

Since the majority of grid-tide renewable energy systems handle DC power for two output and input, a DC microgrid reduces the number of power conversion steps required to move power from the AC to the DC sides. Because there are fewer nodes such as generators, batteries, and loads in a DC microgrid than in an extend AC grid, the line impedances are typically very low. This allows for a high current to pass down the lines even in the case of a small voltage change. A DC-DC converter’s terminal frequency characteristics around its switching frequency can be explained by an output impedance model, according to reference [1].

In order to address the problems arising from variations in the operation modes of energy storage systems, reference [2] suggests a control technique for bidirectional DC-DC converters. Except for a grid configuration that links only two converters and passive resistance loads, research has been conducted in [3]. Reference [4] offers a hierarchical control-based power flow sharing and voltage regulation control system that is successful in lowering the transmission loss of the DC micro-grid. A network configuration example involving the connection of three or more nodes may be found in [5]. Reference [7] describes the creation and operation of a DC microgrid that uses an electric car (EV) as a portable energy storage device. The two-level converter circuit topology was mostly utilized for the aforementioned investigations in [8-10].

Furthermore, enhancing dynamic performance has not taken precedence over other goals. Studies are currently being conducted with the goal of achieving the individual converter’s high-speed response [11–12]. A control strategy for achieving a DC-DC converter’s fast current response was described in [11]. With a switching frequency in the MHz range and a voltage conversion from 3.3 V to 5.5 V, this technique requires that the low-voltage power supply will be incorporated on a chip or in a package. In reference [12], predictive current control was suggested for a bidirectional level-2 DC-DC converter in order to improve the DC microgrid’s dynamic and steady-state performances there are further studies published on the topology circuit of a level -2 bilateral rectifier for the DC microgrid.

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2.1: proposed circuit

Fig. 1 depicts a circuit for examining power flow between two nodes, which is the bare minimum for a DC microgrid. Three different types of components make up a DC microgrid's power flow: unidirectional power sources like solar or wind power, bidirectional supplies and loads like battery banks, and unidirectional loads. There are one-to-plural, one-to-one, or plural-to-plural connections between these elements.

The power supply, loads, and distribution line, along with the power flow controller, are shown in Figure.1 as E1, R1, E2, and R2.

Fig. 2 shows the circuit configurations for the level-2 and multi-level topologies. This study uses the multi-level topology of a flying-capacitor type as an example. TABLE I contains a list of the circuit component numbers for each converter.

2.2: Power flow controller theoretical design process taking consideration of the number of levels

A power flow controller's output filter is designed with the goal of simultaneously reducing the settling time (transient state) and the current ripple (steady state). Designing with the number of layers m in mind is therefore crucial. Typical waveforms in Fig. 3 show the trade-off between the settling time and current ripple in multi-level converters and level-2. The multi-level converter (smaller filter) settles faster for the same ripple than the level-2 converter (lager filter), as seen in Fig. 3(a). But as Fig. 3(b) shows, the ripple is larger for the level-2 rectifier than for the multi-level converter (smaller filter) for the same filter. As seen in Fig. 3(b), there is a trade-off between increasing however, for the identical filter, the ripple is larger for the level-2 rectifier than for the multi-level converter.

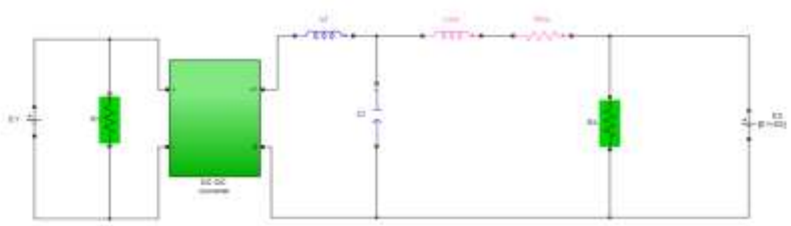
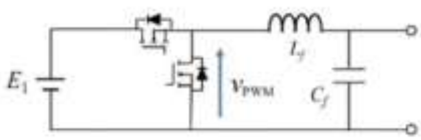
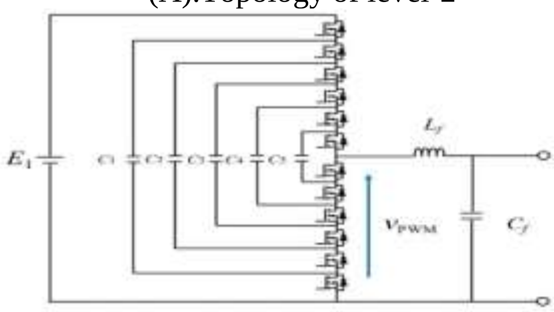


Fig 1: Circuit to control the flow of power between two nodes



(A).Topology of level-2



b: (7 level case) multi-level converter

Fig [2]: network configurations for managing the flow of power

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TABLE-I

THE NUMBER OF ELEMENTS IN CONVERTERS

The levels of number	**Switching device**	**Flying capacitor**	**Output pwm switching frequency**
Level-2	2	-	f_c
Level-7	12	5	$6f_c$
Level-9	16	7	$8f_c$
Level-m	2m-2	m-2	(m-1) f_c

Because it is proportionate to the settling time when the current response is calibrated for critical damping, the gradient of the current rise in a step response is examined in the design rather than the settling time. The corresponding circuits for examining the output current gradient and ripple in a steady state while taking the converter's worst-case behavior into consideration are depicted in Figure 4. (1) makes use of theoretical research to determine the maximum gradient of the current change. For simplicity's sake, we can ignore R1 and R2.

$$\max\frac{di}{dt} = \frac{E1-E2}{Lline\, Lfcf}\frac{1}{(\alpha-\beta)(\alpha-\gamma)} \qquad (1)$$

Here, s in the following equation (2) has solutions α, β, and γ, where and are the conjugate values.

$$s^3+\frac{Rline}{Llin}S^2+\left(\frac{1}{Lline\ cf}+\frac{1}{LfCf}\right)s+\frac{1}{LlineLfCf}=0 \quad (2)$$

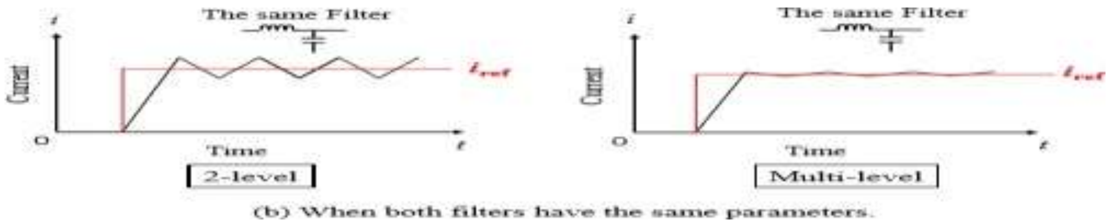

Fig.3. An instance of a current waveform with a step response determined by the output filters and output level of the number of converters.

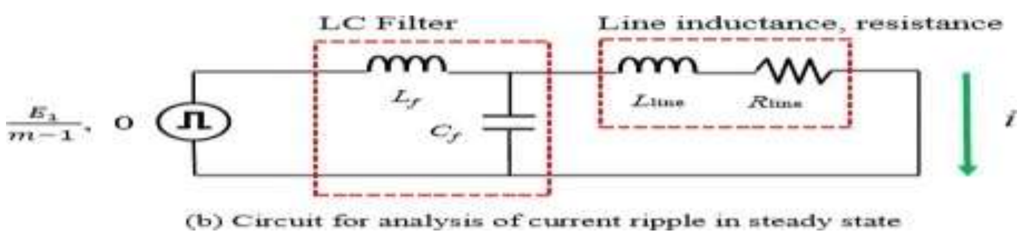

Fig.4. Comparable circuits for power flow controller filter design that take the worst-case scenario into account

Equations (1) through (5) can be used to perform numerical calculations to design the filter's LF and CF as well as the output level (m). This is a theoretical explanation of how filters and power flow controllers are designed.

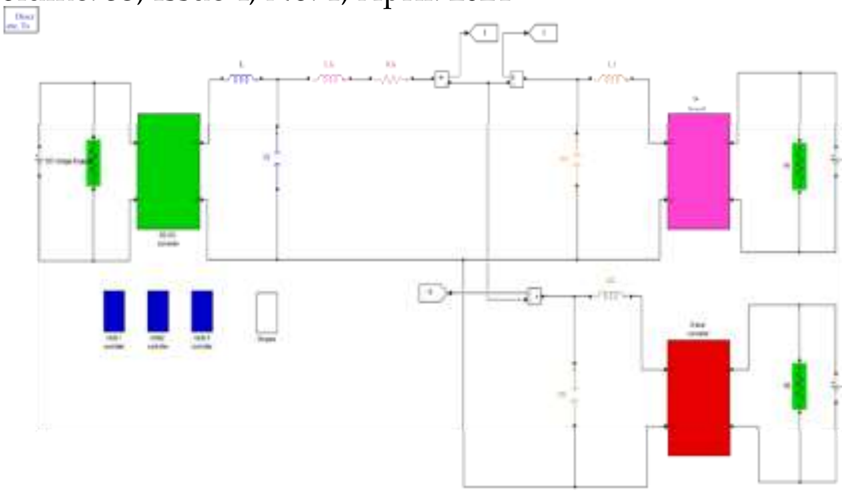

Fig.5. Three nodes and three converters make up the circuit architecture of distribution network used to validate power flow control

III. Studying the Control Performance of Power Flow Controllers with Two and Seven Levels

3.1: Examining the suggested circuit's state

The control current capacity of the multi-level converter and level-2 is confirmed by simulation. Figure 5 shows the distribution network that is considered part of the postulated DC microgrid in this investigation. It consists of three converters and three nodes.

3.2: Finding the Effective Filter Design for Power Flow Controllers with Two and More Levels A list of the circuit parameters shown in Fig. 5 can be found in Table-II. The level-7 and level-2 power flow controller's; output filters are developed using (1) to (5) for a current ripple of 0.01 AAs a result, TABLE III filter construction for the level-7 and level-2 converters is followed. For ease of comparison, filter capacitors with the same value are used in this design
example. It is verified by TABLE III that the level-2 converter's filter parameter drops by roughly a sixth of the level-7 converters. The level-2 converter's output voltage ripple, which reduces to a sixth of that of the level-7 converter, is the reason for this decrease, according to the operating principle.

3.3: Validation of simulation in a distribution network with three nodes

The step response of this simulation accounts for transient variations in the power flow and assesses each output current's control performance using the circuit simulator PSIM, or Power. Fig. 6 displays the reference output current of each converter.

Furthermore, the response values of i3 and i2 are seen to deviate from the reference values at the corresponding instants of the step change (0.0028 and 0.0020 s); It is anticipated that the multi- level converter's faster power flow capability will increase the DC microgrid's stability and dependability.

TABLE-II

Conditions for investing

THE NUMBER OF LEVELS	M	2-LEVEL	7-LEVEL	9-LEVEL
Node voltage	E	200v	200v	200v
Line resistance	R_{line}	0.0022Ω	0.0022Ω	0.0022Ω
Line inductance	L_{line}	0.3μH	0.3μH	0.3μH
Load resistance	R	200	200Ω	200Ω
Capacitance of flying capacitors		-	19.8μF	19.8μF
PWM switching frequency	f_{pwm}	500KHZ	83.3khz*6=500KHZ	83.3khz*8=666KHZ

Industrial Engineering Journal
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TABLE III
DESIGN FILTERS UNDER TABLE II CONDITION

The number of levels	The number of levels	Filter capacitance
M	**Cf**	**Lf**
Level-2	**18nf**	**10mh**
Level-7	**18nf**	**1.8mh**
Level-9	**18nf**	**1.8mh**

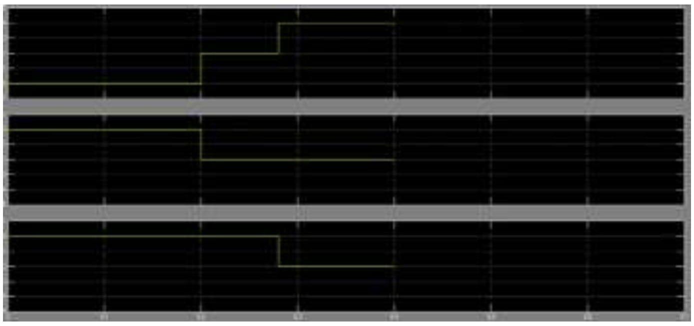

Fig.6. recent sources used in this research

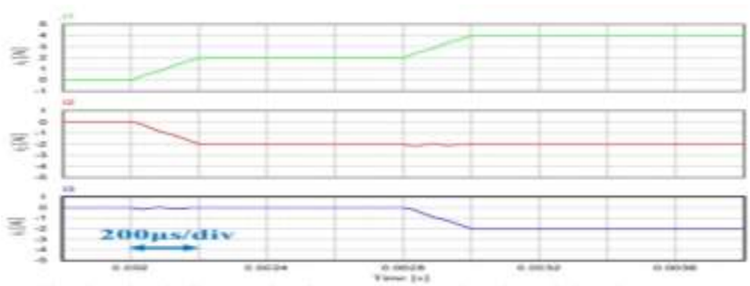

Fig.7. Power flow mat lab simulation link result with three level-2 converters (fpwm=500khz)

This led to the modification of the filter's inductance to 60mH and an adjustment of the level-2 converter's switching frequency from 83.3 kHz to 500 kHz. Figure 9 presents the results of a power flow simulation with three level-2 converters (fpwm = 83.3 kHz).

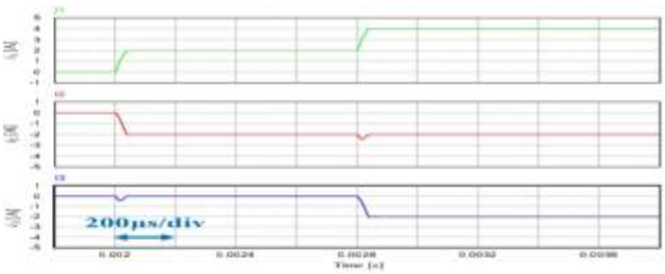

Fig.8. Power flow matlab simulation link result with three level -7 converters (fpwm=500khz)

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IV Conclusion

In conclusion, there are a number of significant advantages to using multi-level converters in small-scale DC power networks for quick current management. First off, multi-level converters offer more control over voltage, enabling more precise adjustments to current levels. In small-scale networks, where accurate current regulation is critical to preserving system efficiency and stability, this flexibility is vital. Furthermore, multi-level converters; quick switching speeds enable quick reactions to changes in load and disruptions, guaranteeing dependable performance and reducing downtime. This feature is especially helpful in dynamic settings where load swings are frequent. Multi- level converters offer a convincing way to overcome the difficulties faced by contemporary power systems when used for quick current management in small-scale DC power networks.

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