Design and Simulation of Five-Level Inverter: Simulation Study of Five-Level Inverter

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Abstract— Multilevel Inverter is very efficient alternative for Medium voltage and High power applications. The demand for Multilevel Inverter is increasing now-a-days since it is impossible to connect the power semiconductor switch to high voltage network directly. One of the most important features of the multilevel Inverter is that as the number of level increases, the THD (Total Harmonic Distortion) in the output-voltage waveform decreases. This paper presents the CHB (Cascaded H-bridge) with equal and unequal dc voltage and their comparison. In order to obtain the increased voltage level Cascaded H-bridge with unequal DC voltage is beneficial than Cascaded H-bridge with equal DC voltage. But there are some disadvantages associated with Cascaded H-bridge with unequal DC voltage. Multilevel Inverter consists of the H-bridges connected in cascade (series). The number of the H-bridge connected in series increases with the increased number of levels. The structure of Cascaded H-bridge is simple as compared to other types of Multilevel Inverter as it does not require clamping diodes and flying capacitors. The advantage of using H-bridge is that both positive and negative level at the output is obtained. This is called the Developed Cascaded H-bridge Inverter. Reduction in the number of power switches, driver circuits and dc voltage sources are advantages of the Developed Single-Phase Cascaded H-bridge Inverter. Since reduced number of components is required in each H-bridge therefore cost and losses are reduced resulting in increased efficiency. With the increased efficiency maximum output is obtained.
As the modulation index increases the THD (Total Harmonic Distortion) for output voltage and current waveform decreases.

Keywords- *Cascaded multilevel Inverter, Developed cascaded multilevel Inverter, H-bridge*

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I. INTRODUCTION

The demand for high voltage and high power Inverters are increasing day by day. Therefore multilevel Inverters are increasing and developing now. The Cascaded H-bridge (CHB) consists of number of switches connected in cascade on their ac side to achieve medium voltage operation and low harmonic distortion. Each H-bridge requires an individual DC supplies. As each H-bridge requires an individual DC supply the total Harmonic distortion is reduced [1-3]. As the cascaded H-bridge consists of reduced number of switches, the switching losses are also reduced. Each switch requires an individual gate driver circuit. Therefore the number of switches is equal to number of gate drive circuits. As the number of level increases, the harmonics in the output voltage waveform decreases. As the output voltage waveform decreases and the output harmonics is reduced, the system become more reliable and gives the maximum efficiency. The cost of the inverter is determined by the size of the filter. If the size of the filter reduces, the total cost of the inverter decreases. Multilevel Inverter is classified into three types that is Cascaded H-bridge, Diode clamped and Flying capacitor. Cascaded H-bridge is advantageous over the Diode-clamped and Flying capacitors as it does not require clamping diodes and Flying capacitors [4-5].

Cascaded H-bridge Inverters are generally of two types i.e. Symmetric and Asymmetric. In Symmetric Cascaded H-bridge multilevel inverter the two dc voltage sources have equal amplitudes. Therefore in order to increase the total dc voltage the number of H-bridges in series should be increased. This means that as the number of level increases the number of dc voltage sources in series also increases as each H-bridge requires an individual dc source. The asymmetric cascaded multilevel inverter generates higher number of output levels in comparison with the symmetric one by same number of power electronic devices because of different amplitude of its dc voltage sources. As a result, the installation space and total cost of an asymmetric cascaded multilevel inverter is lower than symmetric one. The main disadvantages of the symmetric cascaded multilevel inverters are the high required number of power switches, insulated gate bipolar transistors, power diodes and driver circuits because of the same magnitude of dc voltage sources. Each unidirectional switch requires an IGBT with an anti-parallel diode and a driver circuit while bidirectional one includes of two numbers of IGBTs, two anti parallel diodes and one driver circuit if common emitter configuration is used. However both unidirectional and bidirectional power switches conduct current in both directions. In order to increase the number of output levels different asymmetric cascaded multilevel inverters have been presented [6-8]. The main disadvantages of these inverters are the high magnitude of dc voltage sources.

Although, different symmetric and asymmetric cascaded multilevel inverters have been described a new basic unit is used to increase the number of generated output levels by using lower number of power electronic devices. The unit only generates positive level at the output. Therefore in order to generate both positive and negative level at the output an H-

bridge is added to the basic unit. This is called as developed cascaded multilevel Inverter.

II. BASIC THREE-LEVEL INVERTER

Figure 1 shows a simplified circuit diagram of a single-phase H-bridge inverter .It is composed of two inverter legs with two IGBT devices in each leg. Out of the four switches two switches conduct at a time. When switches S1 and S2 conduct V0=VAB and when switches S3 and S4 conduct V0= -VAB.

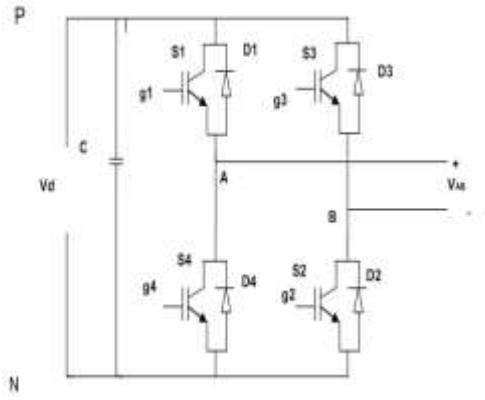

Fig. 1. Basic Three-level Inverter.

The inverter dc bus voltage is usually fixed, while its ac output voltage VAB can be adjusted by either unipolar or bipolar modulation schemes.

TABLE I. PERMITTED TURN ON AND OFF STATES FOR SWITCHES

State	S1	S2	S3	S4	V0
1	OFF	OFF	OFF	OFF	0
2	ON	ON	OFF	OFF	VAB
3	OFF	OFF	ON	ON	-VAB

III. CASCADED H-BRIDGE FIVE-LEVEL INVERTER

A] Cascaded H-bridge Inverter with Equal dc voltage

As the name suggests, the cascaded H-bridge multilevel inverter uses multiple units of H-bridge power cells connected in a series chain to produce high ac voltages. A typical configuration of a five-level CHB inverter is shown in figure 2, where each phase leg consists of two H-bridge cells powered by two isolated dc supplies of equal voltage E. When the switches S11, S21, S12, S22 conduct the output voltage for bridge 1 is VH1=E and the output voltage for bridge 2 is VH2=E. Therefore the resultant inverter phase voltage is VAN is equal to VH1+VH2=2E. When the switches S31, S41, S32, S42 conduct VH1= -E and VH2= -E. Therefore the resultant inverter voltage is -2E.

TABLE II. A PERMITTED TURN ON AND OFF STATES FOR SWITCHES

1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	0	0	1	1	0	0	E	E	2E
2	0	0	1	1	0	0	1	1	E	E	2E
3	1	0	0	0	1	0	1	0	E	0	E
4	0	0	1	0	1	0	1	0	E	0	E

TABLE II.B. COLOUMN SPECIFICATIONS

Column No.	Specifications
1	State
2	For Switch S11
3	For Switch S21
4	For Switch S31
5	For Switch S41
6	For Switch S12
7	For Switch S22
8	For Switch S32
9	For Switch S42
10	VH1
11	VH2
12	VAN=VH1+VH2

Now when the switches S11 conduct VH1=E and when the switches S12 and S32 conduct VH2=0. Therefore the total output voltage is equal to E .When the switches S31 conduct VH1= -E and When the switches S12 and S32 conduct VH2=0.Therefore the total output voltage is equal to –E. Thus 0, E, 2E,-E,-2E gives the five-level Inverter. Table II. Shown above shows the permitted Turn and Off states for switches and Table II.B shows the specifications of the column given in TABLE II.

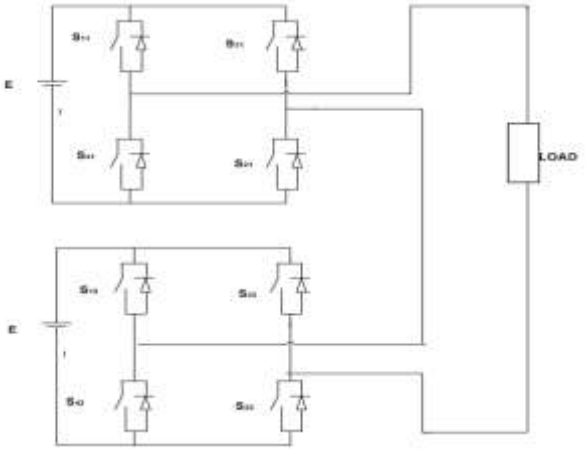

Fig. 2. Five-Level Inverter with Equal dc voltage

The number of voltage levels in a CHB inverter can be found from

$$m= (2H+1)$$

Where H is the number of H-bridge cells per phase leg.

The voltage level m is always an odd number for the CHB inverter while in other multilevel topologies such as diode-clamped inverters; it can be either even or odd numbers.

The load can be R and R-L. If the load is resistive, then the waveform for voltage and current remains same and if the load is R-L then the waveform is different. As the number of level increases the total harmonic distortion reduces [4].

B] Cascaded H-bridge Inverter with Unequal dc voltage

In these different dc voltages is selected for power cells. With unequal dc voltages, the number of voltage levels can be increased without necessarily increasing the number of H-bridge cells in cascade.

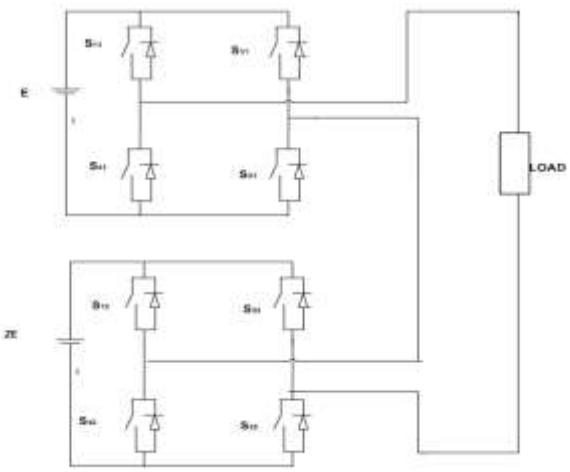

Fig. 3. Per - phase diagram of CHB with Unequal dc voltage

Figure above shows two inverter topologies, where the dc voltages for the H-bridge cells are not equal. In the seven-level topology, the dc voltages for H1 and H2 are E and 2E respectively. The two-cell inverter leg is able to produce seven voltage levels: 3E, 2E, E, 0, -E, -2E, -3E.In this when the switches S11and S12 conduct VH1=E and VH2=2E.Therefore the output voltage VAN is equal to 3E.When switches S11, S31, S12 conduct VH1=0 and VH2=2E. Therefore the output voltage VAN=2E. When switches S11, S32, S12 conduct VH1=E and VH2=0. Therefore the output voltage VAN=E. When switches S11, S32 conduct VH1=E and VH2= -2E. Therefore the output voltage VAN=-E. When switches S11, S31, S32 conduct VH1=0 and VH2= -2E. Therefore the output voltage VAN=-2E. When switches S31, S32 conduct VH1= -E and VH2= -2E. Therefore the output voltage VAN= -3E.

IV. Comparison between CHB With Equal and Unequal DC Voltage

In order to obtain the increased voltage level it is preferable to use CHB with unequal DC voltage. In CHB with equal DC voltage in order to increase the number of voltage levels the number of H-bridge connected in series increases. As the number of H-bridge increases large number of components is required which results in reduced efficiency and increase losses. There are some drawbacks associated with CHB with unequal DC voltage. The merits of the modular structure of the CHB with unequal DC voltage are essentially lost. In addition, the switching pattern design becomes much more difficult due to the reduction in redundant switching states. This is not the case with CHB with equal DC voltage.

V. Simulation Results

The experimental results have been used to clarify the correct performance of the Developed Cascaded H-bridge Inverter. The results are verified by simulating the circuit in MATLAB. The cost of the inverter is also determined by the amount of blocked voltage by switches. The circuit for Single- Phase Cascaded H-Bridge Inverter and the Three-Phase Cascaded H-Bridge Inverter are simulated in MATLAB and it is found that the THD for Single-Phase Cascaded H-bridge Inverter is higher than that of the Three-Phase Cascaded H-Bridge Inverter. The gate Driver circuit for Single-Phase Cascaded H-Bridge Inverter and the Three-Phase Cascaded H-Bridge Inverter is exactly same. In Three-Phase Cascaded H-Bridge Inverter three Single-Phase Cascaded H-Bridge circuits are connected and an individual gate driver circuit is required for each Single-Phase Cascaded H-Bridge circuit with a phase shift of 120 degrees. If the value of blocked voltage by switches is reduced the total cost of the inverter reduces. By using reduced number of switches losses are reduced. Reduction in losses results in increased efficiency. FFT Analysis is shown below for Single-Phase Cascaded H-Bridge Inverter and Three-Phase Cascaded H-Bridge Inverter.

TABLE III. Simulation Parameters

Parameters	Value
DC Source Voltage	100 [V]
Switching Frequency	2 [kHz]
Line Frequency	50 [Hz]
Modulation Index	0.95
Resistor	4Ω
Inductor	4mH

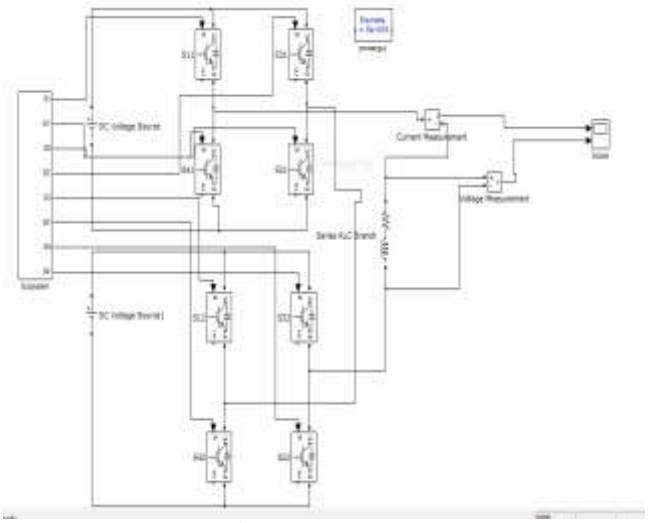

Fig. 4.Simulink circuit for Single-Phase Cascaded H-bridge Five-Level Inverter.

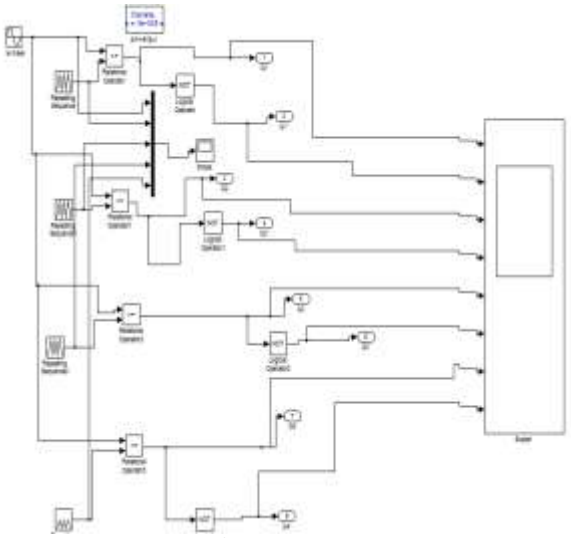

Fig. 5. Gate Drive circuit for Single-Phase Cascaded H-bridge Five-Level Inverter.

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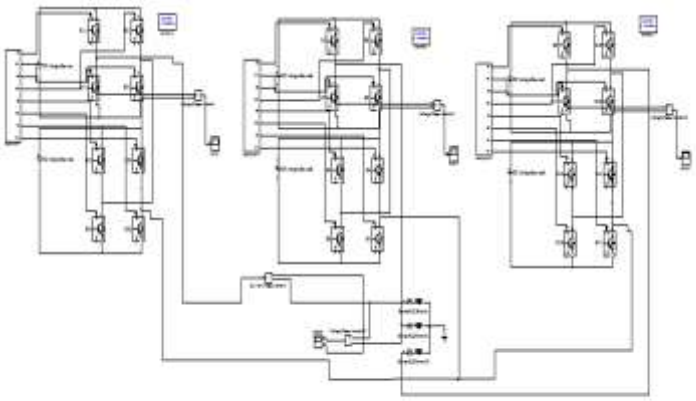

Fig. 6.Simulink circuit for Three-Phase Cascaded H-bridge Five-Level Inverter

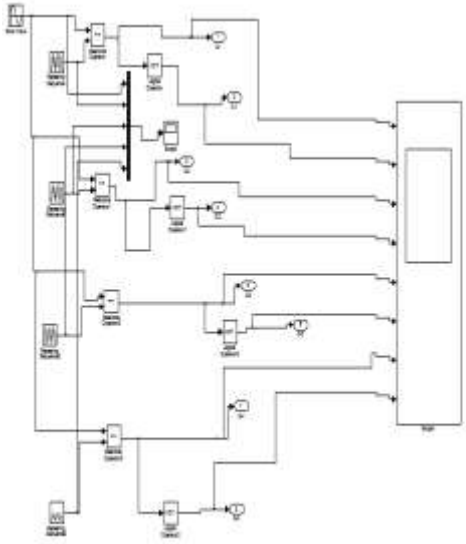

Fig. 7. Gate Drive circuit for Three-Phase Cascaded H-bridge Five-Level Inverter for R-Phase.

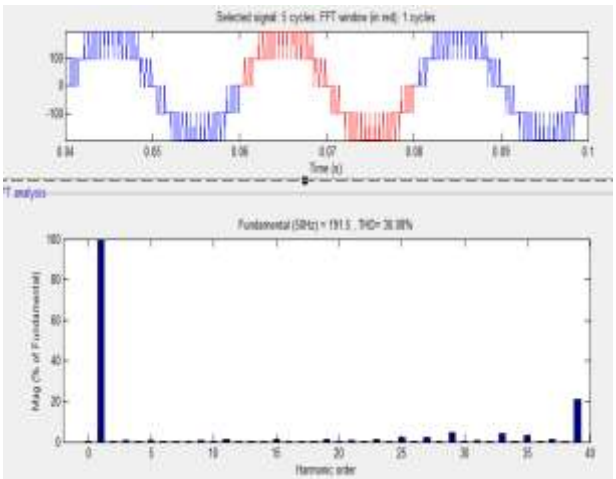

Fig. 8. Harmonic spectrum of output voltage waveform for Single-Phase Five-Level Inverter.

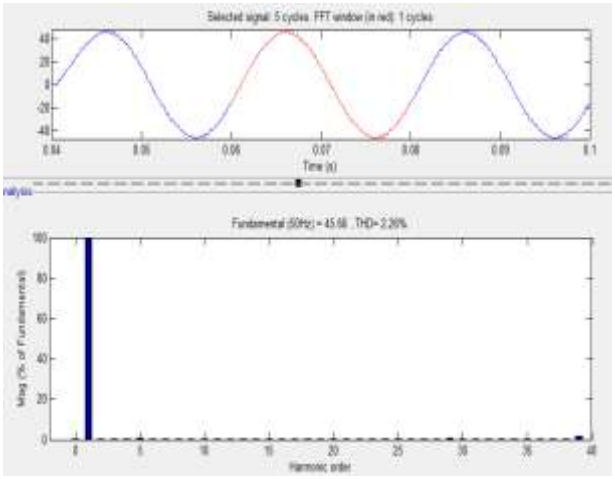

Fig. 9. Harmonic spectrum of output current waveform for Single-Phase Five-Level Inverter.

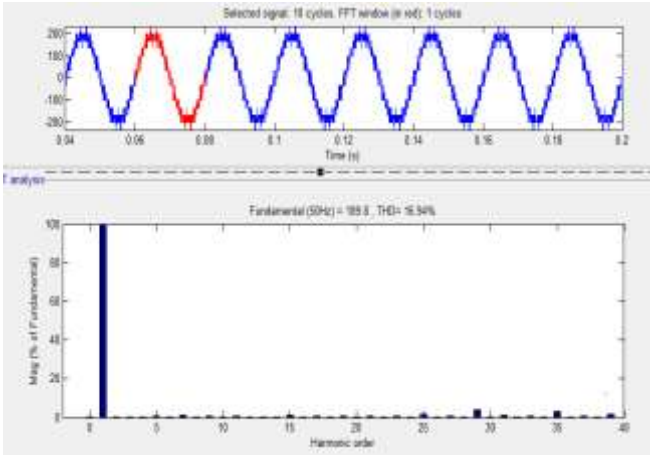

Fig. 10. Harmonic spectrum of soutput voltage waveform for Three-Phase Five-Level Inverter for R-Phase.

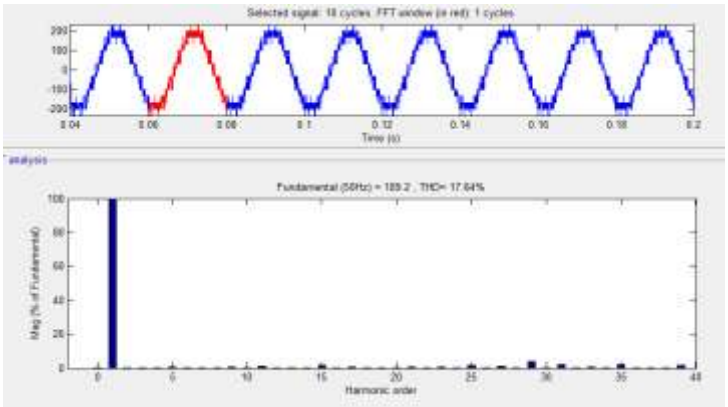

Fig.11. Harmonic spectrum of output voltage waveform for Three-Phase Five-Level Inverter for Y-Phase.

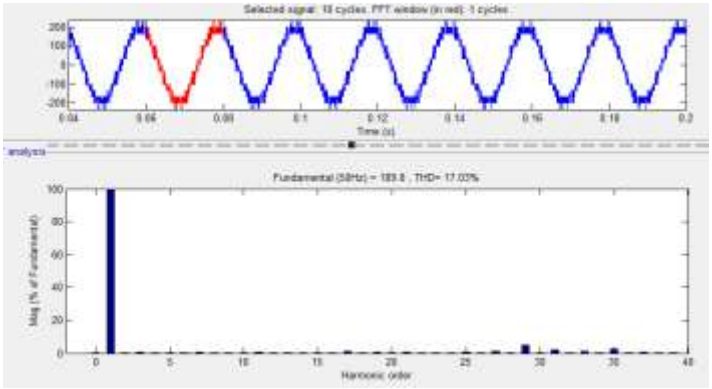

Fig. 12. Harmonic spectrum of output voltage waveform for Three-Phase Five-Level Inverter for B-Phase.

VI. Conclusion

In the H-Bridge Topology, a basic circuit is shown which generates only positive level at the output. In order to get both positive and negative level at the output an H-Bridge is added to the basic unit to generate all voltage levels. This is called as Developed Cascaded Multilevel Inverter. The Developed Cascaded Multilevel Inverter requires less number of IGBT's and MOSFET's than other cascaded Topologies. IGBT's are generally used for high power ratings. For medium voltage ratings MOSFET's are used instead of IGBT's. Since Cascaded H-bridge consists of reduced number of components, losses are reduced and maximum efficiency is obtained. CHB Five-level Inverter with equal DC voltage is compared with CHB with unequal DC voltage and it is found that in order to obtain increased voltage level CHB with unequal DC voltage is more beneficial.PWM strategy is generally used to obtain minimum number of commutations so as to maximize efficiency.PWM Strategy allow the use of MOSFET's as active devices, making it possible to reduce the conduction power losses .Filters are generally used to reduce harmonics.

TABLE IV. THD Table For Single –Phase Cascaded H-Bridge Five-Level Inverter

Modulation Index	Output Phase voltage THD	Output Current THD
0.1	220.73%	15.39%
0.2	145.16%	12.82%
0.3	111.55%	8.90%
0.4	78.06%	5.95%
0.5	53.54%	3.77%
0.6	44.89%	3.24%
0.7	41.94%	3.11%
0.8	38.83%	2.94%
0.9	34.05%	2.87%
0.95	30.08%	2.26%

As shown in above table as the modulation index increases the THD of output voltage and output current waveform for Single-Phase Cascaded H-bridge Five-Level Inverter decreases.

Future Scope

Now a day's better topologies have been developed than cascaded which consist of reduced number of switches thereby resulting in reduced losses and better efficiency than cascaded H-bridge Five-Level Inverter Topology.

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