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Modified Strategy for Hybrid Cascaded H-Bridge Multilevel Inverter

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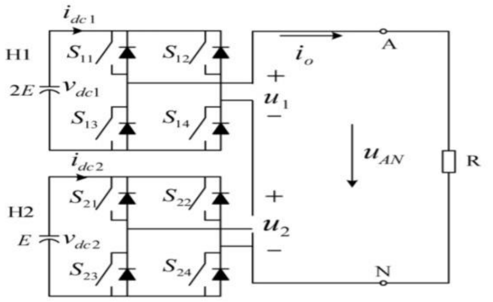
***Abstract*:- Compared with the traditional cascaded H-bridge multi-level inverters, the hybrid cascaded multi-level inverters have been receiving attention because they can generate more levels with the same number of power cells. However, with the general hybrid pulse width modulation (PWM), the output power distribution between the high-voltage and low-voltage H-bridge cells is extremely uneven in low amplitude modulation, and it may appear that the high-voltage cell feeds power into the low voltage cell in some modulation ratio intervals causing the low-voltage cell capacitor voltage boost. To avoid this problem, a method of a modified hybrid PWM strategy with power balance control is proposed. It has achieved the output power balance of H-bridge cells in full amplitude modulation, the occurrence of the phenomena of extremely uneven output power distribution between the high- and low-voltage cells in low amplitude modulation is avoided, and the performance of the inverter is improved.**

INTRODUCTION:

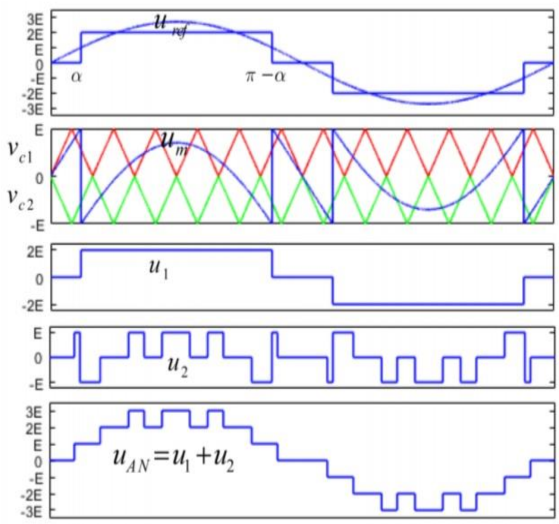
The cascaded H-bridge (CHB) inverter is one of the most widely used inverter topologies in medium voltage and high power drive systems, which has various advantages such as redundant phase voltage, low harmonic content and being easy to modular design and manufacture. Each power cell of cascaded multilevel inverters requires a separate direct current (dc) power supply, suitable for systems powered by solar cells and fuel cells. The topologies of hybrid CHB inverters are derived from traditional CHB inverters. Its main circuit is the cascade structure with H-bridge cells. However, the voltage level and switching frequency of each H-bridge cell are different. The hybrid CHB inverters can generate more output levels with the same number of cascaded cells, reduce the number of power switchers and dc sources with the same voltage level, thus allowing a variety of power switches with different voltage levels to work in the same topology, increase the flexibility of the application, thus, it has been widely concerned.



Topology of seven level hybrid CHB inverter

MODULATION TECHNIQUES:

Modulation technique is very important for an H-bridge hybrid cascaded inverter to obtain better output power quality, the modulation techniques for the hybrid cascaded inverter can be classified into three kinds based on frequency. The fundamental frequency modulations, such as multilevel selective harmonic elimination, have the advantage of less switching loss. However, it is often necessary to calculate a set of complex nonlinear equations, resulting in a slow dynamic response. As one of the high frequency modulation techniques, phase-shifted pulse width modulation (PS-PWM) is the only real commercial modulation scheme used in CHB, which is not applicable if used directly in the hybrid cascaded H-bridges because of the different dc-bus voltages. The level-shifted PWM produces a better harmonic performance when compared with the PS-PWM.



Principle of hybrid PWM strategy

H-PWM FOR HYBRID SEVEN-LEVEL CHB INVERTER:

The general strategy is the hybrid PWM (H-PWM) strategy, which can make power devices with higher voltage rating operate at low frequency, and power devices with lower voltage rating operate at high frequency, hence, the quality of output voltage is improved.

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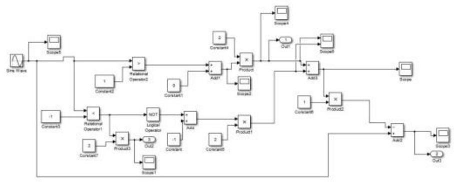
STAIRCASE PWM FOR HIGH VOLTAGE CELL:

The staircase wave is specially used to selective harmonic elimination. The number of steps determines the quality of output. This type of PWM is mainly used for higher output voltage where the minimum number of pulses to be generated in a half cycle is 15. In the staircase modulation, the switching angles can be calculated.

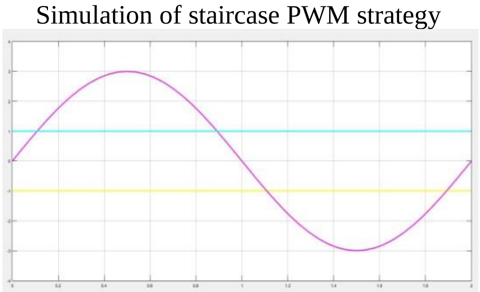
Input current harmonics in the power distribution line can be minimized by this PWM technique. Here by comparing the staircase wave reference wave and the carrier wave, the number of pulses can be easily generated.

The general strategy is the hybrid PWM (H-PWM) strategy [20], which can make power devices with higher voltage rating operate at low frequency, and power devices with lower voltage rating operate at high frequency, hence, the quality of output voltage is improved.

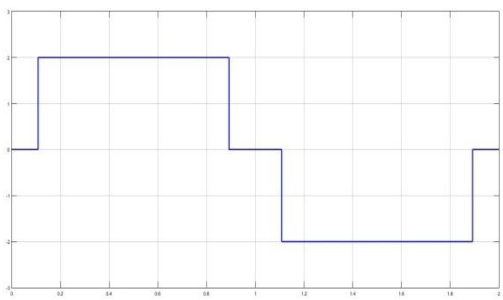
The high-voltage cell adopts staircase modulation and the power switch operates at the fundamental frequency, α ($0 < \alpha < 90$) is defined as the conduction angle of the high-voltage cell and its corresponding modulation waveform amplitude is E, the conduction angle α I α = arcsin (1/ 3M) where M is modulation index.



Simulation of staircase PWM strategy



Input waveform of staircase modulation



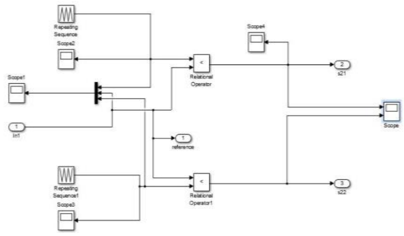
Output waveform of high voltage cell

CARRIER MODULATION FOR LOW VOLTAGE CELL:

The reference is sinusoidal, and the pattern for each ACMI module is different. The reference for the upper module is obtained by comparing the reference to the DC value. Its result is the switching pattern for the upper module. The reference for the lower module is obtained by subtracting the sinusoidal reference from the switching pattern for the upper module.

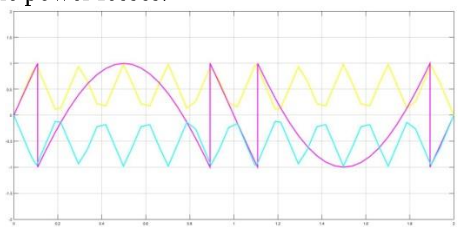
The resulting signal is then compared to carrier signals. Moreover, the resulting output signal is close to the reference signal, indicating the possibility of a reduction in the volume of the output filter. The staircase modulation has the disadvantage of presenting a regenerative process in the smaller voltage cells depending on the fundamental component amplitude and it must be avoided.

In Phase Opposition Deposition PWM control technique, the carrier signals which are above the zero level are in phase and the carrier signals which are below the zero level are in phase of each other and out of phase by 180 to the above signals.

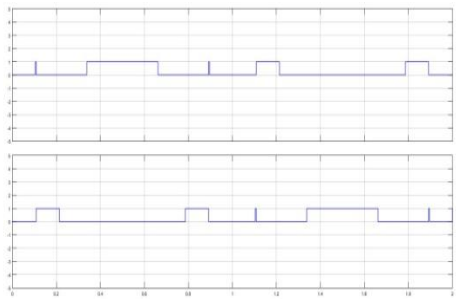


Simulation of carrier modulation

The switching losses are directly proportional to the voltage and current across a switch and also across the switching frequency. The result is the higher the switching frequency, the higher the number of transitions and the higher the power losses.



Comparison of reference and carrier signals



Switching pulses for low voltage cell

OUTPUT VOLTAGE FROM HPWM STRATEGY OF HYBRID CHB INVERTER:

The topology of seven level hybrid CHB inverter is composed of two H bridge cells i.e upper and lower voltage cells with their voltage in the ratio of 2:1 respectively. Assuming that output voltages of the high-voltage cell are u1 and output voltages of the low-voltage cell are u2 , the output current of each cell is io . Since the H-bridge cells are connected in series, the output current of

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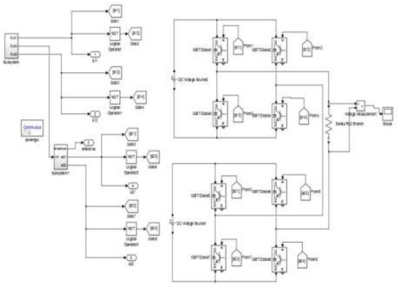
each cell is equal, then the total output voltage uAN can be expressed as uAN = u1 + u2 .
Therefore, the output voltage uAN of the hybrid seven-level CHB inverter has seven levels:±3E, ±2E, ±E and 0, thus resulting in a seven level hybrid CHB. Hence more levels can be generated with same number of power cells.
In staircase modulation based on the conduction angle, the switching states differ from one arm to another. For switches S11 & S13 the pulses are applied at conduction angle starting from α to 180- α. For the remaining switches i.e S12 & S14, the pulses are applied at a conduction angle starting from 180+ α to 360- α.
The switching states of S21 and S23, S22 and S24 are complementary to each other. So it only needs two triangular carriers' vc1 and vc2 with amplitude of ±E and one modulation waveform um to participate in the PWM modulation.
When the um is greater than vc1, the power switch S21 is switched on, when the um is less than vc2, the power switch S22 is switched on. By carrier modulation, the output voltage of the low-voltage cell u2 can be obtained.
From the staircase and carrier modulation techniques, the pulses for the corresponding switches for both the upper and lower cells are obtained respectively. The switching states of switches in the same arm are complementary to each other.



Simulation of Hybrid CHB with control scheme

DRAWBACKS:

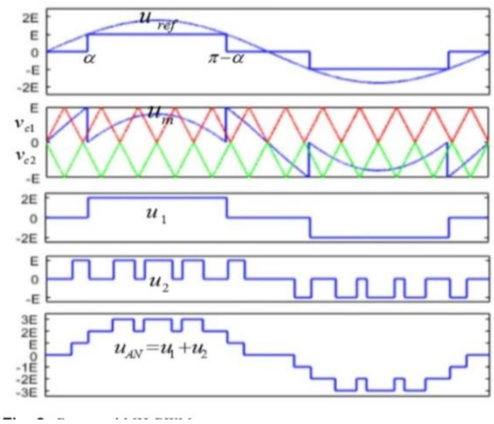
Even though the quality of output voltage is improved, with the H-PWM strategy, the output voltages u1 and u2 have opposite polarity when uAN is in intervals [E, 2E] and [−E,−2E], causing the reverse current to flow to the low-voltage cell.
It can be observed that the output power distribution of high- and low voltage cells are extremely uneven, the high-voltage cell have no output voltage between the modulation ratio from 0 to 0.3. The high-voltage cell synthesizes more voltage than necessary and low voltage cell synthesizes negative voltage between the modulation ratio from 0.37 to 0.78.

.IMPROVEMENTS:

A uni polar carrier disposition PWM strategy is proposed, in which the opposite polarities are avoided by adjusting the voltage levels polarity in the interval [+E, +2E] and [−E, −2E], which enables the output voltages of both cells to have the same polarity in the whole period. Therefore, the dc-bus capacitor of the low-voltage cell does not have reverse current and the diode rectifier is available. However, it still has the problems of inconsistent utilization of battery modules, and the output power distribution between the high- and low-voltage cells is extremely uneven in low amplitude modulation, and the output power between high- and low-voltage cell is still unbalanced.

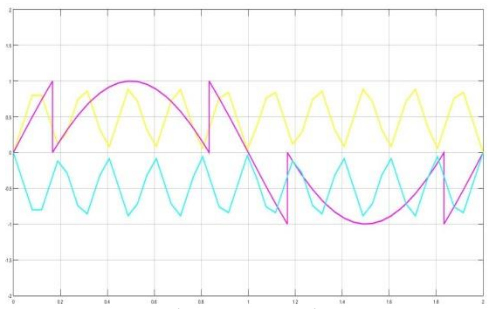
IMPROPOSED MODIFIED HYBRID PWM STRATEGY:

The principle of the proposed MH-PWM strategy for the seven level hybrid CHB inverter is the phase opposite disposition carrier PWM modulation is performed on the low voltage cell in the case of the high-voltage cell operating at the fundamental frequency.
with the H-PWM strategy, the MH-PWM strategy shows that the modulation waveform of the low-voltage cell has no negative value in the positive half period and has no positive value in the negative half period, in the full modulation range, the output voltage polarity of the high- and low voltage cells is the same, and the output voltage proportion of cells can vary with the change of modulation, so the problem that the high-voltage cell feeds power into the low-voltage cell in some modulation intervals is avoided.
The conduction angle of high voltage cell is α = arcsin (1/2M).



Proposed Modified Hybrid PWM strategy

From this strategy when Compared with conventional modulation strategies, it increases the switching frequency of low-frequency legs and decreases the switching frequency of high-frequency legs, which can achieve the same output power quality while the maximum switching frequency is decreased by half and the pulses during the positive half cycle of reference signal is positive so that backfeeding of the lower cell from the upper cell is eliminated. The reference used is Um = 2EM sinwt – u!/2



Comparison of Carrier and reference signals

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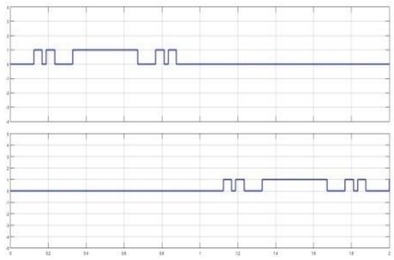
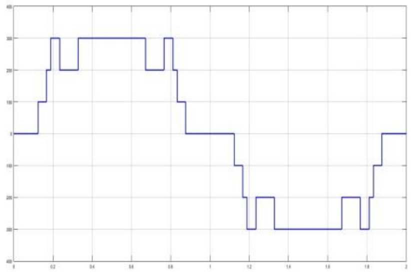
Thus, from the modified hybrid PWM strategy, the signal u2 is positive for all ranges of modulation ratio, so the problem of power inversion will not appear again. Tthe output voltage is increased non linearly between [0,2E + 2 3E/π]. The power shared by the upper cell is more compared to the lower cell, thus the power is unbalanced.



Switching signals for low voltage cell



Output waveform for MH PWM strategy

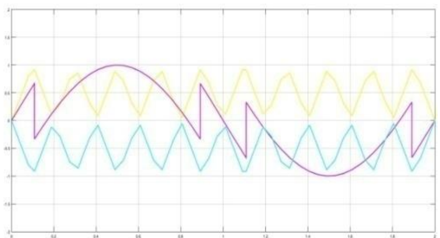
DRAWBACKS:

When outputting active power, the power imbalance problems will be caused. Such as the charge and discharge imbalance and inconsistent utilization of battery modules increased the harmonic content of output voltage, which will directly influence the performance of inverters, therefore, it is particularly important to keep the balance of output power of cascaded multilevel inverters.

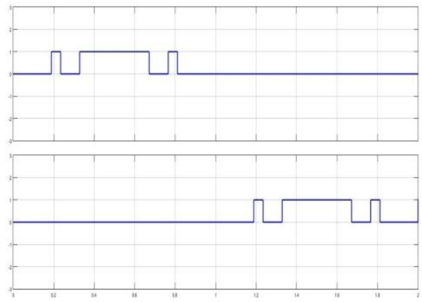
MH PWM STRATEGY WITH POWER BALANCE CONTROL:

With the MH-PWM strategy, the phase voltage uAN is increased non-linearly and the output power distribution between high- and low-voltage cells is extremely uneven. To avoid these problems, a power balance control scheme with the MH-PWM is proposed

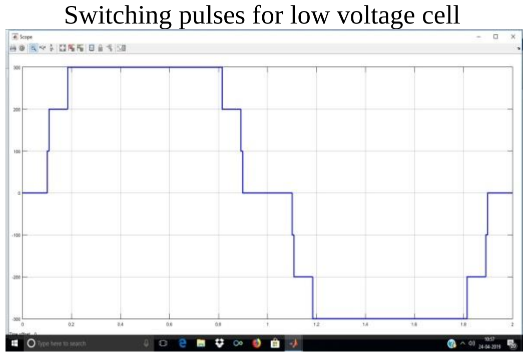
A modified hybrid PWM (MH-PWM) strategy with power balance control is proposed for the seven-level hybrid CHB inverter. The strategy can keep that voltage fundamental amplitude of high- and low-voltage cell is 2:1 in all modulation ranges, so the problems of voltage rise in low-voltage unit, power inversion and power output imbalance of each unit can be solved at the same time.



Comparison of reference and carrier signals



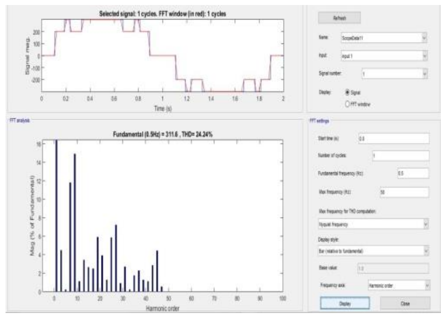
Switching pulses for low voltage cell



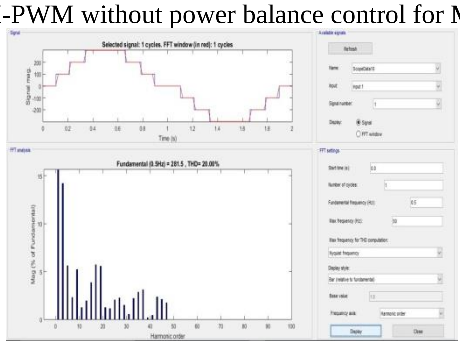
Output voltage of MH-PWM strategy with power balance control

SIMULATION RESULTS:

The FFT analysis of output voltage of hybrid CHB inverter without and with power balance control is obtained as follows.



MH-PWM without power balance control for M=1



MH-PWM with power balance control for M=1

HYBRID CASCADED 9 LEVEL H- BRIDGE INVERTER

A convectional H bridge consists of 4 H bridge. Each cell has a separate dc source . By using modified CHB inverter topology, it is possible to produce 9 output voltage levels including zero by the serial connection of two modified H-bridge modules.

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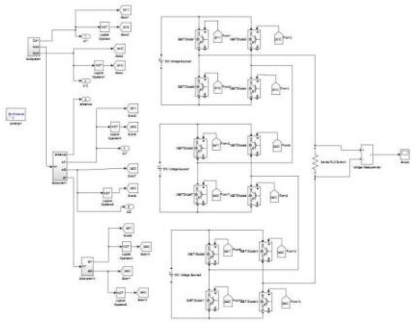
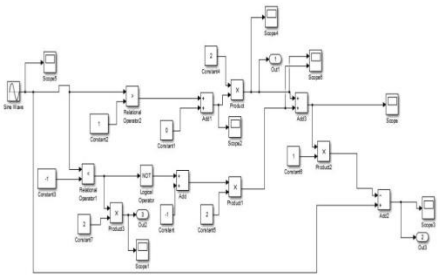
The modified modules consists of two high voltage cells with dc voltage sources of magnitude 2E and a lower voltage cell of dc voltage source of magnitude E.This topology produces 9 voltage levels ±4E,±3E, ±2E, ±E and 0.Assuming that output voltages of the high-voltage cells are u1, u2 and output voltages of the low-voltage cell is u3 , the output current of each cell is io . Since the H-bridge cells are connected in series, the output current of each cell is equal, then the total output voltage uAN can be expressed as uAN = u1 + u2 + u3

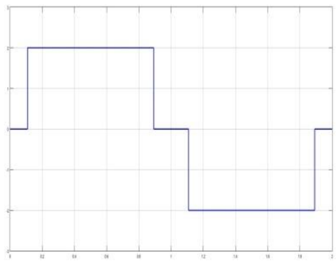


HYBRID PWM WITHOUT BALANCE CONTROL:

A criterion for evaluating the quality of the output voltage (the weighted relative harmonic content) is presented. The control logic is uncomplicated and implemented by inexpensive complementary metal-oxide semiconductor logic with high noise immunity and reliability.The first H bridge cell consists of two arms, each with switches named s11 and s13, s12 and s14. These pair of switches act complementary to each other. The sinusoidal PWM techniques is used for the first voltage cell.

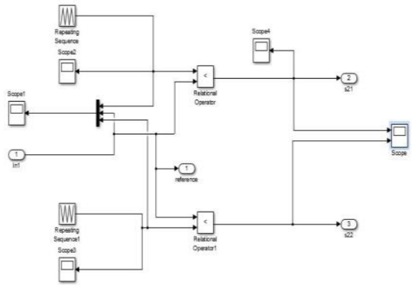


Simulation of sinusoidal PWM strategy

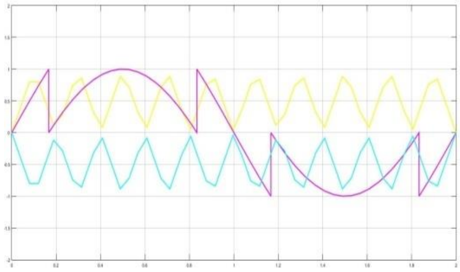


output voltage of first H bridge cell

The reference is sinusoidal, and the pattern for each ACMI module is different. The reference for the upper module is obtained by comparing the reference to the DC value. Its result is the switching pattern for the upper module. The reference for the second module is obtained by subtracting the sinusoidal reference from the switching pattern for the upper module.

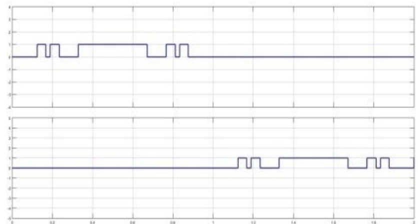


Simulation of Phase Opposition Disposition PWM

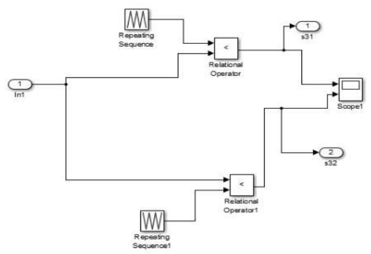


Comparisons of reference and carrier signals in simulation

The switching states of S21 and S23, S22 and S24 are complementary to each other. So it only needs two triangular carriers' vc1 and vc2 with amplitude of ±E and one modulation waveform um to participate in the PWM modulation. When the um is greater than vc1, the power switch S21 is switched on, when the um is less than vc2, the power switch S22 is switched on. By carrier modulation, the output voltage of the low-voltage cell u2 can be obtained.



Switching pulses for second H bridge cell

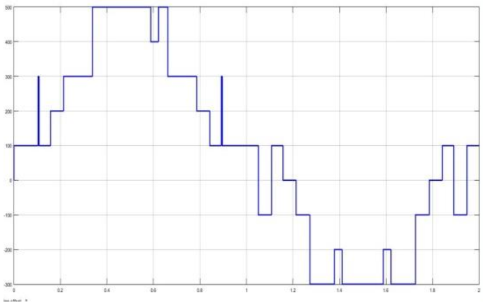


Simulation for PWM technique at third H bridge cell

The reference signal for the staircase PWM technique of third H bridge cell is obtained by subtracting the reference signal of the second H bridge cell from the switching pulses of the second bridge. The resulting signal is compared with the triangular carrier signals which are in phase opposition to obtain the switching pulses for the third H module.

When the reference signal is greater than vc1, the power switch S21 is switched on, when the reference signal is less than vc2, the power switch S22 is switched on. By carrier modulation, the output voltage of the low-voltage cell u3 can be obtained.

The control technique provides the switching pulses to the corresponding arms in the complementary mode. All the H bridge modules are connected in series across the resistive load.



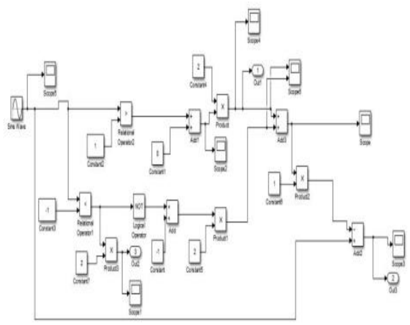
Output voltage 9 level Hybrid CHB Inverter without power balance

DRAWBACKS:

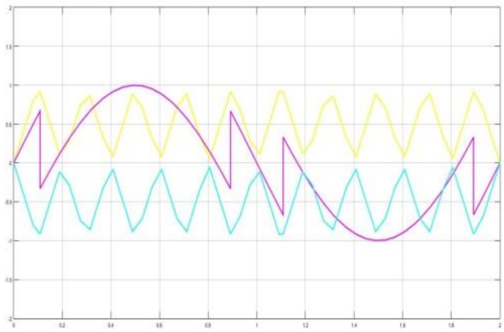
With the MH-PWM strategy, the phase voltage uAN is increased non-linearly and the output power distribution between high- and low-voltage cells is extremely uneven. To avoid these problems, a power balance control scheme with the MH-PWM is proposed.

MH-PWM STRATEGY WITH POWER BALANCE CONTROL:

The sinusoidal PWM technique for power balance control is as same as that of not having power balance control. Here, the negative pulses during the positive half cycle and vice versa is achieved by changing the reference signal and the conduction angle at the staircase modulation.

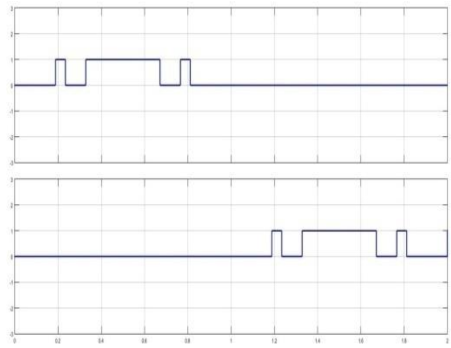


Simulation of staircase PWM strategy

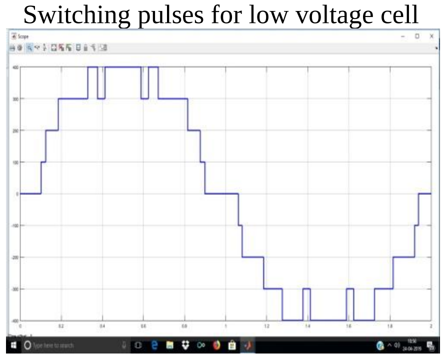


Comparison of reference and carrier signals

When the reference wave is compared with two triangular carriers, then the following pulses can be obtained.



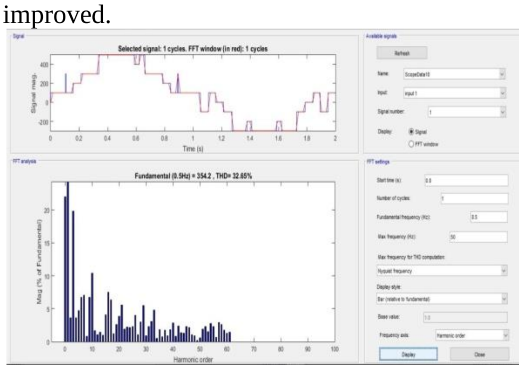
Switching pulses for low voltage cell



Output voltage 9 level Hybrid CHB Inverter with power balance

SIMULATION RESULTS:

When compared to the MH PWM strategy without power balance, MH PWM strategy with power balance has low threshold. Thus, we can say that the power quality is improved.



MH PWM strategy without power balance control

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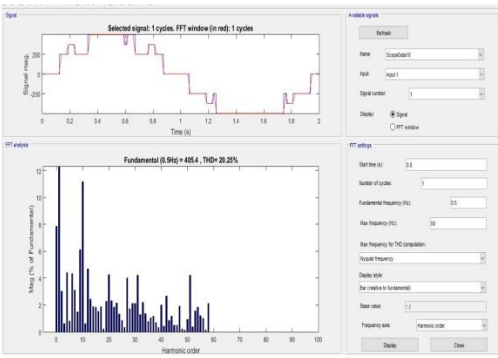


MH PWM strategy without power balance control

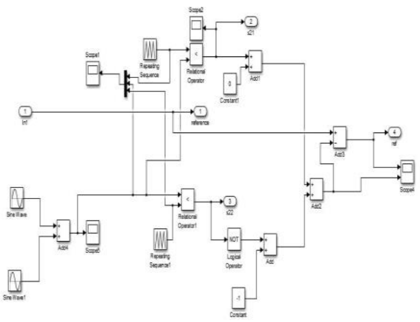
H-CHB USING THIRD HARMONIC INJECTION PWM:

Harmonic injection is nothing but adding higher frequency sine wave with the reference sine. Fundamental output voltage is greatly decided by the width of the pulses in the middle region of the PWM patterns.

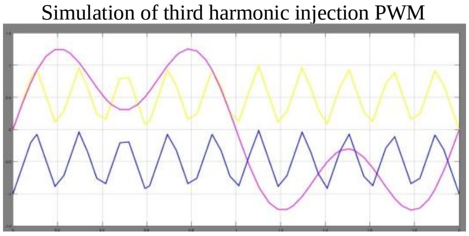
The number of pulses described by frequency of the carrier and width of the pulses decided by the reference magnitude are known through the developed mathematical relations. It is readily understood that making the reference sine flat by injecting higher order harmonics (3, 9, 15…) with the basic reference, the area of the centre pulses can be increased.

Many techniques were developed for harmonic Elimination especially for suppressing the lower order harmonics. when a suitable amount of third harmonic signal is added to the sinusoidal modulating signal of fundamental frequency, it provides higher fundamental voltage with low harmonic distortion.

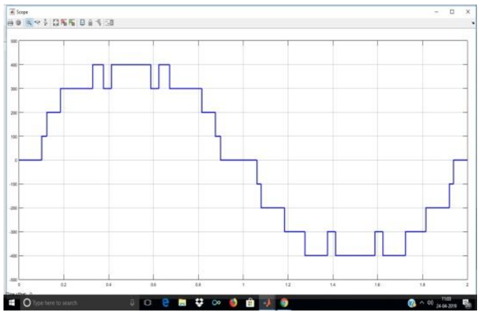
The best modification that can be made to the inverter phase output waveform is assumed a priori to be the addition of a measure of third harmonics. The degree of flatness of the new reference (third harmonic injected reference) depends on the proportion ‘a’ of third harmonic added.



Simulation of third harmonic injection PWM



comparison of reference and carrier signals

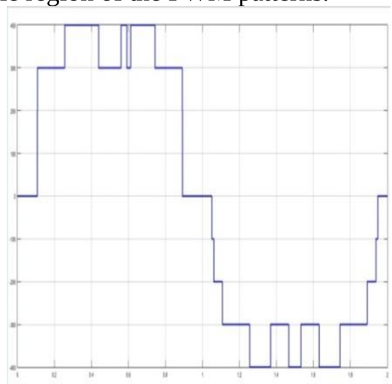


Output voltage 9 level Hybrid CHB Inverter without power balance

POWER BALANCE CONTROL OF H-CHB USING THIRD HARMONIC INJECTION PWM:

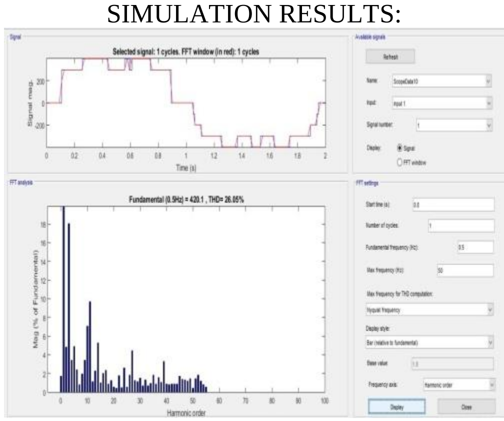
A modified hybrid PWM (MH-PWM) strategy with power balance control is proposed for the nine-level hybrid CHB inverter. The strategy can keep that voltage fundamental amplitude of high- and low-voltage cell is 2:1 in all modulation ranges, so the problems of voltage rise in low-voltage unit, power inversion and power output imbalance of each unit can be solved at the same time.It is observed that the threshold values is reduced at some particulars values of the dip. The reference wave for the third harmonic injection is obtained by adding the sinusoidal waveform to the third harmonic sinusoidal waveform whose frequency is almost 3 times the frequency of sine wave.

The reference wave is then compared with the carrier signals of amplitude E and the switching pulses for the corresponding H bridge cell can be obtained. Fundamental output voltage is greatly decided by the width of the pulses in the middle region of the PWM patterns.

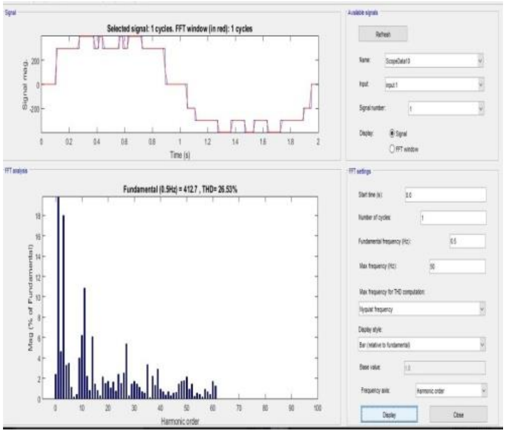


Output voltage 9 level Hybrid CHB Inverter with power balance

SIMULATION RESULTS:



MH PWM strategy without power balance control



MH PWM strategy with power balance control

OBSERVATIONS:

CATEGORY	THD (WITHOUT POWER BALANCE)	THD(WITH POWER BALANCE)
7 level hybrid CHB inverter with Modified Hybrid PWM technique	24.24%	20.00%
9 level Hybrid CHB Inverter with Modified Hybrid PWM technique	32.65%	20.25%
9 level Hybrid CHB Inverter with Third Harmonic Injection PWM technique	26.53%	26.05%

CONCLUSION

In this study, a modified H-PWM strategy with power balance control is proposed for an H-bridge hybrid cascaded seven-level inverter. The following conclusions are obtained by simulation research. For the H-PWM strategy. The fundamental amplitude of uAN increases linearly from 0 to 3E in the full modulation range. However, the output power of the high-voltage cell will feed power into the low-voltage cell. Therefore, the output distribution between the high- and low voltage cells is uneven.

For the Modified Hybrid PWM strategy, the fundamental amplitude of total output (uAN) increases non-linearly from 0 to 2E + 2 3E/π in the full modulation range, when $M \leq 0.5$, the inverter output is entirely borne by the low-voltage cell. Therefore, the output distribution between the high- and low-voltage cells is extremely uneven; when $M > 0.5$, with the increase of M, the u1(1) increases from 0 to 4 3E/π non-linearly.

REFERENCES

[1] Lopez, M.G., Moran, Abu-Rub, H., Holtz, J., Rodriguez, J., *et al.*: 'Medium-voltage multilevel converters—state of the art, challenges, and requirements in industrial applications', *IEEE Trans. Ind. Electron.*, 2010, **57**, (8), pp. 2581–2596

[2] Nademi, H., Das, A., Burgos, R., *et al.*: 'A new circuit performance of modular multilevel inverter suitable for photovoltaic conversion plants', *IEEE J. Emerg. Sel. Top. Power Electron.*, 2016, **4**, (2), pp. 393–404

[3] Noman, A., Addoweesh, K., Al-Haddad, K.: 'Cascaded multilevel inverter topology with high frequency galvanic isolation for grid connected PV system'. IECON 2016–42nd Annual Conf. of the IEEE Industrial Electronics Society, Florence, Italy, 2016, pp. 3030–3037

[4] Caluisi, C., Cecati, C., Piccolo, A., *et al.*: 'Multilevel inverters and fuzzy logic for fuel cells power conditioning and control'. 2010 IEEE Int. Symp. on Industrial Electronics, Bari, 2010, pp. 2739–2744

[5] Edpuganti, A., Rathore, A.: 'Fundamental switching frequency optimal pulsewidth modulation of medium-voltage cascaded seven-level inverter', *IEEE Trans. Ind. Appl.*, 2015, **51**, (4), pp. 3485–3492

[6] Kumar, A.S., Poddar, G., Ganesan, P.: 'Control strategy to naturally balance hybrid converter for variable-speed medium-voltage drive applications', *IEEE Trans. Ind. Electron.*, 2015, **62**, (2), pp. 866–876

[7] Adam, G., Abdelsalam, I., Ahmed, K., *et al.*: 'Hybrid multilevel converter with cascaded H-bridge cells for HVDC applications: operating principle and scalability', *IEEE Trans. Power Electron.*, 2015, **30**, (1), pp. 65–77

[8] Elias, M., Rahim, N., Ping, H., *et al.*: 'Asymmetrical cascaded multilevel inverter based on transistor-clamped H-bridge power cell', *IEEE Trans. Ind. Appl.*, 2014, **50**, (6), pp. 4281–4288

[9] Manjrekar, M., Lipo, T.: 'A hybrid multilevel inverter topology for drive applications'. Applied Power Electronics Conf. and Exposition, 1998 (APEC'98), Conf. Proc. 1998, Thirteenth Annual, Anaheim, CA, 1998, vol. 2, pp. 523–529

[10] Khoucha, F., Lagoun, S.M., Marouani, K., *et al.*: 'Hybrid cascaded H-bridge multilevel-inverter induction-motor-drive direct torque control for automotive applications', *IEEE Trans. Ind. Electron.*, 2010, **57**, (3), pp. 892–899

[11] Jana, P., Chattopadhyay, S., Maiti, S., *et al.*: 'Hybrid modulation technique for binary asymmetrical cascaded multilevel inverter for PV application'. IEEE Int. Conf. on Power Electronics, Drives and Energy Systems, 2017, pp. 1–6
J. Emerg. Sel. Top. Power Electron., 2016, 4, (2), pp. 393–404

[12] Noman, A., Addoweesh, K., Al-Haddad, K.: 'Cascaded multilevel inverter topology with high frequency galvanic isolation for grid connected PV system'. IECON 2016–42nd Annual Conf. of the IEEE Industrial Electronics Society, Florence, Italy, 2016, pp. 3030–3037

[13] Caluisi, C., Cecati, C., Piccolo, A., *et al.*: 'Multilevel inverters and fuzzy logic for fuel cells power conditioning and control'. 2010 IEEE Int. Symp. on Industrial Electronics, Bari, 2010, pp. 2739–2744

[14] Edpuganti, A., Rathore, A.: 'Fundamental switching frequency optimal pulsewidth modulation of medium-voltage cascaded seven-level inverter', *IEEE Trans. Ind. Appl.*, 2015, 51, (4), pp. 3485–3492

[15] Kumar, A.S., Poddar, G., Ganesan, P.: 'Control strategy to naturally balance hybrid converter for variable-speed medium-voltage drive applications', *IEEE Trans. Ind. Electron.*, 2015, 62, (2), pp. 866–876

[16] Adam, G., Abdelsalam, I., Ahmed, K., *et al.*: 'Hybrid multilevel converter with cascaded H-bridge cells for HVDC applications: operating principle and scalability', *IEEE Trans. Power Electron.*, 2015, 30, (1), pp. 65–77

[17] Elias, M., Rahim, N., Ping, H., *et al.*: 'Asymmetrical cascaded multilevel inverter based on transistor-clamped H-bridge power cell', *IEEE Trans. Ind. Appl.*, 2014, 50, (6), pp. 4281–4288

[18] Manjrekar, M., Lipo, T.: 'A hybrid multilevel inverter topology for drive applications'. Applied Power Electronics Conf. and Exposition, 1998 (APEC'98), Conf. Proc. 1998, Thirteenth Annual, Anaheim, CA, 1998, vol. 2, pp. 523–529

[19] Khoucha, F., Lagoun, S.M., Marouani, K., *et al.*: 'Hybrid cascaded H-bridge multilevel-inverter induction-motor-drive direct torque control for automotive applications', *IEEE Trans. Ind. Electron.*, 2010, 57, (3), pp. 892–899

[20] Jana, P., Chattopadhyay, S., Maiti, S., *et al.*: 'Hybrid modulation technique for binary asymmetrical cascaded multilevel inverter for PV application'. IEEE Int. Conf. on Power Electronics, Drives and Energy Systems, 2017, pp. 1