农业装备中三电平二极管箝位式逆变器拓扑结构的改进

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摘　要：传统的二极管箝位式(NPC)三电平逆变器结构中，中点电压波动过大将导致输出电压的谐波总畸变率（total harmonic distortion,THD）增大及开关器件损坏，影响了该结构在农业机电中的应用。该文提出了一种带中点电压自平衡的NPC三电平逆变器拓扑结构，通过在传统NPC三电平逆变器结构中加入一套由单相全桥逆变电路组成的电压主动补偿装置，对三相桥臂中点电压的波动进行主动补偿。实时检测三相桥臂中点电压，与给定值比较后，控制补偿装置实时产生补偿电压。不需要坐标变换，控制方案简单。同时对系统的稳定性进行了理论分析。仿真结果表明提出的拓扑结构能够将三相桥臂中点电压的波动控制在3%以下，并且在负载突变时，仍然能快速的平衡中点电压的波动，具有良好的动态性能。

关键词：拓扑，电压，设计，三电平逆变器，二极管箝位式，中点电压，平衡
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Liu Guohai, Qian Peng, Chen Zhaoling, et al. Improved neutral point clamped three-level VSI topology in agricultural equipment[J]. Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE), 2013, 29(22): 189－195. (in Chinese with English abstract)

0　引　言

如今，随着农村工农业的发展，大量大功率的农业电气化装备投入农业生产之中，如大功率灌溉水泵，农业风机，农电网中的电力电子设备[1-2]。二极管箝位式（neutral point clamped，NPC）三电平逆变器结构[3]于1981年首次提出以来，已经在多个领域得到了广泛的应用[4-9]。该结构原理图如图1所示，相对于传统两电平结构有输出谐波小、输出波形更接近正弦波、开关器件承受的电压低等优点，因而成为当今电力电子技术中的研究热点[10-15]。由于电容制造误差、开关器件特性不一致、电路运行条件改变等原因往往造成NPC三电平逆变器中点电压波动，导致输出电压的*THD*增大及开关器件损坏，影响该结构的正常工作[16-22]。为了解决以上问题，通常采用的方法有：1）改进控制策略，合理选择冗余矢量的作用顺序和时间，这种方法使用最为广泛，但是该方法的平衡能力有限[23-28]；2）采用两路直流电源串入直流侧来平衡直流侧电压，该方法需用2个独立的直流电源，还要协调2个直流电源的输出电压，会加大系统的成本[29-30]。

本文提出了一种带中点电压自平衡的NPC三电平逆变器拓扑结构，该结构在传统NPC三电平逆变器结构中加入一个由单相全桥逆变电路组成的电压主动补偿装置，实时检测三相桥臂中点电压，与给定值比较后，控制补偿装置实时产生补偿电压，将三相桥臂中点电压的波动控制在允许的范围内。建立了电压主动补偿装置的数学模型，推导了稳定条件，采用Matlab/Simulink仿真环境进行仿真分析，验证拓扑结构的有效性和正确性。

1　主电路拓扑结构

传统NPC三电平逆变器中直流侧电容中点N和逆变器三相桥臂中点O是连在一起的，N点电压波动必然引起O点电压波动，影响NPC三电平逆变器正常工作。图2为本文提出的带中点电压自平衡的NPC三电平逆变器拓扑结构。该拓扑结构由2个功率单元组成，功率单元1为NPC三电平逆变器，功率单元2为由单相全桥逆变器构成的主动电压补偿装置，直流侧采用稳定直流电源。断开功率单元1中的*N*和*O*点联系，在其间串入功率单元2。u_n、u_o和u_S分别为*N*点、*O*点和直流侧电压，u_b为主动电压补偿装置产生的补偿电压，$u_o = u_n - u_b$。当功率单元1工作时，u_n波动较大，功率单元2实

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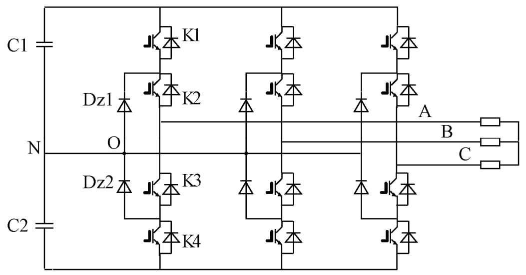
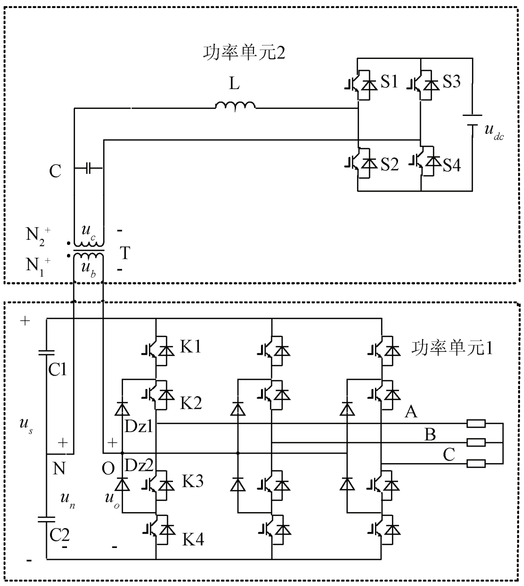
时检测 u_n、u_o 和 u_S，通过控制单相全桥逆变器开关管的开关，产生补偿电压 u_b，维持 u_o=0.5u_s。



注：C_1、C_2 为直流侧电容，Dz1、Dz2 为箝位二极管，K1、K2、K3、K4 为 IGBT。
Note: C_1、C_2 DC are side capacitor, Dz1、Dz2 are clamp diode, K1、K2、K3、K4 are IGBT

图 1 NPC 三电平逆变器原理图
Fig.1 Principle diagram of NPC three-level inverter



注：u_s 为直流侧电压，u_n 为 N 点电压，u_o 为 O 点电压，u_c 为变压器原边电压，u_b 为补偿电压。
Note: u_s is voltage of DC side, u_n is voltage of point N, u_o is voltage of point O, u_c is the transformer primary side voltage, u_b is compensating voltage.

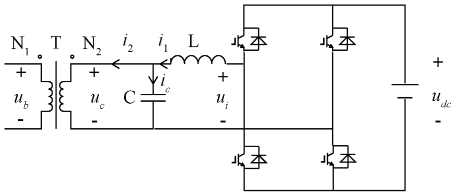
图 2 新型 NPC 三电平逆变器原理图
Fig.2 Principle diagram of new type NPC three-level inverter

2 数学模型

图 3 为主动补偿装置的结构图，L 为滤波电感，C 为滤波电容。u_{dc} 为单相全桥逆变电路直流侧电压，u_i 为单相全桥逆变电路交流侧电压，u_c 为变压器原边电压，u_b 为补偿电压，i_1 为滤波电感电流，i_2 为变压器原边电流，i_c 为滤波电容电流，变压器的变比为 n。

变压器原边侧的电流为：

$$i_2 = i_1 - i_c \qquad (1)$$



注：u_{dc} 为逆变器直流侧电压，u_i 为逆变器交流侧电压，u_c 为变压器原边电压，u_b 为补偿电压，i_1 为滤波电感电流，i_2 为变压器原边电流。
Note: u_{dc} is voltage of inverter DC side, u_i is voltage of inverter DC side, u_c is the transformer primary side voltage, u_b is compensating voltage, i_1 is currents of filter inductance, i_2 is the transformer primary side currents.

图 3 电压主动补偿装置的原理图
Fig.3 Principle diagram of active compensation voltage device

式（1）也可写成如下：

$$i_2 = i_1 - C\frac{\mathrm{d}u_c}{\mathrm{d}t} \qquad (2)$$

变压器原边电压为：

$$u_c = u_i - L\frac{\mathrm{d}i_1}{\mathrm{d}t} \qquad (3)$$

变压器副边电压即为补偿电压：

$$u_b = nu_c \qquad (4)$$

可以推导出：

$$u_n - n(u_i - L\frac{\mathrm{d}i_1}{\mathrm{d}t}) = 0.5u_s \qquad (5)$$

逆变器交流侧电压为：

$$u_i = S^* u_{dc} \qquad (6)$$

式中，S^* 为开关函数，S_1、S_4 导通时，S^*=1，S_2、S_3 导通时，S^*=−1。

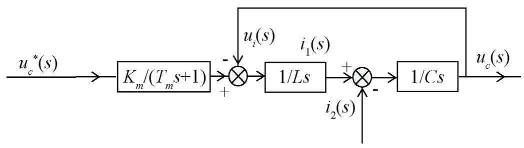
将式（6）代入式（5）整理得出：

$$u_n - n(S^* u_{dc} - L\frac{\mathrm{d}i_1}{\mathrm{d}t}) = 0.5u_s \qquad (7)$$

因此，主动电压补偿装置的状态方程为：

$$\frac{\mathrm{d}u_c}{\mathrm{d}t} = \frac{1}{C}(i_1 - i_2) \qquad (8)$$

$$\frac{\mathrm{d}i_1}{\mathrm{d}t} = \frac{1}{L}(u_i - u_c) \qquad (9)$$



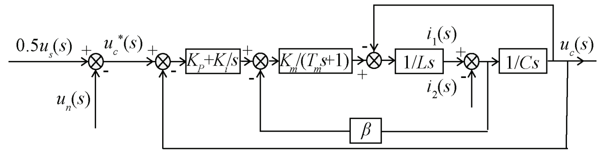
注：$u_c^*(s)$为指令电压信号，$u_i(s)$为单相全桥逆变电路交流侧电压，$u_c(s)$为变压器原边电压，$i_1(s)$为滤波电感电流，$i_2(s)$为变压器原边电流。
Note: $u_c^*(s)$ is signal of voltage instruction, $u_i(s)$ is Single phase full bridge inverter circuit ac voltage, $u_c(s)$ is the transformer primary side voltage, $i_1(s)$ is currents of filter inductance, $i_2(s)$ is the transformer primary side currents

图 4 电压主动补偿装置主电路结构图
Fig.4 Diagram of main circuit of active compensation voltage device

可将主动电压补偿装置中的单相全桥逆变电路（不含 LC 滤波部分）等效为一个增益为 K_m 的比例环节和 $1/(T_m s+1)$的惯性环节。根据仿真结果，u_b 电压值一般在 350 V 以内，可取 n=1，这样得到主动电压补偿装置结构图如图 4 所示。

3　控制策略和稳定性分析

为使系统稳定，采用双闭环控制方案，电压反馈作为外环，电流反馈作为内环，采用 PI 控制器,PI 控制器等效为 K_p+K_i/s。主动电压补偿装置控制结构图，如图 5 所示。



注：K_p+K_i/s 为 PI 控制器，$1/(T_m s+1)$ 为惯性环节，K_m 为比例环节，β 为反馈系数。

Note: K_p+K_i/s is PI controller, $1/(T_m s+1)$ is inertial element, K_m is proportion element, β is feedback coefficient

图 5　主动电压补偿装置控制结构图

Fig.5　Diagram of control scheme of active compensation voltage device

由结构图得出系统输出表达式为：

$$u_c(s)=\frac{K_mK_ps+K_mK_i}{T_mLCs^4+LCs^3+(T_m+K_m\beta C)s^2+(1+K_mK_p)s+K_mK_i}u_c^*(s)-\frac{LT_ms^3+Ls^2}{T_mLCs^4+LCs^3+(T_m+K_m\beta C)s^2+(1+K_mK_p)s+K_mK_i}i_2(s) \tag{10}$$

系统的特征方程为：

$$T_mLCs^4+LCs^3+(T_m+K_m\beta C)s^2+(1+K_mK_p)s+K_mK_i=0 \tag{11}$$

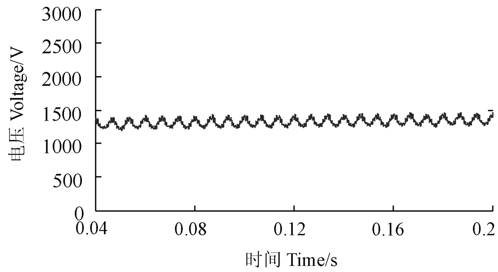
根据劳斯稳定判据，推导出系统稳定的充要条件是为：

$$\frac{T_mK_p}{\beta}<C<\frac{T_mK_p(1+K_mK_p)}{\beta+\beta K_mK_p-LK_i} \tag{12}$$

4　仿真结果及分析

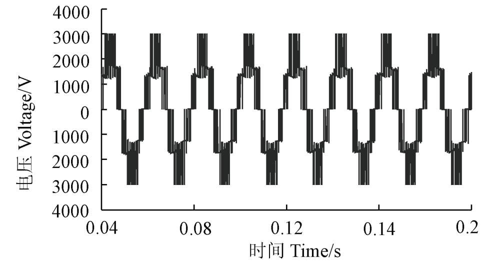
为了验证所采用的新型拓扑结构的有效性和正确性，采用 Matlab 软件对带中点电压自平衡的 NPC 三电平逆变器拓扑结构进行仿真。仿真系统参数设置如下：u_s=3 000 V，u_{dc}=500 V，变压器变比 n=1，NPC 三电平逆变器的开关频率为 3 kHz，电压主动补偿装置的开关频率为 10 kHz，C=1 000 μF，L=0.4 mH，负载为三相桥式整流电路带阻感负载。

图 6a, b, c 分别表示传统 NPC 三电平逆变器正常运行时，三相桥臂中点电压 u_o 波动、三电平 NPC 逆变器交流侧 AB 相输出电压 u_{AB} 波形及其频谱的情况。可以看出，三相桥臂中点电压会发生波动，波动最大值达到 280 V，同时造成输出电压波形畸变，电压 u_{AB} 的谐波总畸变率 THD=18.97%。



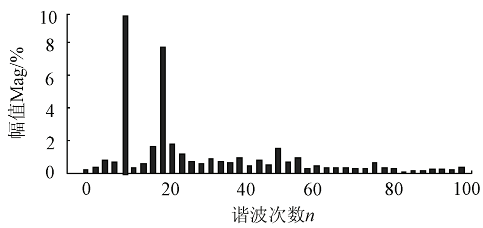
a. u_o 的电压波形

a. u_o voltage waveform



b. u_{AB} 的电压波形

b. u_{AB} voltage waveform



注：基波(50 Hz)=2080 总谐波失真THD=18.97%

Note: Fndamental(50 Hz)=2080 THD=18.97%

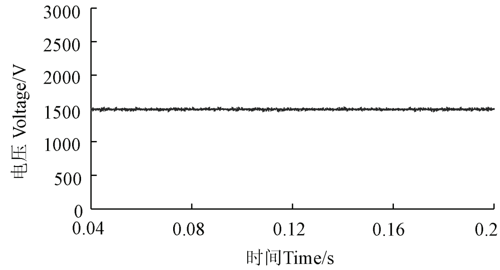
c. u_{AB} 的频谱

c. u_{AB} spectrogram

图 6　传统 NPC 三电平逆变器正常运行时 u_o、u_{AB} 的电压波形和频谱图

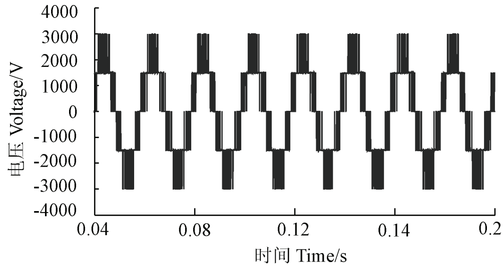
Fig.6　u_o, u_{AB} voltage waveform and spectrogram of traditional NPC three-level inverter in normal operation

图 7a、b、c 分别表示提出的新型 NPC 三电平逆变器正常运行时，三相桥臂中点电压 u_o 波动和输出电压 u_{AB} 波形及其频谱的情况。可以看出，当新型的带中点电压自平衡的 NPC 三电平逆变器正常运行时，三相桥臂中点电压发生波动的幅度明显减小，波动最大值仅为 40V，u_{AB} 的谐波总畸变率下降为 THD=14.11%。从图 6 和图 7 的对比中可以看出新型的带中点电压自平衡的 NPC 三电平逆变器能够有效地平衡直流侧中点电压波动，提高了逆变器输出波形质量。



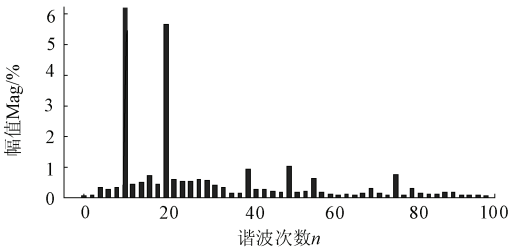
a. u_o的电压波形

a. u_o voltage waveform



b. u_{AB}的电压波形

b. u_{AB} voltage waveform



注：基波(50 Hz)=2071 总谐波失真THD=14.11%

Note: Fundamental(50 Hz)=2071 THD=14.11%

c. u_{AB}的频谱

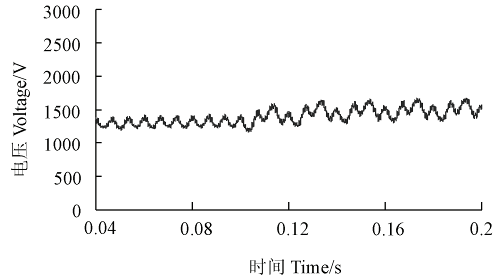
c. u_{AB} spectrogram

图 7 新型的 NPC 三电平逆变器运行时 u_o、u_{AB}的电压波形和频谱图

Fig.7 u_o, u_{AB} voltage waveform and spectrogram of proposed NPC three-level inverter in normal operation

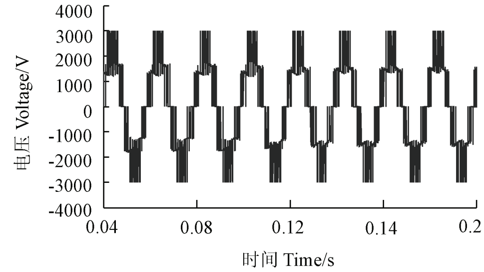
为了验证提出的电路拓扑结构的快速响应性能，在仿真进行到 0.1 s 时，在 NPC 三电平逆变器结构的交流输出端 AB 相接入单相阻感负载，使得逆变器所接的负载变为三相不平衡，从而使得中点电压波动突变。图 8a、b、c 分别表示传统 NPC 三电平逆变器在负载突变时，三相桥臂中点电压 u_o 波动和交流侧 AB 相输出电压 u_{AB} 波形及其频谱的情况。可以看出，三相桥臂中点电压的波动加重，波动最大值达到 330 V，同时 u_{AB} 的畸变更加严重，其谐波总畸变率 THD=22.47%。

图 9a、b、c 分别表示提出的新型带中点电压自平衡的 NPC 三电平逆变器在负载突变情况下运行时，三相桥臂中点电压 u_o 波动和交流侧 AB 相输出电压 u_{AB} 波形及其频谱的情况。可以看出，在负载突变情况下运行时，中点电压发生波动得到有效平衡，波动最大值仅为 45 V，交流侧输出电压的谐波总畸变率得到控制，THD=16.29%。从图 8 和图 9



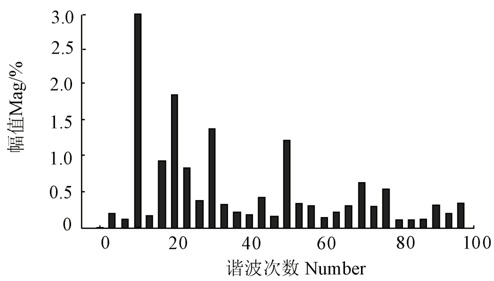
a. u_o的电压波形

a. u_o voltage waveform



b. u_{AB}的电压波形

b. u_{AB} voltage waveform



注：基波(50 Hz)=2065 总谐波失真THD=22.47%

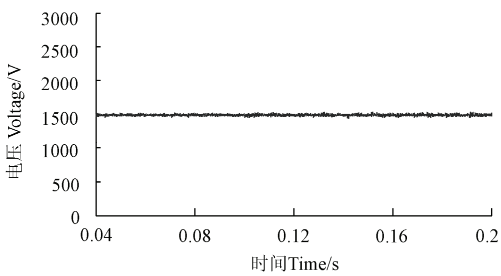
Note: Fundamental(50 Hz)=2065 THD=22.47%

c. u_{AB}的频谱

c. u_{AB} spectrogram

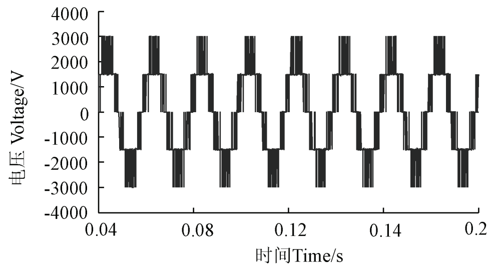
图 8 传统 NPC 三电平逆变器在负载突变时 u_o、u_{AB}的电压波形和频谱图

Fig.8 u_o, u_{AB} voltage waveform and spectrogram of traditional NPC three-level inverter in load swell



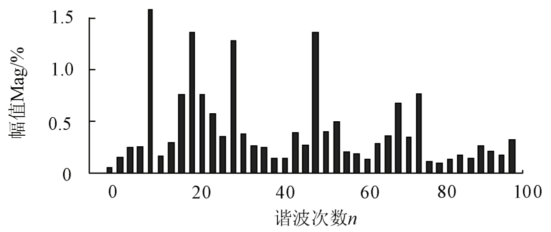
a. u_o的电压波形

a. u_o voltage waveform



b. u_{AB}的电压波形

b. u_{AB} voltage waveform



注：基波(50 Hz)=2067 总谐波失真 *THD*=16.29%
Note: Fundamental (50 Hz)=2067 *THD*=16.29%

c. u_{AB} 的频谱
c. u_{AB} spectrogram

图 9　新型 NPC 三电平逆变器在负载突变时 u_o、u_{AB} 的电压波形和频谱图

Fig.9　u_o, u_{AB} voltage waveform and spectrogram of proposed NPC three-level inverter in load swell

的对比中可以看出提出的新型带中点电压自平衡的 NPC 三电平逆变器在中点电压波动突变时，也能有效地平衡。由此可见，该电路拓扑结具有良好的响应速度，动态性能好。

5　结　论

本文针对传统的 NPC 三电平逆变器结构存在的中点电压波动问题，提出了一种新型的带中点电压自平衡的二极管箝位式(三电平逆变器拓扑结构。该结构由一套主动补偿装置对 NPC 逆变器中点电压的波动进行抑制。仿真结果表明：无论负载如何变化，提出的电路拓扑结构都能有效地平衡三相桥臂中点的电压波动，将三相桥臂中点电压的波动控制在 3%以下，减轻输出电压波形的畸变，使得谐波总畸变率 *THD* 小于 16.29%，并且响应迅速，动态性能好。

[参　考　文　献]

[1] 张博，朴在林，李鹏. 农村配电网中多谐波源叠加算法的研究[J]. 农业工程学报，2008，24(6)：200－202.
Zhang Bo, Piao Zailin, Li Peng. Algorithm for calculating harmonics superposition of multi-harmonic source in rural power grid[J]. Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE), 2008, 24(6): 200－202. (in Chinese with English abstract)

[2] 孔斌，刘宪林，赵卫华. 农村变电所并联补偿电容器谐波放大问题分析[J]. 中国农村水利水电，2008，4(2)：133－134.
Kong Bin, Liu Xianlin, Zhao Weihua. An analysis of harmonic amplification problem of paralleling condensers in rural power stations[J]. China Rural Water and Hydropower, 2008, 4(2): 133－134. (in Chinese with English abstract)

[3] Akira N, Isao T, Hirofumi A. A new neutral-point-clamped PWM inverter[J]. IEEE Transactions on Industrial Application, 1981, 17(5): 518－523.

[4] Ralph T, Steffen B. A comparison of three-level converters versus two-level converters for low-voltage drives, traction and utility applications[J]. IEEE Transaction on Industry Applications, 2005, 41(3): 855－865.

[5] Newton C, Sumner M. Multi-level convertors，a real solution to medium/high-voltage drives[J]. Power Engineering Journal, 1998, 12(1): 21－26.

[6] Iqbal Messaif, El Madjid Berkouk, Nadia Saadia. Ripple reduction in DTC drives by using a three-Level NPC VSI[J]. Electronics, Circuits and Systems, 2007. ICECS 2007.4511206. 14th IEEE International Conference on Electronics, Circuits and Systems, 2007: 1179－1182.

[7] Yang Xiaoping, Zhang Yanxiao, Zhong Yanru. Three-phase four-wire DSTATCOM based on a three-Dimensional PWM algorithm[J]. Electric Utility Deregulation and Restructuring and Power Technologies, 2008. DRPT 2008. Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, 2008: 2061－2066.

[8] Aurtenechea S, A.Rodriguez M, Oyarbide E. Predictive direct power control of MV-Grid-connected two-level and three-Level NPC converrters experimental results[C]// 2007 European Conference on Power Electronics and Applications, 2007: 1－10.

[9] Ningyi Dai, Manchung Wong, Yingduo Han. Application of a three-level NPC inverter as a three-phase four-wire power quality compensator by generalized 3DSVM[J]. Power Electronics IEEE Transactions on, 2006, 21(2): 440－449.

[10] Kanchan R S, Tekwani P N, Baiju M R. Three-level inverter configuration with commonmode voltage elimination for induction motor drive[J]. Electric Power Applications,IEE Proceedings, 2005, 152(2): 261－270.

[11] Ping Li, Qingxiao Zhang.Research on vector control method of neutral-point-clamped(NPC)three-lever inverter with bootstrap driver[C]// 2013 Fourth Internation Conference on Intelligent Control and Information Processing(ICICIP), 2013: 10－14.

[12] Gopal Mondal, Gopakumar K, Tekwani P N. A five-level inverter scheme with common-mode voltage elimination by cascading conventional two-level and three-lever NPC inverters for an induction motor drive[C]//Power Electronics and Applications, 2007 European Conference on, 2007: 1－10.

[13] Zhe Zhang, Ole C Thomsen, Michael A E Andersen. Discontinuous PWM modulation strategy With circuit-

level decoupling concept of three-level neutral- point-clamped(NPC) inverter[J]. IEEE Transactions on Industrial Electronics, 2013, 60(5): 1897－1906.

[14] Lianghe Zhe, Yunpin Zou, Xudong Zou. A novel 3-D space vector modulation scheme for three-level three-leg NPC converter in three-phase four-wire APF system[C]// Energy Conversion Congress and Exposition(ECCE), 2012 IEEE, 2012: 1527－1532.

[15] Ramom Portillo, Sergio Vazquez, Jose I.Leon. Model based adaptive direct power control for three-level NPC converters[J]. IEEE Transactions on Industrial Informatics , 2013, 9(2): 1148－1157.

[16] Nikloa C, Dusan B. A comprehensive study of neutral-point voltage balancing problem in three-level neutral- point-clamped voltage source PWM inverters[J]. IEEE Transactions on Power Electronics, 2000, 15(2): 242－248.

[17] Oscar A, Luis M, Pablo S, et al. Analysis of neutral-point voltage balancing problem in three-level neutral-point-clamped inverters with SVPWM modulation[C]// Industrial Electronics Society, IEEE 2002 28th Annual Conference, 2002: 920－925.

[18] H. du Toit Mouton. Natural balancing of three-level neutral-point-clamped PWM inverters[J]. IEEE Transactions on Industrial Electronics, 2002, 49(5): 1017－1025.

[19] Liu C, Wu B, Xu D. Progressive natural balance of neutral-point voltage of three-level NPC inverter with a modified SVM scheme[C]//Applied Power Electronics Conference and Exposition, 2006. APEC'06. Twenty-First Annual IEEE, 2006: 1666－1669.

[20] Stala R. Application of balancing circuit for DC-link coltages balance in a single-phase diode-clamped inverter with two three-level legs[J]. IEEE Transactions on Industrial Electronics, 2011, 58(9): 4185－4195.

[21] Cai Kai, Liu Bin, Xu Zhengxi. General analysis on imbalanced voltage of DC capacitors in NPC three-level inverter[C]//2011 International Conference on Electrical Machines and Systems(ICEMS), 2011: 1－6.

[22] Mohzani Z, McGrath B P, Holmes D G. Natural balancing of the neutral point voltage for a three-phase NPC multilevel converter[C]//IECON 2011-37th Annual Conference on IEEE Industrial Electronics Society, 2011: 4445－4450.

[23] Joachim H, Nikolaos O. Neutral point potential balancing algorithm at low modulation index for three-level inverter medium-voltage drives[J]. IEEE Transactions on Industry Applications, 2007, 43(3): 761－768.

[24] Amit Kumar G, Khambadkone Ashwin M. A simple space vector PWM scheme to operate a three-level NPC inverter at high modulation index including over modulation region，with neutral point balancing[J]. IEEE Transactions on Industry Applications, 2007, 43(3): 751－760.

[25] Omar B, Bruno F, et al. DC link capacitor voltage balancing in a three-phase diode clamped inverter controlled by a direct space vector of line-to-line voltages[J]. IEEE Transactions on Power Electronics, 2007, 22(5): 1636－1648.

[26] 翁海清，孙旭东，刘丛伟，等. 三电平逆变器直流侧电压平衡控制方法的改进，中国电机工程学报[J]. 2002，22(9)：94－97.
Weng Haiqing, Sun Xudong, Liu Congwei, et al. Improvement on DC-voltage balance control method of three-level inverter[J]. Proceedings of the CSEE, 2002, 22(9): 94－97. (in Chinese with English abstract)

[27] 宋文祥，陈国呈，武慧，等. 一种具有中点电压平衡功能的三电平空间矢量调制方法及其实现[J]. 中国电机工程学报，2006，26(12)：95－100.
Song Wenxiang, Chen Guocheng, Wu Hui, et al. A novel SVPWM strategy and its implementation considering neutral-point potential balancing for three-level NPC inverter[J]. Proceedings of the CSEE, 2006, 26(12): 95－100. (in Chinese with English abstract)

[28] 宋文祥，陈国呈，束满堂，等. 中点箝位式三电平逆变器空间矢量调制及其中点控制研究[J]. 中国电机工程学报，2006，26(5)：106－109.
Song Wenxiang, Chen Guocheng, Shu Mantang, et al. Research on SVPWM method and its neutral-point-potential control for three-level neutral-point-clamped (NPC) inverter[J]. Proceedings of the CSEE, 2006, 26(5): 106－109. (in Chinese with English abstract)

[29] Amirnaser Y, Reza Reza I. Generalized state-space averaged model of the three-level NPC converter for systematic DC-voltage-balancer and current-controller design[J]. IEEE Transactions on Power Delivery, 2005, 20(2): 1105－1114.

[30] Menzies Robert W, Steimer Peter K, Steinke Jurgen K. Five level GTO inverter for large induction motor drives[J]. IEEE Transaction on Industry Application, 1994, 30(4): 938－944.

Improved neutral point clamped three-level VSI topology construction in agricultural device

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Abstract: A NPC three-level inverter is suitable to be used in the field of high power, high voltage. A DC side neutral-point N and three-phase bridge arm neutral-point O of a traditional NPC three-level inverter were linked together. The voltage of the three-phase bridge arm neutral-point would fluctuate, because of the DC side neutral-point voltage fluctuation. It would influence the efficiency of the NPC three-level inverter's work. The neutral-point voltage excessive fluctuation of the traditional neutral point clamped (NPC) three-level inverter would cause the total harmonic distortion (THD) of output voltage increase and switch devices damage. This problem limits its engineering applications in the field of agriculture. A NPC three-level inverter topology with a neutral-point voltage self-balancing function was proposed. It consisted of two parts. Part 1 was the traditional NPC three-level inverter. Part 2 was the active compensation voltage device, and was composed of a single-phase full-bridge inverter circuit, which was used to compensate for the voltage fluctuation of a three-phase bridge arm neutral-point in a traditional NPC three-level inverter. The active compensation voltage device is similar to a controllable voltage source. It was used in a series between point O and point N in a traditional NPC three-level inverter. The three-phase bridge arm neutral-point real-time voltage value was detected and compared with a given value. Then, a real-time compensation voltage was generated by the active compensation voltage device. The voltage of the three-phase bridge arm neutral-point was u_o, the voltage of the DC side neutral-point was u_n, and the voltage of the DC side was u_s. The real-time compensation voltage was u_b, $u_o = u_n - u_b$. When the neutral-point voltage of part 1 fluctuates excessively, the active compensation voltage device would generate a real-time compensation voltage to keep neutral-point voltage stability, $u_o = 0.5u_s$. Because coordinate transformation is not required, the control scheme is simple. Further, a theoretical analysis of the system stability was achieved. In order to verify the proposed control method, the system was simulated by using the "Power system Blockset" in the Matlab/Simulink environment. The parameters used for simulation are defined as follows: u_s=3000 V，u_{dc}=500 V, dc link capacitor, C=1000 uF, L=0.4 mH, the switching frequency of the NPC three-level inverter was 3kHz, and the switching frequency of the active compensation voltage device was 10 kHz. After the compensation, a voltage fluctuation value of the three-phase bridge arm neutral-point in the traditional NPC three-level inverter was limited under 3%. In addition, simulation results showed that the proposed topology has good dynamic performance. In conclusion, a NPC three-level inverter with a neutral-point voltage self-balancing function was proposed due to the problem of neutral-point voltage excessive fluctuation of a traditional neutral point clamped (NPC) three-level inverter. This structure consisted of an active compensation voltage device to eliminate the neutral-point voltage excessive fluctuation. Simulation results have shown that no matter how the load varies, the presented circuit structure can eliminate the three-phase bridge arm neutral-point voltage fluctuation effectively with quick response and good dynamic performance.

Key words: topology, voltage, design, three-level inverter, neutral point clamped, neutral-point voltage, balance

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