A Novel Neutral Point Potential Balance Control of Three-Level Converters Based on The Search Optimization Method of Dual Degrees of Freedom

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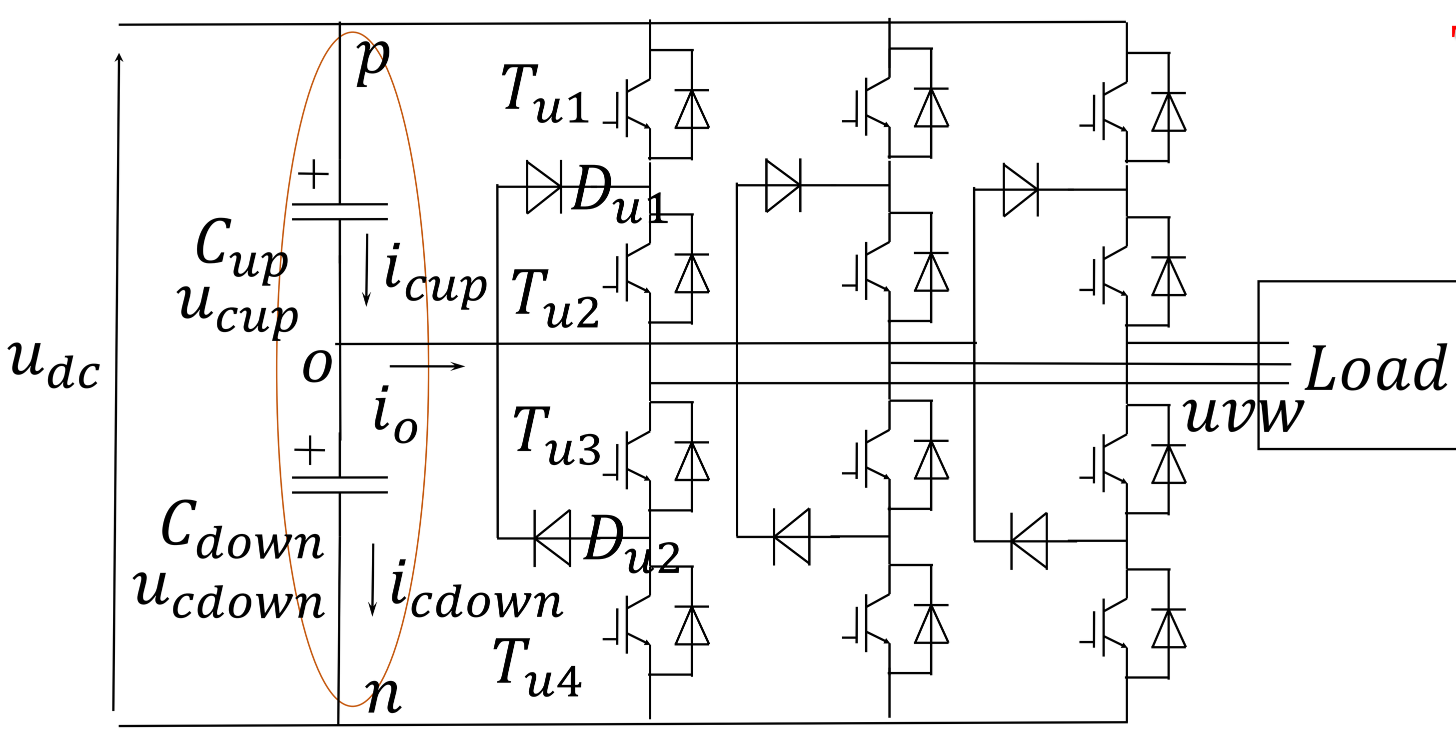
Introduction

Recently, three level converters have been widely utilized in medium/high voltage high power applications, such as wind power generation, steel rolling, electric traction and so on.



The advantages of TL-NPC converters:

- The rated withstand voltage of switch devices could be halved.
- The output voltage and current waveforms become more sinusoidal.
- The electromagnetic interference (EMI) problem can be improved, since voltage change rate (*du/dt*) could be halved



Three level neutral point clamped (TL-NPC) converter

The neutral point potential (NPP) problem is critical for TL-NPC converters

The reasons for the NPP unbalance:

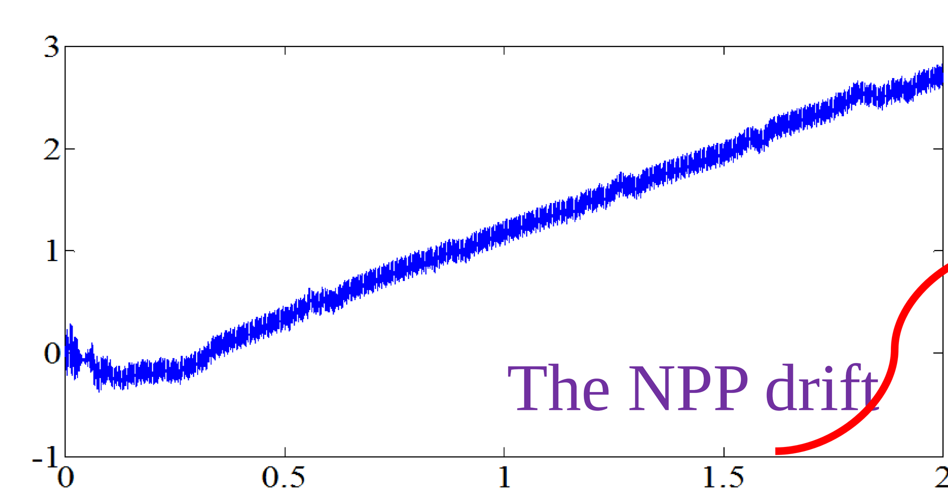
- If the neutral point current (i_o) is positive, the upper capacitor (C_{up}) charges and the bottom capacitor (C_{down}) discharges.
- If i_o is negative, C_{up} discharges and C_{down} charges

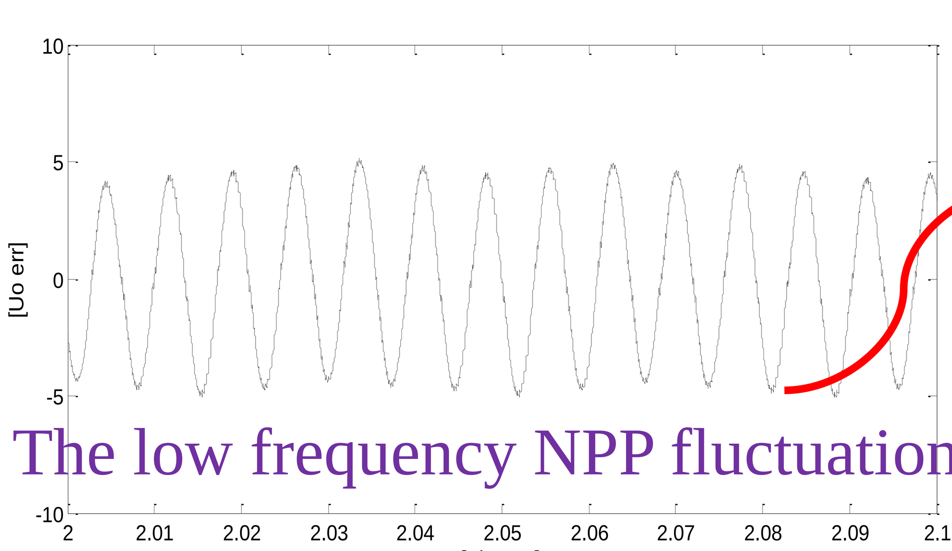
$$\begin{cases} u_{cdown} = u_{dc}/2 + \Delta v_o, u_{cup} = u_{dc}/2 - \Delta v_o \\ 2\Delta v_o = u_{cdown} - u_{cup} \end{cases}$$

$$i_{oc} = -i_o = C\left(u_{cdown} - u_{cup}\right)/T_s$$

The target for the study

The classification of NPP problem:



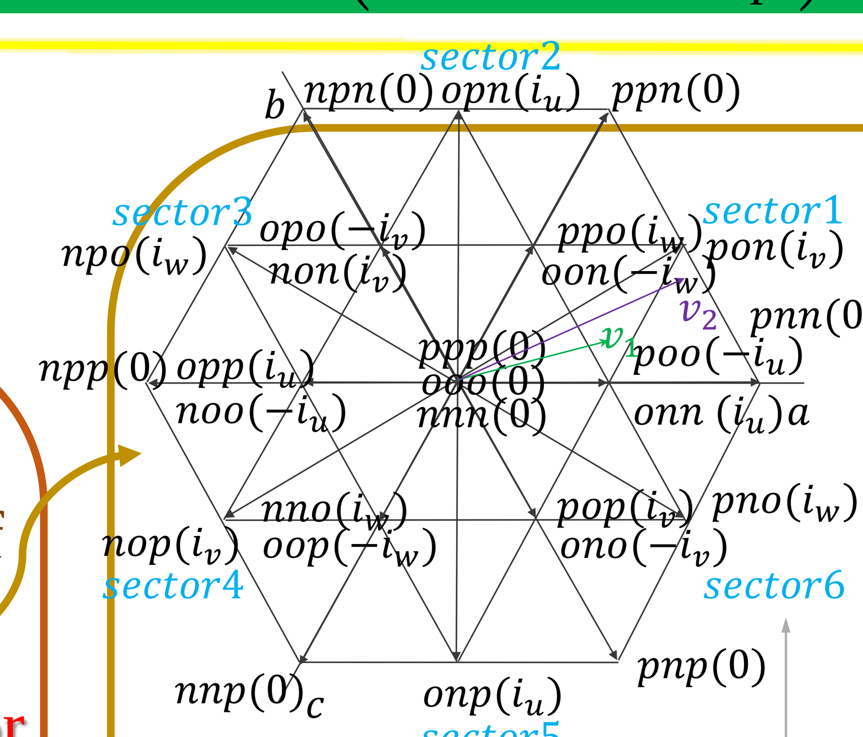


Which is original from the dead time, asymmetric loads, the inconsistency of switch devices, etc.

It damages the switch device and capacitor

That is derived from the modulation methods, which is based on nearest three vector PWM (NTV-PWM), such as SVPWM, SPWM, etc.

The bulk capacitor is necessary.

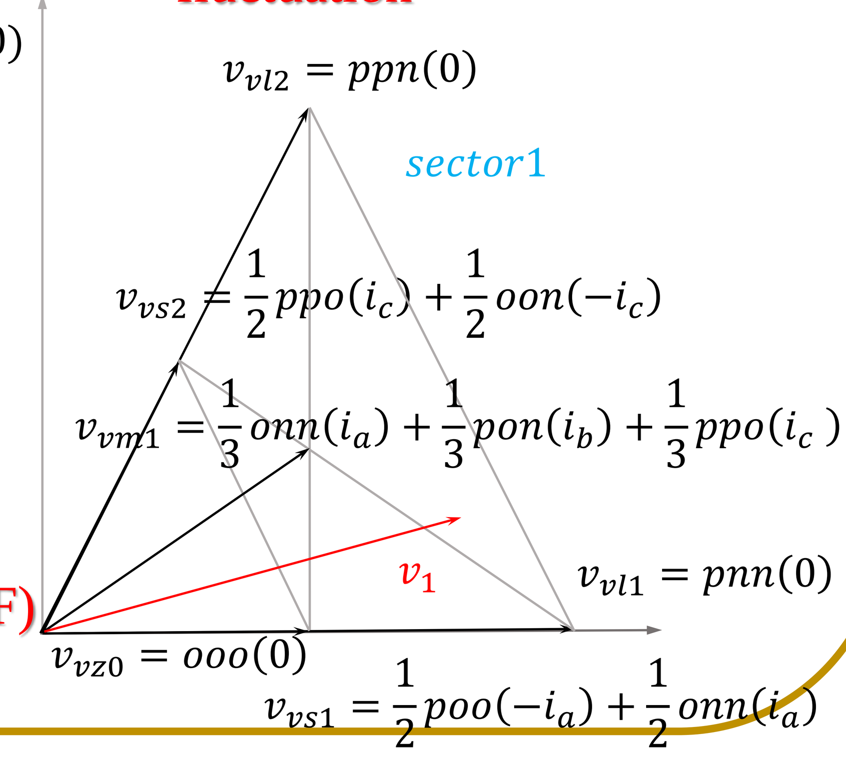


The NPP drift is overcame based on NTV-PWM, such as zero-sequence voltage injection method

Cause the low frequency NPP fluctuation

The low frequency NPP fluctuation is solved based on virtual space vectors, such as dual modulation wave (DMW) method.

High switching frequency (SF)
Weaken ability for NPP drift



This paper proposes a novel NPP control to solve the both NPP problems with a low SF and stronger ability for NPP drift

The basic principle of the DMW method

$$\begin{cases} v_{zu} = v_u + v_z \\ v_{zv} = v_v + v_z \\ v_{zw} = v_w + v_z \end{cases}$$

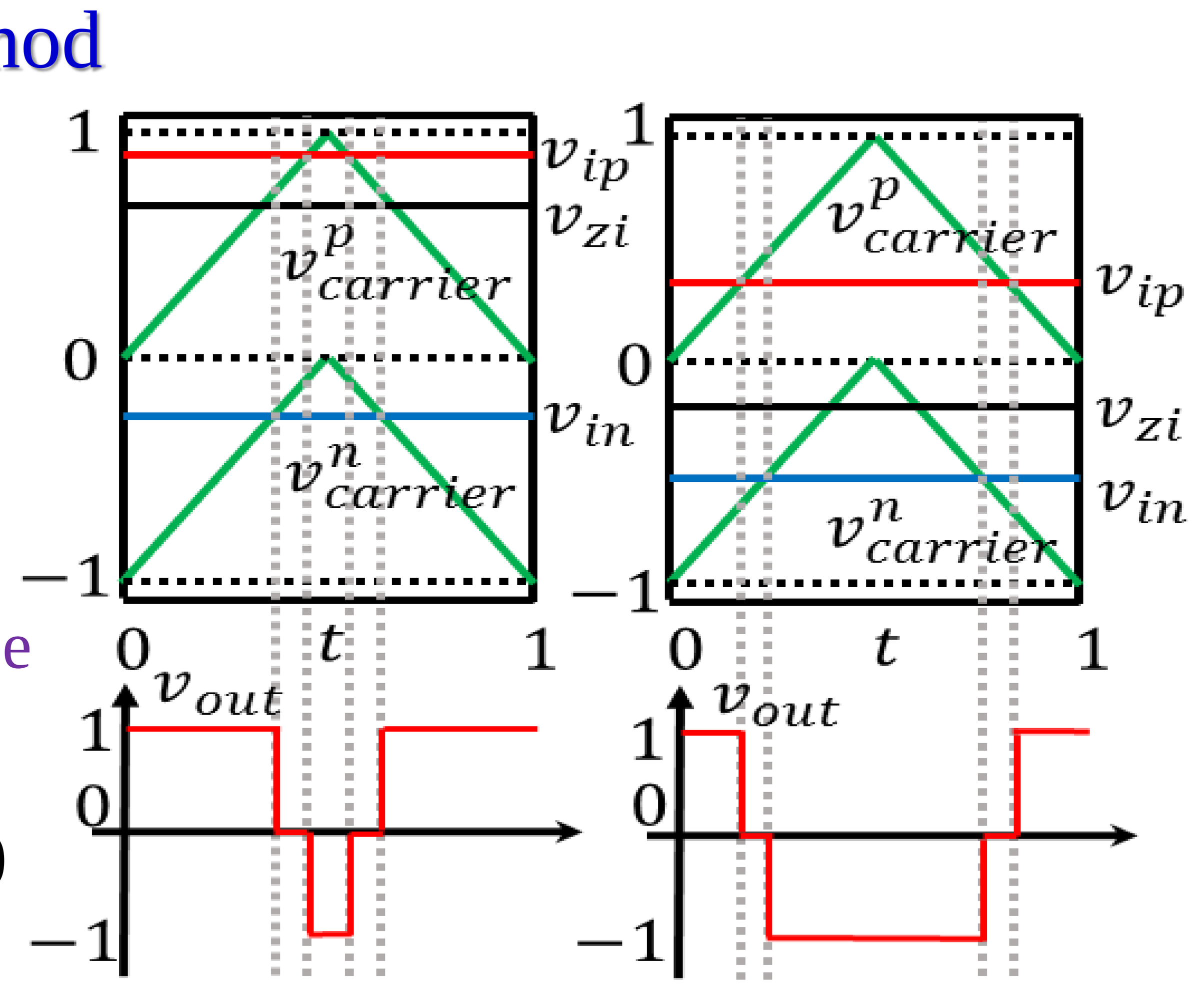
Step one

$$v_z = -\left(v_{max} + v_{min}\right)/2$$

$$\begin{cases} v_{zu} = v_{up} + v_{un} \\ v_{zv} = v_{vp} + v_{vn} \\ v_{zw} = v_{wp} + v_{wn} \end{cases} \Leftrightarrow \begin{cases} v_{zi} = v_{ip} + v_{in} \\ 0 \le v_{ip} \le 1, -1 \le v_{in} \le 0 \\ i = u, v, w \end{cases}$$

Step two

Step three



$$i_o = \left|1 + v_{un} - v_{up}\right| i_u + \left|1 + v_{vn} - v_{vp}\right| i_v + \left|1 + v_{wn} - v_{wp}\right| i_w$$

The solution, which keeps i_o zero in any time.

$$\left|1 + v_{un} - v_{up}\right| = \left|1 + v_{vn} - v_{vp}\right| = \left|1 + v_{wn} - v_{wp}\right|$$

$$i_o = \left|1 + v_x\right|\left(i_u + i_v + i_w\right) = 0$$

$$v_x = \left(v_{min} - v_{max}\right)/2$$

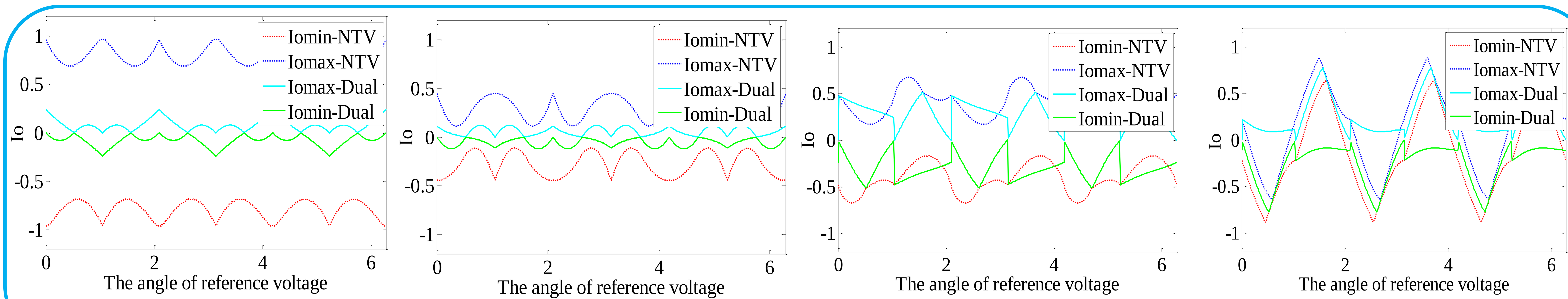
$$\begin{cases} v_{ip} = \dfrac{v_i - v_{min}}{2} \ge 0 \\ v_{in} = \dfrac{v_i - v_{max}}{2} \le 0 \end{cases}, \quad i = \{u, v, w\}$$

The disadvantages of DMW method

The switching frequency of DMW method is 4/3 times as large as that of NTV-PWM method

The DMW method without a compensator is just an open-loop way.

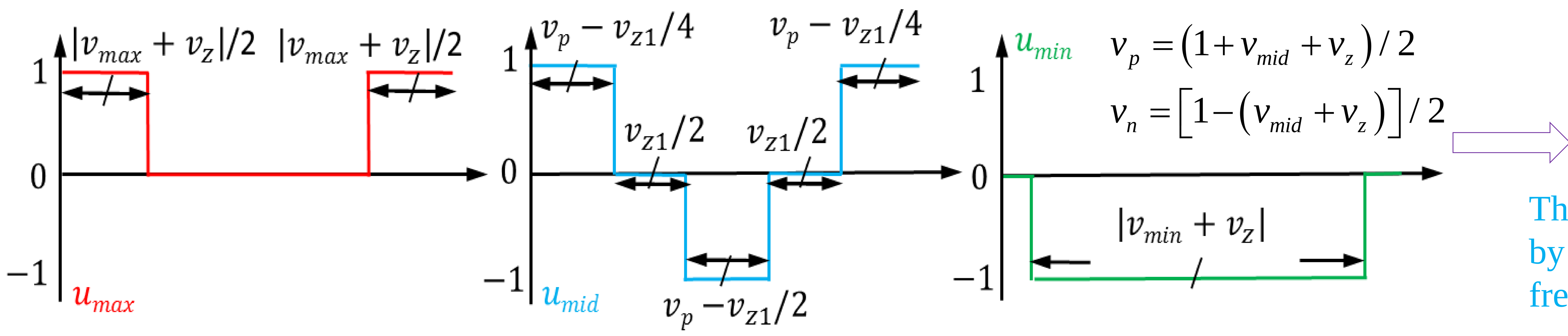
The control ability for the NPP drift problem is still weak for the DMW method with a compensator



$\varphi=0$, $m=0.6$ | $\varphi=0$, $m=0.9$ | $\varphi=\pi/3$, $m=0.6$ | $\varphi=\pi/3$, $m=0.9$

The proposed NPP control based on search optimization method of dual degrees of freedom

The proposed method is done using the following PWM waveforms



$$v_p=(1+v_{mid}+v_z)/2$$
$$v_n=\left[1-(v_{mid}+v_z)\right]/2$$

$$i_0=i_{\max 0}+i_{mid\,0}+i_{\min 0}$$
$$\begin{cases} i_{\max 0}=\left(1-|v_{\max}+v_z|\right)i_{\max} \\ i_{\min 0}=\left(1-|v_{\min}+v_z|\right)i_{\min} \\ i_{mid\,0}=v_{z1}i_{mid} \end{cases}$$

The i_o and NPP can be controlled by adjusting the dual degrees of freedom (v_{z1} and v_z)

The limit range of zero sequence voltage (v_z)

$$-1-v_{\min}\le v_z\le 1-v_{\max}$$

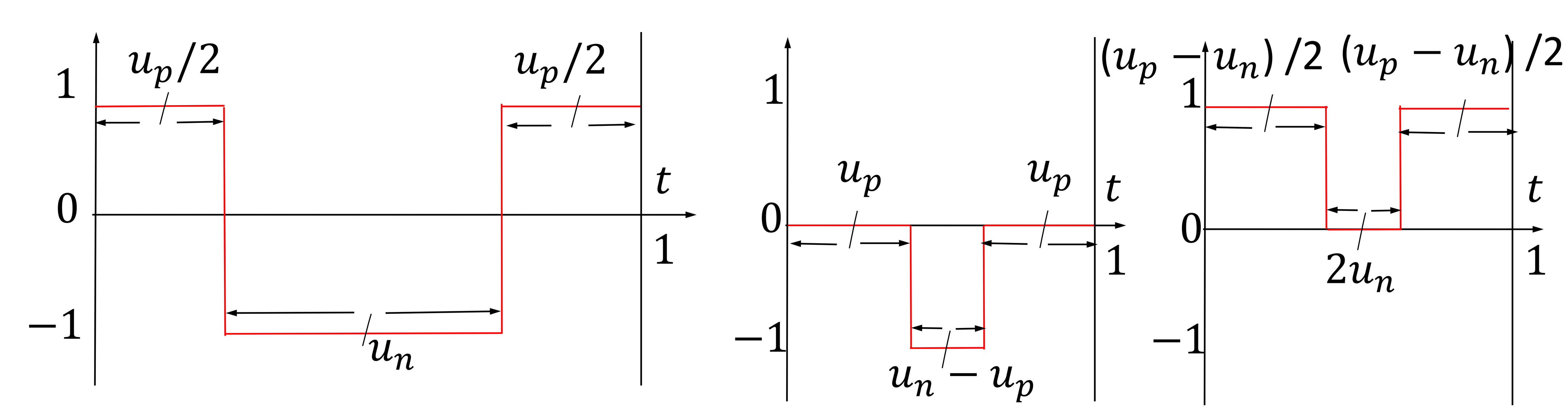
To ensure the linear modulation

The limit range of the degree of freedom (v_{z1})

$0\le v_{z1}$, *from Case one*

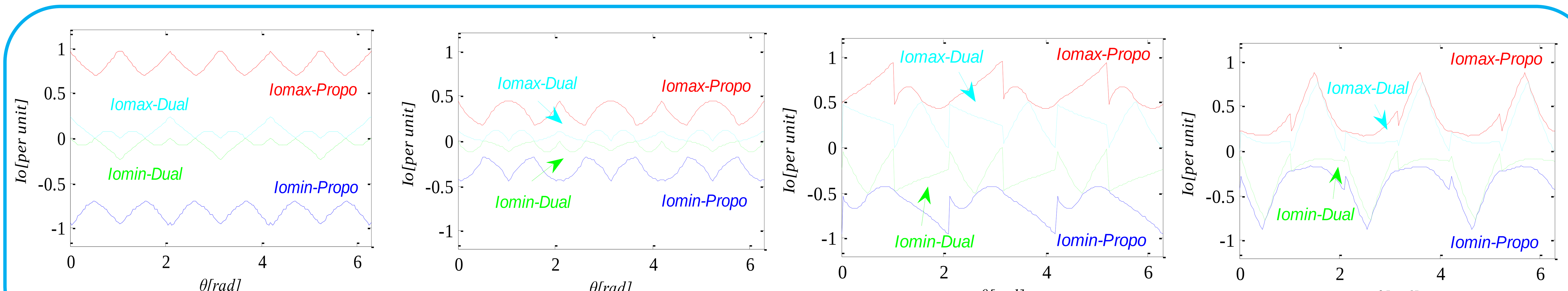
$v_{z1}\le 2\min(v_p, v_n)$, *from Case two*

$$0\le v_{z1}\le 2\min(v_p, v_n)$$



Case one | Case two

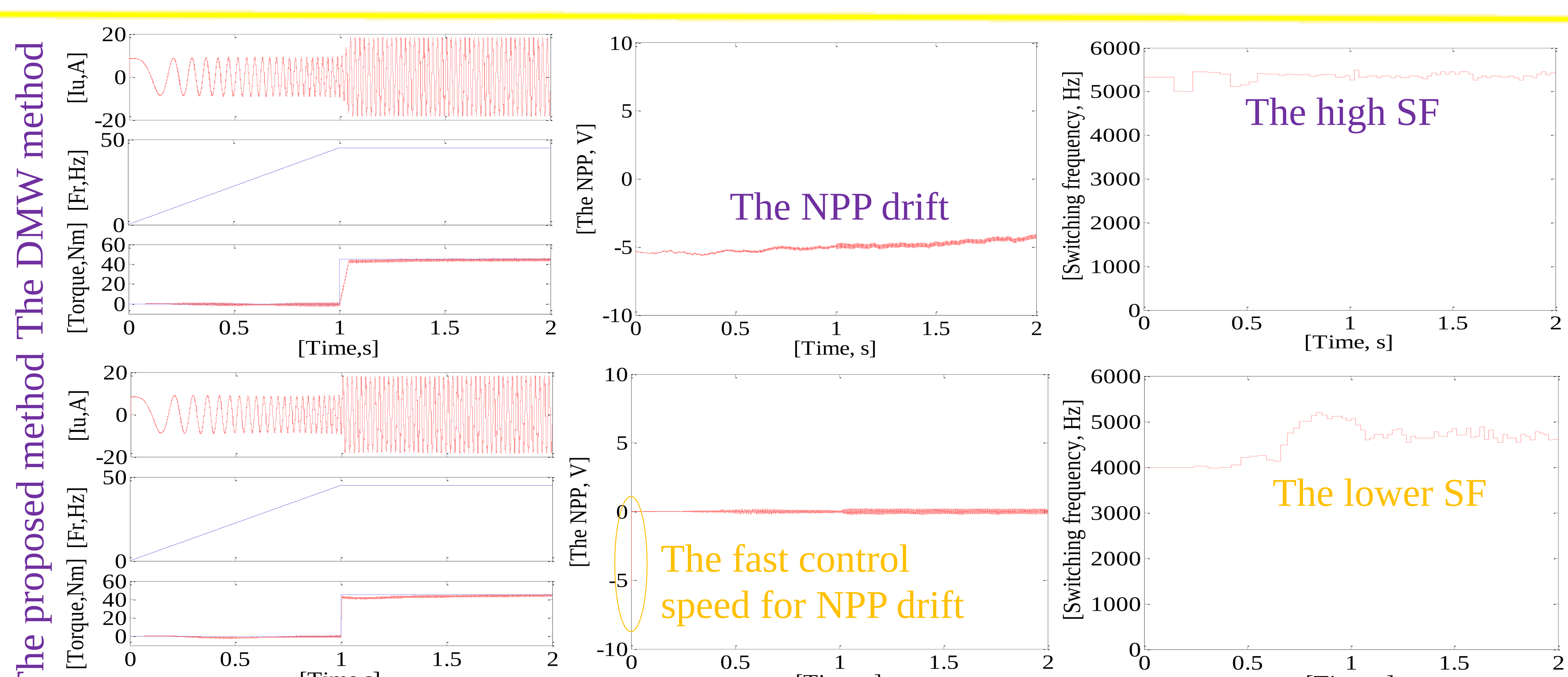
The maximum control ability for the NPP drift problem



$\varphi=0$, $m=0.6$ | $\varphi=0$, $m=0.9$ | $\varphi=\pi/3$, $m=0.6$ | $\varphi=\pi/3$, $m=0.9$

The simulation results

The induction motor is controlled based on the VVVF and an initial NPP error is set to 5.4V



Conclusion:

- The NPP drift problem can be solved faster, since the proposed method has a stronger NPP control ability.
- The SF of proposed method is also lower than that of DMW method.