

# UNIFIED VOLTAGE DROOP CONTROL STRATEGY FOR VSC-MTDC IN HVDC SYSTEM

*Shahid Aziz Khan<sup>1\*</sup>, Chongru Liu<sup>2</sup>, Jamshed Ahmed Ansari<sup>3</sup>*

<sup>1</sup>North China Electric Power University (NCEPU), Beijing, China

<sup>2</sup>North China Electric Power University (NCEPU), Beijing, China

<sup>3</sup>North China Electric Power University (NCEPU), Beijing, China

\*shahidazizkhan1@gmail.com

**Keywords:** DROOP CONTROL, DC GRID, SMART GRID, VOLTAGE SOURCE CONVERTER

## Abstract

Grid stability is directly proportional to the voltage control, which becomes complex when multiple grids are involved. Due to the increasing trend of renewable energy integration and smart grid systems, a multi-terminal direct current (MTDC) grid system is the trending approach in the power system. Voltage control strategies like voltage margin control, master-slave control, etc. have some drawbacks associated with them. Such as the generation of oscillations, delayed time response, etc. A new centralized Voltage droop control strategy for voltage source converter (VSC) is proposed. The aspiration of this strategy comes from the frequency control in the AC system. Voltage control in the DC system is the counterpart of frequency control in the AC system. The unified voltage droop control strategy balances the instantaneous power amongst all converters in case of any disturbance. All the converters automatically adjust themselves to maintain the balance of power within the DC grid based on the measurement of terminal voltage. Resulting in minimum overshoot, minimum undershoot, instantaneous fault clearing, and fast settling time. A four-terminal VSC-MTDC system is simulated in the PSCAD environment to test the performance of the unified or centralized voltage droop control strategy.

## 1. Introduction

Depleting conventional energy sources and the environmental hazards associated with them opened a pathway towards the adoption of renewable energy sources. Distributed generation and renewable energy integration through microgrids and multi-terminal direct current (MTDC) grids are becoming common commercially. The growing offshore installation of wind farms is enhancing the development of Multi-terminal direct current (MTDC) technology [1]. The most efficient solution to connect wind farms and solar parks to the onshore grids is through MTDC technology. HVDC installations have offered economic

solutions for transmission purposes. HVDC transmission system provides a lot of benefits as compared to the traditional HVAC transmission system. Some of the prominent advantages include bulk power and economical transmission, long-distance and asynchronous interconnections. HVDC transmission system also offers reactive power compensation based on VSC and extends the advantages in terms of overall system performance [2]. Due to the advancement of power electronics technology, insulated gate bipolar transistors (IGBT) used in VSC now allows a bidirectional control. Unlike line commutated converters (LCC), VSC offers independent active and reactive power control. Independent, responsive power control ensures dynamic voltage regulation in an interconnected system [3]. Voltage control inside a VSC station is crucial. The power balance of the entire system depends upon the voltage control and dynamic voltage regulation of the converters in an interconnected or multi-terminal grid system. For meshed HVDC grids, the outdated voltage control strategies do not suffice. This research focuses on improved voltage control strategies for meshed networks, i.e., unified voltage droop control method. The novelty of this work lies in the unified or centralized approach. It can be understood as a centralized control that is different from simple droop control. In centralized control, all the decisions are taken with respect to the inputs from all the converters at a single control center, which increases efficiency and accuracy.

## 2. Literature Review

Literature suggests a wide range of strategies for voltage control such as master-slave control, voltage margin control strategy, etc. Voltage control strategies overall are classified into two categories, i.e., centralized and distributed control. A master-slave control strategy is a widely used, centralized control strategy [4]. The voltage margin control strategy is thought to be an improved version of the master-slave control strategy. Also known as a centralized control strategy with backup [5]. The major drawback of the master-slave

control method arises in case of significant power fluctuation in the system, causing the master converter to reach its limit. In this case, the system loses the ability to operate stably. Unlike master-slave control voltage margin control does not require inter-station communication to function. If one main converter exceeds the limits or becomes offline, another converter will replace its functionality to keep the system stable and balanced. The drawbacks of voltage margin control include: Out of control DC voltage regulation during the transition process, the requirement of multiple priorities due to multiple backup converters increasing the design complexity and priority setting difficulties [6]. This research focuses on a new approach to sustain the power balance in the system, i.e., through the unified voltage droop control strategy. In a system operating under the unified droop control strategy, the converters adjust their power accordingly to the droop coefficients. The adjustment is made to maintain the System stability and power balance in the grid system. The droop controller measures the terminal voltage and adjusts the converter accordingly to keep the reference value. Droop coefficient of the respective converter guide the converter about the amount of power sharing. The high droop coefficient means greater power-sharing and vice-versa [7]. Unlike other voltage, control strategies droop controls avoid the growth of oscillations during voltage regulation [8]. This research focuses specifically on a centralized type voltage droop control to get an accurate and efficient response.

### 3. Modeling of the droop-controlled converter

Droop controlled converter is modeled in Eq (1) and Eq (2).

$$i_{d,ref} = \left[ k + \frac{1}{sT} \right] [P_{ref} - P_{mea} + k(U_{dc,ref} - U_{dc,mea})] \quad (1)$$

$$P_{mea} - P_{ref} + k(U_{dc,ref} - U_{dc,mea}) = 0 \quad (2)$$

Where,

$i_{d,ref}$  is the inner current.  $U_{dc,mea}$  and  $U_{dc,ref}$  refers to the measured and reference voltages.  $k$  is the droop constant. Fig.1 depicts the droop control method in the form of a block diagram.

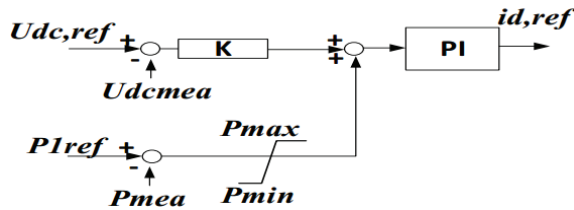


Fig 1. Representation of voltage droop control method.

### 4. Voltage droop control technique

In case of a power fluctuation, a linear deviation is generated with respect to the power reference point, which helps to sustain and stabilize the grid by balancing the power among the converters [9]. Droop control prevents the voltage from falling to critical level. The new reference point is achieved by the movement of an operating point along the characteristic line [10]-[11]. Limiter protects the running point movement beyond the limits. The droop control strategy curve is shown in Fig.2.

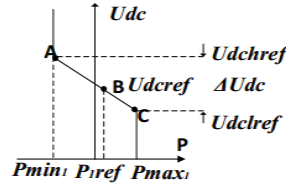


Fig 2. Power Voltage Characteristic curve with a voltage control strategy.

### 5. Modeling of the photovoltaic generation unit

The photovoltaic effect is the phenomenon of the generation of electric current when light incidents on a photovoltaic cell [12]-[13]. The electrons in the cell move to a high energy state when light is incident on them, producing electric current [14]-[15]. The equivalent circuit of the cell is shown in Fig.3.

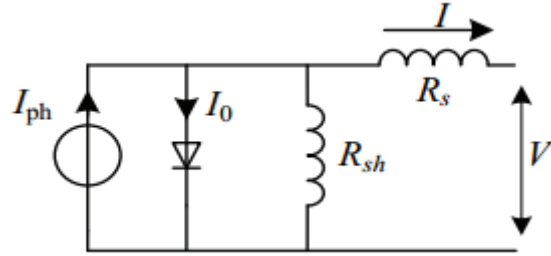


Fig. 3. Equivalent circuit of a photovoltaic cell.

$R_s$  is the series resistance which is very small and  $R_{sh}$  is the parallel resistance, which is enormous, generally, for a single crystalline or Polycrystalline photovoltaic cell. The output characteristic equation of the photovoltaic cell is stated in (3)

$$I = I_{ph} - I_o \left\{ \exp \left[ \frac{q(V + R_s I)}{nkT} \right] - 1 \right\} - \frac{V + R_s I}{R_{sh}} \quad (3)$$

$I$ : photovoltaic array output current [A];

$V$ : photovoltaic array output voltage [V];

$I_{ph}$ : photo-induced current [A];

$I_o$ : reverse saturation current [A];

$I_d$ : diode junction current [A];

$R_s$ : Series resistance for photovoltaic cells;

$n$ : stands for characteristic diode factor;

$k$  stands for Boltzmann constant;  
 $T$  stands for the temperature of photovoltaic cells [K];

## 6. Modeling and control of AC grid

For this research, a two-level VSC with pure sinusoidal pulse width modulation (PWM) is considered. The reason for choosing this topology lies in its ease of implementation and simplicity of its control system and modulation technique [16]-[17]. Fig.4 shows the connection topology of a VSC based converter to the AC grid.

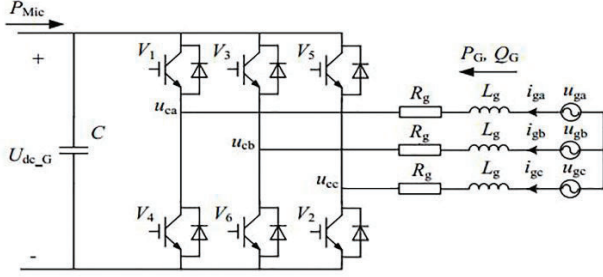


Fig 4. Grid-connected VSC converter

Mathematically a three-phase grid-connected converter in a static coordinate system can be expressed as

$$U_{ga} = R_g i_{ga} + L_g \frac{di_{ga}}{dt} + U_{ca} \quad (4)$$

$$U_{gb} = R_g i_{gb} + L_g \frac{di_{gb}}{dt} + U_{cb} \quad (5)$$

$$U_{gc} = R_g i_{gc} + L_g \frac{di_{gc}}{dt} + U_{cc} \quad (6)$$

Where,

$U_{gx}, i_{gx}, U_{cx}$  are the three-phase grid voltages[V], current [A], and converter output voltage [V]. (x=a, b, c) indicates the respective phase.

Eq. (7) and Eq. (8) represent the active and reactive power of a grid-connected VSC, respectively. Grid vector control approach is used to realize the decoupling of active and reactive power [18]-[19].

$$P_G = \frac{3}{2} u_g i_{gd} \quad (7)$$

$$Q_G = \frac{3}{2} u_g i_{gq} \quad (8)$$

By using grid vector control, the active and reactive input power can be controlled by controlling  $i_{gd}$  (controlling d axis component) and  $i_{gq}$  (q axis component), respectively [20]-[21]. A VSC based converter connected to a DC grid following grid vector control and closed-loop structure is modeled in Fig. 5.

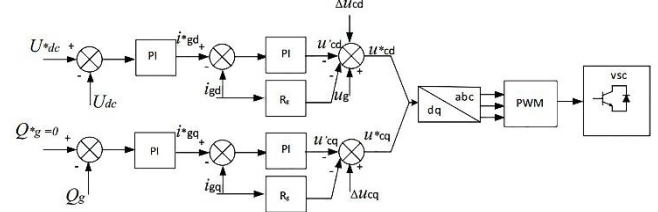


Fig 5. Control topology of a grid-connected converter

The outer loop in the topology shown above deals with the voltage and reactive power control. The outer loop output is the reference value of the active current ( $i_{gd}^*$ ) and reactive current ( $i_{gq}^*$ ). The inner loop is meant to track the active and reactive current. Using the PI controller to minimize the steady-state error and finalize the d-q axis voltage component [22]-[24].

## 7. Results and Analysis

A four-terminal VSC MTDC system with radial topology has been built on PSCAD / EMTDC to test the proposed voltage droop control strategy. The layout is shown in Fig. 6.

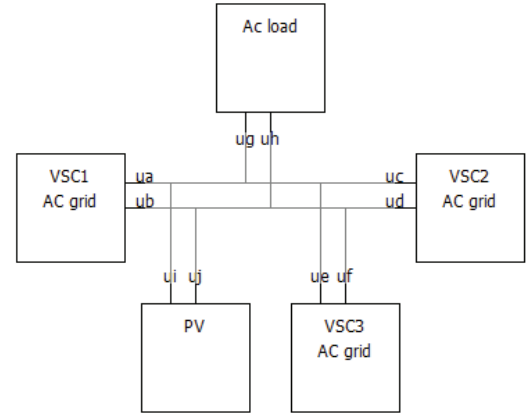


Fig 6. Four terminal VSC-MTDC system

The system consists of three AC grids, one solar source, and one AC load. The terminal voltage of the AC grid is 5 KV, with a frequency of 50 Hz, and 10 KV rated voltage. The resistance of the DC transmission line is ignored. Inductance for each phase reactor is 0.005 H, and the capacitors are of value 4000  $\mu$ F each. During steady state conditions, the output of VSC2 and VSC3 depends on the configuration of the control scheme. The MPPT control strategy is adopted by the PV system, connected to a DC-DC converter.

### 7.1. Steady State Analysis

The DC voltage curve fluctuates slightly due to the irregular fluctuations from the PV source. The output of all the converters is controlled to be identical using voltage droop control strategy, to keep the overshoot value at a minimum. The same system was also tested for other control strategies to prove the superior performance of the proposed strategy. The DC voltage performances are represented in table 1.

This depicts that the voltage droop control strategy offers minimum overshoot when compared to other control strategies. The voltage droop control strategy performs best under a small power fluctuations scenario. Droop control enables all the converters to perform DC voltage regulation simultaneously. During fluctuations, each converter suppresses the power fluctuation and distributes the power deviation according to its droop coefficient, which ensures better performance of the droop controller in a steady state.

Performance Parameter	Voltage Margin	Master Slave	Droop Control
Overshoot (%)	1.9433	0.7004	0.1559

Table 1. DC voltage performance comparison of different control strategies.

Fig.7. Represents the output DC voltage of a converter. The output is smooth and very stable. The droop controller regulates the fluctuations according to the droop coefficient to maintain a steady output DC voltage.

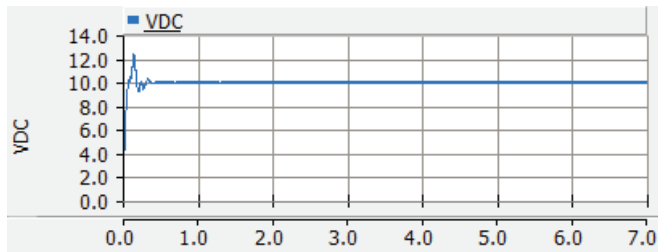


Figure 7. DC voltage

Fig.8 depicts the output power below, which represents the performance of the voltage droop controller. The droop-controlled converters regulate the power fluctuations efficiently to keep the output smooth and stable.

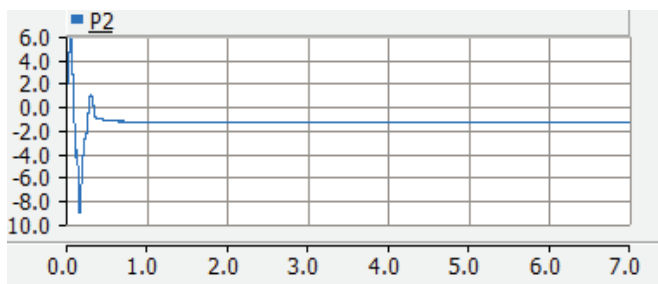


Figure 8. The output power of the converter

### 7.2. Transient Analysis

Transient state performance is the real test of a control strategy in the MTDC network. If a fault occurs in a VSC, which is regulating the network voltage, remaining

converter stations must adjust the power to maintain the stability of the system. Power fluctuations from distributed energy sources add to the complexity of the situation. In this scenario, a suitable control strategy is necessary to deal with the situation. Fig 8. Represents the performance of various control strategies. At  $t=2s$ , the short circuit fault occurs, and at  $t=4s$ , VSC1 exits the operation. It is evident that the droop control strategy performs better than other approaches in terms of overshoot, undershoot, fault clearing etc. droop control strategy ensures the smoothest possible performance of the converter during a fault.

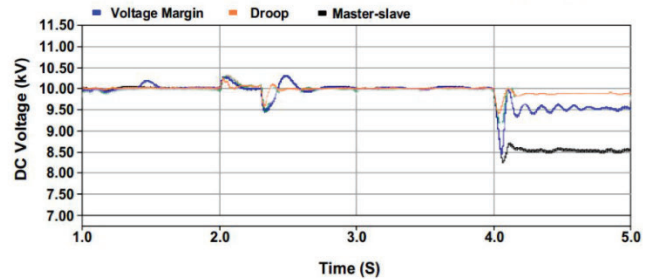


Figure 9. Voltage waveform for different control strategies

In the case of active power, it is evident from Fig.10. That the PV output creates small fluctuations in the voltage. In the droop control strategy, all the converters automatically adjust their power in such a way to maintain the power balance. At  $t=2$ , when short circuit fault occurs, VSC 1, VSC2, and VSC 3 change their ability simultaneously to keep the DC voltage at 10 KV. VSC1 and VSC 3 have the same droop coefficient, which means equal power-sharing. As a result of a fault, the voltage first drops and then after clearing it to get backs to reference. At  $t=4$  s when VSC1 exits operation, the output of VSC1 drops to zero and DC voltage is increased. As a countermeasure, VSC2 and VSC3 quickly adjust their power to find a new stable operating point around 9.8 KV. Compared with other control strategies, the time taken to get back to a unique permanent reference point is very efficient. Moreover, the voltage control strategy provides flexibility in the case if a converter goes out of operation. Other approaches do not offer this flexibility and the whole system may shutdown.

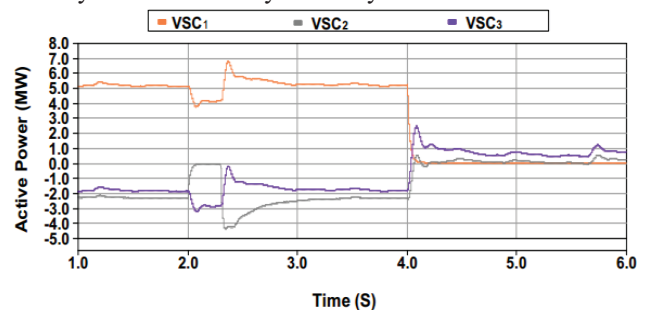


Figure 10. Active power response for voltage droop control

## 8. Conclusion

A unified voltage droop control strategy for the VSC MTDC network was investigated and tested on a four-terminal VSC-MTDC distribution network simulated in the PSCAD environment. The performance of the unified voltage droop control strategy was compared with other control strategies such as voltage margin control and master-slave control. The results and analysis show that the proposed strategy depicts better and efficient performance as compared to the other control strategies in terms of output voltage stability and control. Unified droop control offers the flexibility of voltage regulation for each converter independently according to its droop coefficient. This helps in scenarios where a converter goes out of operation. Thus, the entire grid is prevented from shut down, and the network keeps on operating stably. Droop control strategy ensures the smooth integration of renewable sources and distributed energy sources into the primary grid system. The unified voltage droop control strategy provides an efficient method for the integration and operation of the MTDC network. For future research and development, the voltage droop control method can be integrated with other control strategies to form a hybrid control strategy.

## 9. References

- [1] The European Commission, "Renewable energy: Processing towards the 2020 target." Communication from the Commission to the European Parliament and the Council, January 2014.
- [2] S. Akkari, M. Petit, J. Dai, and X. Guillaud, "Modelisation, simulation et commande des syst`emes `VSC-HVDC multi-terminaux," in Symposium de Genie `Electrique (SGE14) ´, July 2014.
- [3] J. Beerten and R. Belmans, "Modeling and control of multi-terminal VSC HVDC systems," *Energy Procedia*, vol. 24, no. 0, pp. 123 – 130, 2012.
- [4] N. Lianhui, X. Chunxiao, B. Huiyuan, and W. Di, "The amelioration of control strategy of VSC-MTDC based on voltage droop control," *2017 2nd International Conference on Power and Renewable Energy (ICPRE)*, Chengdu, 2017, pp. 157-161. doi: 10.1109/ICPRE.2017.8390519
- [5] Li, M. & Liu, X. & Chen, P.. (2016). Fast voltage margin control strategy for VSC-MTDC systems. 40. 3045-3051. 10.13335/j.1000-3673.pst.2016.10.017.
- [6] Wen-ning Yan, Ke-jun Li, Zhuo-di Wang, Xin-han Meng, and Jianguo Zhao, "Priority Control Strategy of VSC-MTDC System for Integrating Wind Power," *Journal of Electrical and Computer Engineering*, vol. 2015, Article ID 347350, 10 pages, 2015. <https://doi.org/10.1155/2015/347350>.
- [7] L. Dewangan and H. J. Bahirat, "Comparison of HVDC Grid Control Strategies,[C]" in *2017 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, 2017, pp. 1–6.
- [8] S. W. Kim, S. Y. Choi, and R. Y. Kim, "A novel droop control method for distribution loss minimization in DC microgrids with decentralized Communication [C]" *9th Int. Conf. Power Electron. - ECCE Asia "Green World With Power Electron. ICPE 2015-ECCE Asia*, pp. 456–463, 2015.
- [9] Dragicevic, T., Guerrero, J.M., Vasquez, J.C., and Skrlac, D., "Supervisory Control of an Adaptive-Droop Regulated DC Microgrid With Battery Management Capability," *IEEE Transactions on Power Electronics*, vol.29, no.2, pp.695-706, Feb. 2014.
- [10] Y. Wang, H. Jiang, L. Zhou, and P. Xing, "An Improved Adaptive Droop Control Strategy for Power Sharing in Micro-Grid," *2016 8th International Conference on Intelligent Human-Machine Systems and Cybernetics (IHMSC)*, Hangzhou, 2016, pp. 50-53. doi: 10.1109/IHMSC.2016.97
- [11] W. Haiyun *et al.*, "A hierarchical control of microgrid based on droop controlled voltage source converter," *2013 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, Kowloon, 2013, pp. 1-4. doi: 10.1109/APPEEC.2013.6837176.
- [12] J. Leuchter, V. Rerucha, and A. F. Zobaa, "Mathematical modeling of photovoltaic systems," *Proceedings of 14th International Power Electronics and Motion Control Conference EPE-PEMC 2010*, Ohrid, 2010, pp. S4-1-S4-4. doi: 10.1109/EPEPEMC.2010.5606897.
- [13] Y. Belkassmi, A. Rafiki, K. Gueraoui, L. Elmaimouni, O. Tata and N. Hassanain, "Modeling and simulation of photovoltaic module based on one diode model using Matlab/Simulink," *2017 International Conference on Engineering & MIS (ICEMIS)*, Monastir, 2017, pp. 1-6. doi: 10.1109/ICEMIS.2017.8272965.
- [14] G. Hu, S. Li, C. Cai, Z. Wu and L. Li, "Study on Modeling and Simulation of Photovoltaic Energy Storage Microgrid," *2017 4th International Conference on Information Science and Control Engineering (ICISCE)*, Changsha, 2017, pp. 692-695. doi: 10.1109/ICISCE.2017.150.
- [15] M. Babescu, C. Sorandaru, S. Musuroi, M. Svoboda, and N. V. Olarescu, "An approach to mathematical modeling of photovoltaic solar panels," *2013 IEEE 8th International Symposium on Applied Computational Intelligence and Informatics (SACI)*, Timisoara, 2013, pp. 239-243. doi: 10.1109/SACI.2013.6608975.
- [16] H. Zheng, H. Ma, K. Ma, and Z. Bo, "Modeling and analysis of the AC/DC hybrid micro-grid with bidirectional power flow controller," *2017 China International Electrical and Energy Conference (CIEEC)*, Beijing, 2017, pp. 280-284. doi: 10.1109/CIEEC.2017.8388460.
- [17] A. Al-Subhi, S. Al-Alwani, and I. El-Amin, "Mathematical-based accurate prediction model of output AC power for grid-connected photovoltaic system," *2017 Saudi Arabia Smart Grid (SASG)*, Jeddah, 2017, pp. 1-6. doi: 10.1109/SASG.2017.8356466.
- [18] Y. Yong-Sheng *et al.*, "Research on Control Method of VSC Based DC Grid with Weak AC System Integrated," *2018 China International Conference on Electricity Distribution (CICED)*, Tianjin, 2018, pp. 1046-1051. doi: 10.1109/CICED.2018.8592196
- [19] Z. Hu, W. Wu, M. Li, and Z. Lin, "VSC-HVDC Power Control Strategy for Improving Voltage Stability of AC-DC Power Grid," *2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2)*, Beijing, 2018, pp. 1-5. doi: 10.1109/EI2.2018.8582139.
- [20] M. Zhao, Y. Ruan, Y. Shen, B. Ye, Q. Zhong, and Z. Meihua, "Comparative study of vector control with direct power control for grid side converter of DFIG wind power generation system," *2011 International Conference on Electrical and Control Engineering*, Yichang, 2011, pp. 3398-3402. doi: 10.1109/ICECENG.2011.6057803.
- [21] Weiqing Tao, Zhixia Gu, Leqin Wang, and Jiayi Li, "Research on the control strategy of the grid-connected inverter under unbalanced voltage conditions," *2016 IEEE 8th International Power Electronics and Motion Control Conference (IPEMC-ECCE Asia)*, Hefei, 2016, pp. 915-919. doi: 10.1109/IPEMC.2016.7512408
- [22] N. Weise, "DQ current control of a bidirectional, isolated, single-stage AC-DC converter for vehicle-to-grid applications," *2013 IEEE Power & Energy Society General Meeting*, Vancouver, BC, 2013, pp.

1-5.

doi: 10.1109/PESMG.2013.6672847.

- [24] R. Carnieletto, D. B. Ramos, M. G. Simões, and F. A. Farret, "Simulation and analysis of DQ frame and P+Resonant controls for

voltage source inverter to distributed generation," *2009 Brazilian Power Electronics Conference*, Bonito-Mato Grosso do Sul, 2009, pp. 104-109.