

# Voltage droop Coordinating Control applied in UPFC and STATCOM system

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**Abstract.** When UPFC, unified power flow controller is applied with other FACTS into power grid, it is possible that the voltage controlled vibrates constantly to response to a sudden reactive power turbulent in grid if the parameters of these FACTS are not coordinating reasonably. Moreover, the reactive power generated by these equipment will intertwine unexpectedly. The article proposes a method named voltage-reactive power droop control to allow the reference voltage fluctuating around the rating voltage so that the vibration is reduced and the power distribution is improved. Finally, the article cite a electric-magnetic simulation by EMTDC models of east-China power grid to prove it effective when applied to improve the response characteristics to sudden turbulence in power grid.

## 1. Introduction

Modern power grid is developing to a target which is embodied with long distance transmission, high voltage class, and large transport capacity. Grid's sectional reactive power unbalance and unevenness of power flow is increasingly stressing. FACT (flexible alternative current transmission ) is an effective means to solve the problem. UPFC(unified power flow controller) is a one of the most qualified and comprehensive equipment among the FACTs. It can monitor the reactive power and voltage and control them when necessary. Moreover, it can control the power plow of the transmission line which the UPFC is installed.

With the increasing number of the FACTs installed in the power grid, the connections and inter-influences between the FACTs are becoming increasingly obvious. Usually, the district requiring installing the FACTs is area where FACTs are installed densely and concentratedly. If the system operation did not regulate the coordination control between these FACTs and allowed the behaviors of them by control of themselves, detrimental consequences would be anticipated[2][3].

Passage[2] resolve the problem of mutual influence between reactive power control segment with other control parts through decoupled flow control. Passage[3] discusses the unreasonable allocation of parameters used to coordinating the controlling system between different FACTs. Finally, it proposes a strategy realizing the separated-level control. Passage[5] proposes a control smoothing the electric measures during connecting and disconnecting. Passage[6] proposes inner –circle current



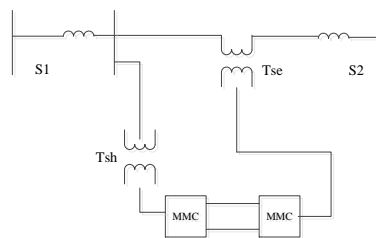
intersecting decoupled control strategy, which realizes the decoupled control of active power and reactive power. Passage[7] proposes a decoupled control strategy based on power flow control and prove the effectiveness of improving the power flow adjusting ability. Passage[10] propose a multi-purpose control strategy. A appended control devise is designed using fuzzy logic.

This passage proposes a voltage-reactive power droop control which allow voltage controlled purpose to move around rating value under different load curve using voltage-reactive power droop characteristic. The result of simulation by EMTDC proves that this strategy is effective to suppress the harmful phenomenon existing in responses to net grid disturbance when equipment parameters do not cooperate reasonably. It hinder the appearance of competing-reactive power and voltage fluctuation of controlled bus.

## 2. Fundamental principles and structure of UPFC based on MMC

### 2.1. Fundamental principles based on MMC-UPFC

UPFC connects a voltage source converter(VSC) to transmission lines through a shunt transformer and a voltage source inverter to transmission lines through series transformer. The converter and inverter interconnect each other through a back-to-back DC structure realizing the simultaneous control of voltage and power flow. The principle figure presents as fig 1.



**Figure 1.** structure of UPFC

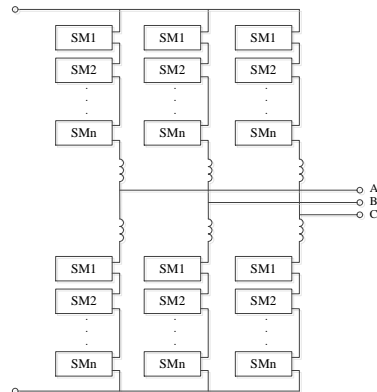
### 2.2. Topology structure of MMC-UPFC

Classical topology MMC structure is comprised of a series of power unites. Every phase consists two arms, the up arm and bottom arm. Each arm is comprised of the same number of power unites. The connection point of the two arms is the AC electric connection.

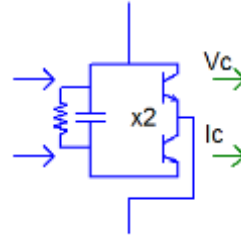
MMC's public DC bus does not need capacitors and other wave filters, which reduces the rate of fault and improves the reliability effectively. Moreover, MMC has large power capacity and fault ride through ability which ensures fast revise from fault condition and high efficiency of black-start.

UPFC based on MMC has stronger voltage and power flow control ability than traditional technology. Its structure is shown as follows.

MMC sub unite has two kinds of structures, full bridge and half bridge. This passage's simulation adopts half bridge structure. Half bridge structure consists of 2 capacitors controlled by IGBT. The structures of the electric circuits of half bridge is shown as fig 3.



**Figure 2.** Diagram of UPFC MMC bridge structure

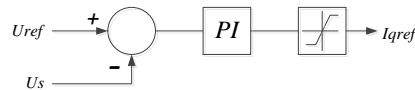


**Figure 3.** Sub-unit of UPFC MMC half bridge structure

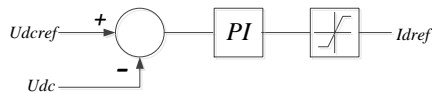
### 3. UPFC control strategy

#### 3.1. Control strategy of UPFC's parallel side

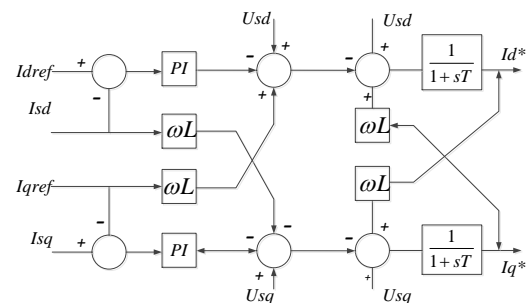
While UPFC exchanges both active power and reactive power through its parallel side, active power control is realized mainly through its series side. The outer loop control can adopt setting-DC voltage-control, setting-AC voltage-control or setting-reactive power-control. The diagram of control is shown as fig 4 and fig 5. To maintain the voltage stability during operation, setting-voltage-control mode is usually adopted. The inner loop control adopts current cross-decoupling control. In practical engineering environment, every control parameter is converted to that present in d-q coordinates in order to realize decoupling calculation. UPFC's series control diagram is shown as fig 6.



**Figure 4.** Diagram of constant AC voltage control



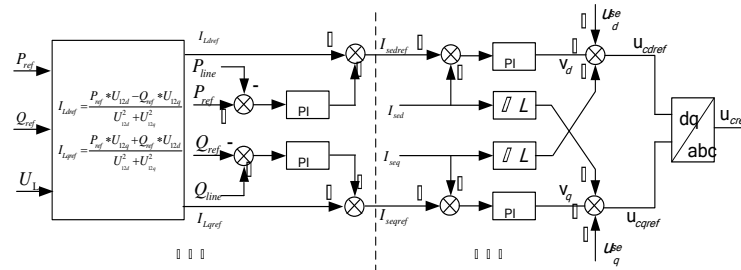
**Figure 5.** Diagram of constant DC voltage control



**Figure 6.** Diagram of inner current decoupling control

#### 3.2. Control strategy of UPFC's parallel side

The purpose of control of parallel side is to accomplish power flow control and reactive power control. So, the outer loop is achieved by power loop empowered by PI section following the grid power signals. The outer control loop converts the power signals to current signals so that it is transferred to inner current control and accomplish close loop finally. The inner current loop is represented as fig 7.



**Figure 7.** Diagram of inner current decoupling control in series side of UPFC

#### 4. Research of coordinating control of UPFC with other FACTS.

The model of system containing UPFC and statcom. The parallel side control of is of the same natural with statcom's. UPFC's voltage control of parallel side is not only related to valves of its own side but to the controlling purpose of series side. The active and reactive controlled at series side need to account for some amount of the parallel side's volume due to the transmission power flowing through DC section. The parameters of both sides will influence each other's corresponding speed[13].

When UPFC and statcom connect to the same connection point or when are placed close in a regional grid, they might exert controlling effect on the same or closely related electrical variables simultaneously. Omitting the leading, lagging segment and magnitude limit segment, the core part of statcom control is PI segment, whose main parameter is Kstatcom\_p and Kstatcom\_i. Considering the integral segment can be omitted when in the electromagnetic environment, the main parameter influencing corresponding speed and magnitude is Kstatcom\_p. Similarly, the main parameter influencing UPFC's parallel control is the proportional parameter K\_p, K\_sp, K\_sq. Consequently, parameter optimality is needed to coordinate well, operate independently and effect well when FACTS are placed closely.

Commonly, UPFC and statcom adopt voltage-setting control pattern to monitor grid voltage so that it is maintained within allowed range and provide timely reactive power support after the fault. However, if the main parameters like Kstatcom\_p, K\_p, K\_sp, K\_sq did not cooperate well, the effect described before might be magnified, which is presented as competing-reactive power and voltage fluctuation of controlled bus.

To solve the problem, two methods are proposed: 1, construct the problem as mathematically optimal problem with constrains and solve it through mathematical methods[10][20]. 2, adopt main-subordinate control in which one equipment adopts voltage-setting control(main) and the others adopt compensatory power-setting control(subordinate). Method 1 is complex and limited by specific grid, which lacks generation. Method 2 needs real time communication so it is limited by equipment reconstruct.

#### 5. Voltage-droop control strategy

##### 5.1. Summary of voltage-droop control strategy

Voltage-droop control strategy has universally been used in multi-terminal DC transmission system as the primary frequency modulation. To realize plug-and-use and PCC voltage stability in islanded pattern, voltage-droop control strategy is commonly adopted.

This passage proposes a voltage-reactive power droop control strategy applied in FACTS concentrated grid. Power control intends to control the amount of power generated by each equipment. Voltage-setting control intends to keep the voltage stable. Voltage-reactive power control combine these two types of characters and achieves the coordinating power generation of each equipment by allowing voltage fluctuating within a small range.

### 5.2. Control character and realization of voltage-droop control strategy

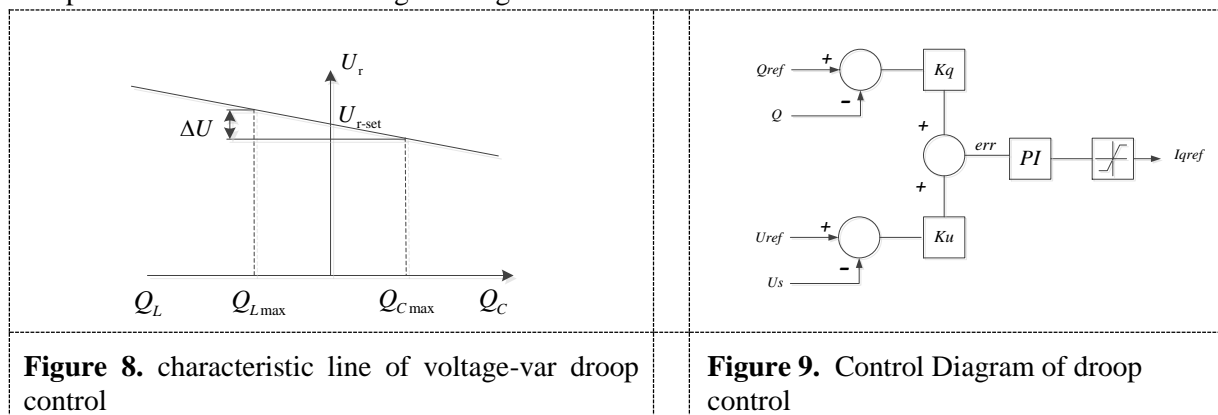
Voltage-droop control's character is presented as fig 8,  $Q_{C\max}$  and  $Q_{L\max}$  is the maximum and minimum infused reactive power in connection point. The Y-axis presents the voltage of the connection point.

$U_{r-set}$  is the controlling purpose when no reactive power is generated.

Control diagram of voltage-droop control is shown as fig 9. In the fig, the err exported is described as follows.

$$err = k_q (Q_{ref} - Q) + k_u (U_{ref} - U_s)$$

In the equation,  $k_q$  and  $k_u$  is the coefficient and the slope of the droop line is  $-k_p / k_u$ , when  $k_q = 0$ , droop control is reduced to voltage-setting control.



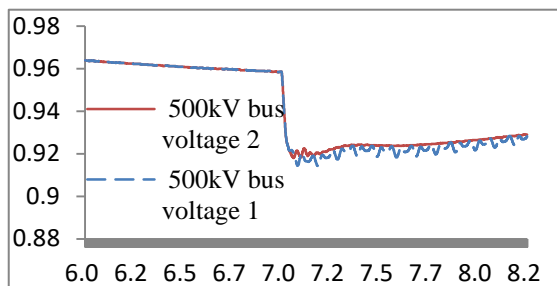
## 6. Simulation and experiment consequences

This passage uses an electromagnetic model describing the power grid of southern Jiangsu province and shanghai city. The model not only includes these two districts but also include other part of the East China power grid, which is processed by dynamic equivalence. The whole grid includes 8 DC transmission systems and more than 1000 AC nodes. In this system, 3 reactive power generators are installed at node #531010(UPFC  $\times$  1, stacom  $\times$  2). UPFC's shunt rating capacity is 300MVA, statcom's capacity is 300Mvar. Before 7s, the three devices have been in stable operation. At 3s, the reactive load increases by 300MW and these devices begin to respond.

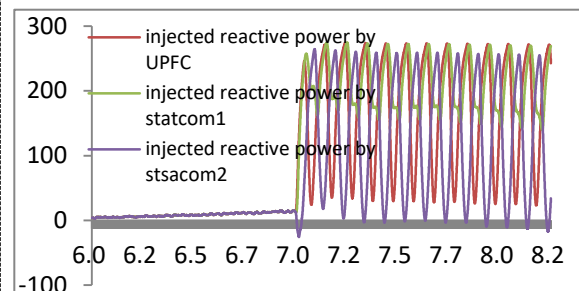
Situation1: none of the devices apply voltage-reactive power control, from fig 10, we can see that after 7s, bus voltage oscillates conspicuously. Fig 11 illustrate the appearance of competing-reactive power and voltage fluctuation of controlled bus.

Situation2: all the devices apply the voltage-reactive power control and the droop rate is -0.027, fig 10 shows that voltage operational point steps into new region and voltage oscillation is hindered. Fig 12 illustrates the average distribution of the free reactive generation devices and the hindered appearance of competing-reactive power and voltage fluctuation of controlled bus.

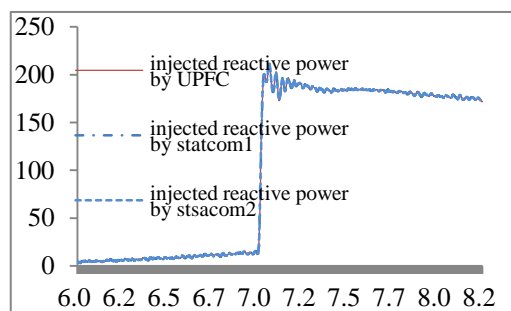
As is discussed above, voltage-droop control can hinder defects caused by parameter when equipment parameters do not cooperate reasonably.



**Figure 10.** Voltage of controlled 500kV bus



**Figure 11.** Injected reactive power of each equipment (without droop control)



**Figure 12.** Voltage of controlled 500kV bus

## References

- [1] B Ren, W Du, H Wang, H Li, Z Chen. Dynamic interaction investigation on a UPFC connecting to Jiangsu UHV AC/DC hybrid power system[J]. Power System Technology[1] 2016, 40(9):2654-2660.
- [2] LIU Qing, MA Peng, ZOU Jiaping, Solution to negative interaction caused by reactive power flow controlling of UPFC[J]. Power System Protection and Control, 2016, 44(6):76-81.
- [3] XU Zhenhua<sup>1</sup>, LU Zhengang<sup>2</sup>, WU Danyue<sup>1</sup>, HUANG Daoshan<sup>1</sup>, Research on Coordinated Control Between Unified Power Flow Controller and Other FACTS Equipments[J]. Smart Grid2016, 4(1):25-32.
- [4] WANG Weiyan<sup>1</sup>, DOU Fei<sup>1</sup>, YANG Lin<sup>1</sup>, ZHOU Yuzhi<sup>2</sup>, XU Zheng<sup>2</sup>, CHEN Guonian<sup>1</sup>, YUAN Jianhua<sup>3</sup>, Applications and Control Results of UPFC in Jiangsu Power Grid[J], Power System and Clean Energy,2016(3):92-97.

- [5] PANLei LIJihong TIANJie DONGYunlong SUN Weizhen ZHANGJing,SmoothStartandStopStrategiesforUnifiedPowerFlowControllers[J],Automation of Electric Power System. 2015, 39(12).
- [6] CHEN Yong1, HUANG Shushu, Initial Allocation of Carbon Emission Right for East China[J], 2016, 35(1):45-48.
- [7] LIU Li-ming, KANG Yong, CHEN Jian, ZHU Peng-cheng, Cross-coupling Control Scheme and Performance Analysis for Power Flow Control of UPFC[J], 2007, 27(10):42-48.
- [8] DU Wen-Juan , WANG Hai-feng , M Jazaeri , JU Ping , CAO Yi-jia, Effect of Variations of Control Operating Points of UPFC on Power System Stability and Control Performance[J], Automation of Electric Power System. 2005, 29(20):40-45.
- [9] XU Chen, DAI Ke, FANG Wuping, KANG Yong, Research on PCC Voltage Droop Control of STATCOM Based on Modular Multilevel Converters, Proceedings of the CSEE, 2015(s1):205-212.
- [10] ZHANG Man1, ZHANG Chunpeng1, JIANG Qirong1, ZHOU Fei2, SONG Jieying2, Study on Multi-Objective Coordinated Control Strategy of Unified Power Flow Controller[J], Power System Technology,2014, 38(4):1008-1013.
- [11] LIN Jinjiao, LI Peng, KONG Xiangping, GAO Lei, YUAN Yubo, HUANG Haosheng, WANG Ye The UPFC Protection System Configuration and Action Strategy[J],in Nanjing Western Power Gird, 2015, 34(6):56-60.
- [12] L Huang, L Zhang, H Xin, J Hu, D Gan, Mechanism analysis of virtual power angle stability in droop-controlled inverters[J], 2016, 40(12):117-123
- [13] LIU Qing, MA Peng, ZOU Jiaping, Solution to negative interaction caused by reactive power flow controlling of UPFC[J]. Power System Protection and Control, 2016, 44(6):76-81.
- [14] ZHAOYuan,YANGXiaosong,XIEKaigui, parameter sensitivity and optimal allocation of UPFCs in bulk power systems reliability assessment[J]. Automation of electric power systems[J] 2012, 36(1):55-60.
- [15] LI Haifeng, WANG Xiangfeng, CHEN Zhong, REN Bixing, DU Wenjuan, Quantitative Comparison Methods of a Power-Angle Controlled and Vector-Current Controlled UPFC[J], Power System Technology [J], 2016, 40(8):2330-2336.
- [16] WANG Shuaibing, LI Lin1, XIE yuqing,ZHAO Guoliang,Research on SCT Characteristics and Simulation Model in UPFC System[J]. Power System Technology, 2016, 41(2):551-557.
- [17] Noroozian M, Angquist L, Ghandhari M, et al. Use of UPFC for optimal power flow control[J]. IEEE Transactions on Power Delivery, 1997, 12(4):1629-1634.
- [18] Guo J, Crow M L, Sarangapani J. An Improved UPFC Control for Oscillation Damping[J]. Power Systems IEEE Transactions on, 2009, 24(1):288-296.
- [19] Tambey N, Kothari M L. Damping of power system oscillations with unified power flow controller (UPFC)[J]. Generation, Transmission and Distribution, IEE Proceedings-, 2003, 150(2):129-140.
- [20] Kamarpshiti M A, Lesani H. Effects of STATCOM, TCSC, SSSC and UPFC on static voltage stability[J]. Electrical Engineering, 2011, 93(1):33-42.